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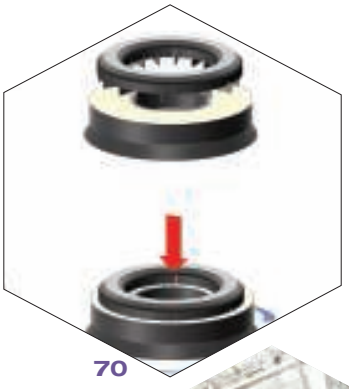

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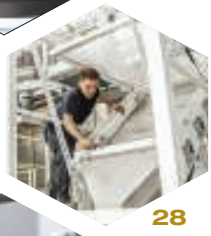

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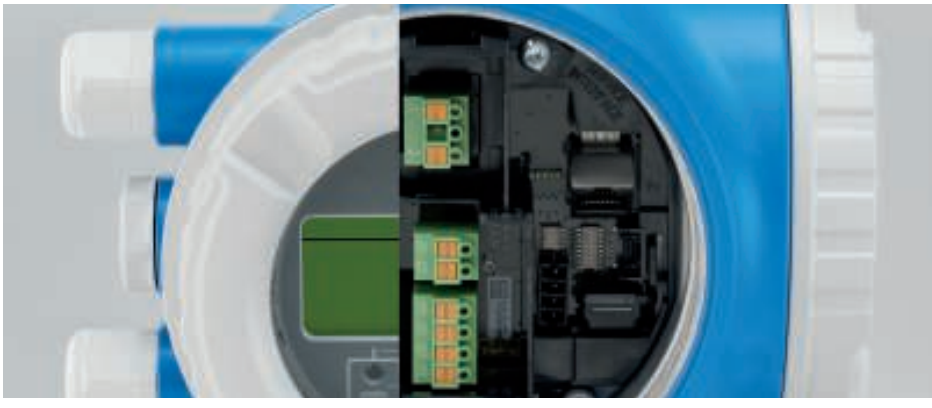

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BPA

Editor's Page

Investing in safety

The U.S. Chemical Safety Board (CSB; Washington, D.C.; www.csb.gov) is a federal agency that is charged with investigating industrial chemical accidents. The Board was created to operate independently of other agencies and its principal role, as described on its website, is "to investigate accidents to determine the conditions and circumstances which led up to the event and to identify the cause or causes so that similar events might be prevented."

The CSB's investigative reports and videos, which are freely available on its website, are informative and professionally done. It was concerning to learn that the recent U.S. Presidential budget proposal does not include any funding for the CSB in 2018. The potential loss of important lessons learned from actual accidents in the chemical process industries (CPI), some of which have very unfortunately been fatal, seems like a big price to pay for an agency whose budget is around $12 million/yr — a small number in the big scheme of the overall budget.

The CPI's commitment to safety

Safety is a core concern of those who work in the CPI. Much effort goes into planning for safety — through hazard review processes, efforts to create intrinsically safe processes and much more. And CPI companies have nurtured a safety-conscious culture amongst their employees through investments in training, safety equipment, safety inspections, rewards for safe practices and more. I experienced this first-hand in the years I worked in the CPI.

Member companies of the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com), for example, voluntarily agree to participate in the Responsible Care Program as a condition of membership. Members commit to follow the guiding principles of the Responsible Care Initiative. These principles are outlined on the ACC's website, and include statements such as "to design and operate facilities in a safe, secure and environmentally sound manner."

Process safety management

Today, in addition to the corporate environment, the importance of process safety is recognized in numerous programs that are helping to make process safety management a mainstream topic. One such program is the Mary Kay O'Conner Process Safety Center at Texas A&M Engineering Experiment Station (College Station, Tex.; psc.tamu.edu). The Center was established in 1995 in memory of its namesake, a chemical engineer who died in an explosion in 1989. The Center, which is directed by Dr. Sam Mannan, describes its mission as follows: "to promote safety as second nature in industry around the world with goals to prevent future incidents."

Safety discussions and learning can also be found in conferences, such as the well-attended annual Global Congress on Process Safety presented by the Center for Chemical Process Safety and the AIChE Safety & Health Division.

Still, with all of the efforts put forth toward safe practices, sometimes things go wrong, and accidents — sometimes disasters — occur. At those times, having an independent agency that can effectively investigate what went wrong and report it to the rest of the community sounds like a very worthwhile investment. I hope a way is found to keep the CSB afloat. ■

Dorothy Lozowski, Editorial Director

Letters

Control Engineering for Chemical Engineers

The March 2017 *Chemical Engineering* issue features the article "Control Engineering for Chemical Engineers" [pp. 42–50]. The author has brought up an interesting topic that should concern everybody working at any chemical processing facility. I certainly agree with Mr. Heavner, the more the process engineers know about process control the better, as it will lead to better understanding of the process possibilities and limitations.

There are , however, some concepts presented in the article that need to be clarified:

"*Ziegler-Nichols tuning rules….But this kind of aggressive tuning results in some cycling*" — Even if Ziegler-Nichols tuning rules are not the best, it must be understood that those rules were proposed to provide PID controlling lagtime-dominated processes with good capability to reject unmeasured disturbances, and that a change in the setpoint will invariably produce PV overshoot, this has been repeatedly misinterpreted as aggressiveness.

"… *so most loops today should be tuned for a first-order response,* …" In the chemical process industries the most infrequent change is to the setpoint, and the most important feature a controller must be provided with is load rejection capability. However, the author is suggesting that controllers' response should follow a first-order response; this is the vice versa situation of the previous comment, a controller tuned for first-order response to setpoint change will invariably lack the required capacity to promptly return the PV to SP following the ubiquitous disturbances the chemical process are constantly subjected to.

"…*controllers can be tuned on integrating processes to achieve a first-order response*….Following a setpoint change, the PV will move to the new setpoint and overshoot slightly before turning around and settling back to setpoint…" What the author describes here is the use of a PI controller in an integrating process, which in general is a recipe for an oscillator. An integrating process should be controlled by a proportional only controller.

"*One guideline that is wisely favored is the 'lambda' tuning method."* Lambda tuning and aggressiveness don't come together. It is a method that detunes the PID controller in favour of robustness — not a good compromise when lagtime-dominated process variables need to stay close to the setpoint following disturbances. This tuning method has been reformulated multiple times, as it is well known for its inability to provide reasonable disturbance rejection, and consequently unable to reduce variability.

Sigifredo Nino, P. Eng.
Process Control Consultant

Author's Response

I am pleased that you took the time to read the article and offer such thoughtful comments.

It is important to understand and

Letters

agree on what robustness and aggressiveness mean. When I refer to aggressiveness, perhaps a better phrase would be speed of response. However, the goal of process control should be to maximize the performance of the process, not necessarily the performance of individual loops. As such, the tuning methodology should allow the user to choose the individual loop responses as needed to fulfill this goal. In some cases, this means very strong emphasis on load regulation; in some cases it means a much slower response and in some cases it means coordination of the closed-loop response of several loops. A loop tuning methodology that only has "one speed" (such as Z-N) does not accommodate this goal.

Furthermore, a tuning methodology for integrating process that does not allow the choice of a closed-loop speed of response, will likely result in an oscillatory response if the controller gain is reduced to slow down the response. This often leads to the comment that "PI tuning for integrating process will oscillate." This inaccurate statement has been made by other control experts. Lambda tuning uses a set of rules that produces a first-order (second-order in the case of an integrating process) response with a closed-loop time constant specified by the user. This allows the tuner to select a faster or slower response as is appropriate for the process. It assumes the process has been accurately identified and is linear, since PID controllers are linear. When there is doubt about the process model or the process is sufficiently nonlinear, the tuner must use judgment, regardless of the selected tuning methodology, to ensure process stability.

Sometimes adaptive techniques are helpful. And again, this is an area where chemical engineers can provide particular insight. As one of my colleagues is fond of saying, "Show me the data." We have published the results of innumerable examples where lambda tuning made quantifiable economic improvements to a process. I have not seen a case that I can recall where properly applied lambda tuning produced a poor response, let alone made things worse and would appreciate seeing one if there is such a case. (refer to the following articles by James Beall: Loop tuning basics: Integrating processes — www.isa.org/intech/201604basics; Loop tuning basics: Self-regulating processes — www.isa.org/intech/201606basics; Loop tuning basics: Complex process responses — www.isa.org/intech/201610web. These articles do not cover all the 11 process response types we see in the field but it is a good primer on the topic.)

Lou Heavner
Emerson Automation Solutions

Editor's note: The two letters above are excerpts. The full letters can be found online at www.chemengonline.com

Postscripts, corrections

April, 2017, "The Future of Safety Sensors is Here Now," pp. 22–26. On p. 24, Upskill's (Herndon, Va.; www.upskill.io) software platform is incorrectly referred to as "Skyline." It should be "Skylight." This has been corrected in the online version of the article at www.chemengonline.com/the-future-of-safety-sensors-is-here-now

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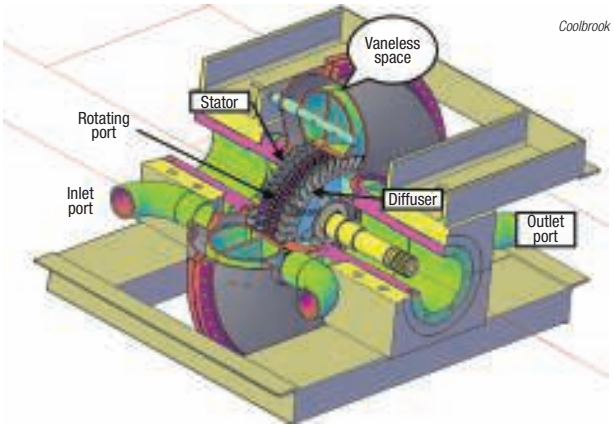
Piloting of a 'revolutionary' approach to olefin cracking

Earlier this year, Coolbrook Oy (Helsinki, Finland; www.coolbrook.fi) received a €3.6-million grant from the Finnish Funding Agency for Innovation Tekes to further develop its patented RotoDynamicReactor (RDR) technology, which has the potential to improve ethylene yields by 34% compared to conventional furnace-based naphtha crackers. The two-year project — led by Coolbrook and Neste Jacobs Oy (Porvoo, Finland; www.nestejacobs.com), in collaboration with the University of Oxford's Osney Thermo Fluids laboratory, the University of Cambridge's Whittle laboratory, and major chemical producers, such as The Dow Chemical Co., as well as equipment manufacturers, including MAN Diesel & Turbo SE — will build and test a pilot reactor based on RDR technology to verify olefin yields and confirm the reactor model, which combines reaction kinetics and computational fluid dynamics (CFD) results. The commercial launch of this new technology is expected during 2019.



Coolbrook

RDR is a regenerative turbomachine (diagram) consisting of three axial blade rows (stator, rotor and diffuser) and a toroidal vaneless space that circumfrentially connects the blade passages, which allows the regenerative heating of the working fluid, explains Coolbrook CEO Harri Johannesdahl. The fluid is accelerated in the stator, and the mechanical energy is converted to internal energy of the fluid by the rotating blade row, thereby increasing the temperature and pressure of the fluid. Unlike conventional crackers, which heat the fluid from outside the furnace, the RDR is heated from within the reactor. As a result, the residence time inside the RDR is just 0.02–0.04 s, which is about one tenth of that achieved in conventional crackers, says Johannesdahl. In this short time, the high temperature (over 900°C) and pressure (1–3 barg) reached in the RDR efficiently pyrolyzes naphtha with a high ethylene yield (over 43%) — 34% higher than conventional crackers, he says.

In the first phase of the project, the collaborators are planning a pilot plant with a capacity of 10 ton/h of naphtha feed. "But of course, the commercial scale will be much higher," says Johannesdahl. "How much higher we will know after the tests."

Our present estimation is that in order to produce 1 million tons of ethylene, one would need eight plant-scale RDR machines (one as a backup for maintenance), he says.

Fuel-upgrading catalyst boosts lifetimes and supports sustainability

A new fuel-upgrading catalyst for petroleum refineries has several features that boost sustainability and minimize environmental impact. In March, specialty chemical maker Clariant (Muttenz, Switzerland; www.clariant.com) launched PolyMax 850, a new generation of its PolyMax catalyst series. The new catalyst, intended to convert olefins created during cracking processes into high-octane gasoline and organic solvents, was designed to allow significantly lower operating temperatures in the refinery unit, Clariant says, which reduces CO_2 production. Also, PolyMax 850 offers a longer service life than other catalysts in the series. The catalyst's manufacturing process is also designed for sustainability, Clariant says. It is manufactured from diatomaceous earth and phosphoric acid in a newly developed process that generates zero wastewater. At the end of its life, the PolyMax 850 catalyst can be completely recycled into fertilizers and other useful phosphorous-containing products, Clariant says.

Edited by:
Gerald Ondrey

FCC CATALYST

BASF SE (Ludwigshafen, Germany; www.basf.com) recently launched Borotec, the newest evolution of its resid-oil fluid-catalytic-cracking (FCC) catalysts portfolio. Borotec is the latest innovation using BASF's unique Boron-Based Technology (BBT) platform to provide mild- and moderate-resid-feed FCC units more flexibility in crude-oil selection, which results in increased yields of high-value products.

A successful commercial trial has verified the ability of Borotec to improve performance, leading to higher yields of valuable products and lower bottom-of-the-barrel yields compared to competitive technologies, says BASF. The improved metals-tolerance feature provided by Borotec allows improved crude flexibility for refiners that increasingly engage in spot buying to maximize profits. The catalyst was developed to offer refiners optimized operation and maximized margins.

This launch of Borotec follows last year's introduction of Borocat to the market, the first FCC catalyst based on the BBT platform. Since then, Borocat has been successfully introduced in petroleum refineries all over the world.

HEAT-EXCHANGER COATING

A new nano-coating that imparts anti-adhesive, anti-corrosive and antimicrobial behavior to heat exchangers was introduced by the Leibniz Institute for New Materials (INM; Saarbrücken, Germany; www.leibniz-unm.de) at this year's Hannover Messe (April 24–28).

The developers achieve the anti-adhesive characteristics by introducing hydrophobic compounds (similar to Teflon) that inhibit the formation

(Continues on p. 10)

of any undesired biofilm and allow residues to be transported out more easily before they clog up the channels of the heat exchangers. At the same time, the researchers used structures that act as a diffusion barrier, which inhibits the attack from corrosive substances or aggressive cleaning agents. Finally, to prevent microbes, bacteria or fungus from adhering to surfaces, the scientists additionally used colloidal copper in the coating. The presence of O_2 or water occurring in many processes causes copper ions to be released from the colloids. These migrate to the surface and, as a result of their antimicrobial effect, they prevent microbes from proliferation and growth.

The paint can be applied using standard methods, such as spraying or immersion, and subsequent hardening. It can be used on stainless steel, steel, titanium or aluminum. Promising applications include heat exchangers used in the food-and-beverage and air-conditioning industries, as well as for equipment in water-purification plants, for example.

DIAMOND FOIL

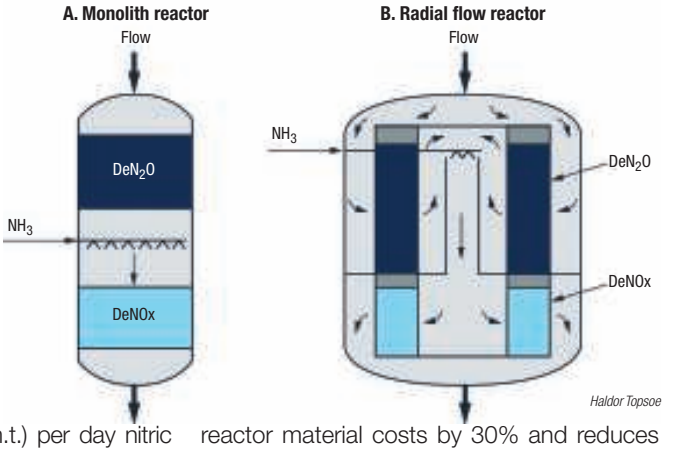
Diamond foils feature extreme hardness and wear resistance, exceptional chemical inertness and maximum thermal conductivity. Up to now, however, coating substrates directly with crystalline diamond is only possible on a limited range of materials. Now, researchers from the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU; Germany; www.fau.eu) have developed a process for making large (28-cm dia. — the world's largest) diamond foils on silicon substrates. The foils can then be removed and applied to materials not suitable for direct coating.

The process, developed by the Ultra Hard Coatings (UHC) group at FAU's Chair of Materials Science and Technology of Metals, and described in a recent issue of *Philosophical Transactions A*, takes place inside a test reactor operating under a low-pressure

(Continues on p. 12)

A more efficient way to reduce emissions from nitric acid plants

Haldor Topsoe A/S (Lyngby, Denmark; www.topsoe.com) has recently introduced TertiNOx, a new catalyst for simultaneously reducing nitrous oxide (N_2O) and oxides-of-nitrogen (NOx) emissions from the tailgas of nitric-acid production plants. The company estimates that this alternative to conventional abatement methods will save up to €350,000/yr in a typical 1,000 metric tons (m.t.) per day nitric acid plant, based on a €5 per ton of CO_2 price annually per 100 parts per million (ppm) N_2O emissions reduction.



Haldor Topsoe

N_2O is an unwanted byproduct in the production of nitric acid and adipic acid, and its global warming potential is about 300 times higher than CO_2. In recent years, N_2O emissions have decreased significantly, especially in Europe. However, there is still considerable potential for further reductions of this hazard.

Unlike pellet-type catalysts that require a complex, two-bed radial-flow reactor design, TertiNOx is a monolith impregnated with iron zeolite that enables a much simpler, smaller and less expensive reactor design (diagram), says the company. This combination reduces reactor material costs by 30% and reduces pressure drop by up to 80% compared to the radial-flow design. It will also result in an increased acid production, says the company.

The TertiNOx catalyst is active from 350°C and can remove up to 99% of the N_2O, in contrast to the less than 90% reduction typical for conventional secondary catalysts. The compact and simple reactor makes it possible to install a TertiNOx polisher solution together with existing secondary N_2O abatement, to further reduce emissions in a very cost-efficient way.

The monolith concept is already part of more than 1,100 industrial installations worldwide for removing NOx, dioxins and furans (for example in incinerators).

This product helps vaccine manufacturers reduce downstream processing costs

Biopharmaceutical companies — especially those involved in manufacturing vaccines — spend a lot of effort and money to remove host cell nucleic acid (DNA and RNA) impurities from fermentation batches. The total downstream processing costs can account for up to 80% of the total manufacturing cost, says Stefan Schoenert, head of strain and process development at c-LEcta GmbH (Leipzig, Germany; www.c-lecta.com). In addition, the purification processes should ideally be performed without using animal-derived products, he says.

To help reduce the effort and costs associated with downstream processing, c-LEcta has developed an advanced nuclease product, tradenamed Denarase, which makes it easy to remove host cell DNA/RNA impurities from biological production processes. Denarase cleaves all forms of DNA and RNA (single-stranded, double-stranded, linear and circular) in an unspecified (sequence-independent) way, explains Schoenert. The enzyme product is active in all commonly used buffers in the presence of both ionic and nonionic surfactants, as well as many reducing and chaotropic agents. It is also long-term stable at room temperature.

Unlike competitive nuclease products, which are usually produced using *Escherichia coli* as expression host, Denarase is manufactured using a patented production process based on a *Bacillus* strain and a fermentation medium that is free of antibiotics and animal-derived products, says Schoenert. Denarase is based on a very active endonuclease secreted by *Serratia marcesens*, a gram-negative bacterium. Denarase is genetically engineered and produced using *Bacillus sp*. Besides the absence of *E. coli* typical endotoxins and the absence of antibiotics and animal-derived products, the production process is in full compliance with current good-manufacturing-practice (cGMP) guidelines, he says.

Novel approach to Si-metal anodes could lower Li-ion battery cost

A new approach to making silicon-based anodes for lithium-ion batteries has the potential to lower materials costs for batteries, while achieving higher energy and power. Silicon-based anodes are attractive because of silicon's natural abundance and its high specific capacity, but R&D efforts aimed at incorporating silicon into electrodes have not succeeded at allowing sufficiently long cycle lives and high performance at lower cost.

As an anode in Li-ion batteries, silicon's volume expands and contracts a great deal during charge-discharge cycles, which strains the material and pulverizes it, reducing lifetime. Therefore, Si-based anodes require a balancing act to maximize energy capacity by increasing Si content, while maintaining the structural integrity of the anode over many charge-discharge cycles, and doing all that at low cost, explains David Lee, CEO of BioSolar LLC (Santa Clarita, Calif.; www.biosolar.com). Lee's company has demonstrated a novel Si-metal anode that accommodates Si's expansion, maintains electrode capacity and allows for the use of less expensive raw materials.

Biosolar uses a unique set of materials and a proprietary process to embed Si nanoparticles in a metal-alloy matrix. Special efforts are made to minimize tiny defects in the initial manufacture of the anode to prevent cracking during charge-discharge. Further, the material is designed to improve hardness and retard crack growth, resulting in a resilient and longer-lasting material, Lee says.

A critical aspect of the design of the anode material is its ability to use a higher level of raw metal material for the matrix as a cost-reduction measure. "By allowing the use of more raw metal, we can lower our material costs without losing any electrode performance," Lee says. "In this way, we can realize a Si-based anode with higher capacity that is less expensive than the Si-graphite composites and Si-oxide anodes currently under development as successors to the conventional graphite anode."

Biosolar is aiming to commercialize the anode material for use with a host of commercially available Li-ion battery cell configurations, in addition to its ability to be paired with a novel cathode material already commercialized by the company (*Chem. Eng.*, March 2016, p. 8). After successfully demonstrating the anode material in a prototype battery, Biosolar is seeking a joint development partner to scale up and build larger prototypes.

atmosphere of H_2 and 2% CH_4. The foils (40-µm thick) form over a period of several days on a 30-cm silicon disc under wires that are heated to 2,000°C. After the coating process, a short-pulse laser is used to introduce a circular fracture site (28.5-cm dia.) into the diamond surface, which makes it possible to separate the deposited layer as a very smooth diamond foil from the silicon substrate.

"By scaling up the manufacturing process, we have demonstrated that we can produce diamond foils in the future as a semi-finished product for industry, even in large dimensions," explains Stefan Rosiwal, head of the UHC research group. "In these diamond layers, we can adjust the diamond grain size, the electrical conductivity and thermal conductivity by varying the manufacturing parameters by many orders of magnitude."

Potential applications include erosion protection for water turbines, mechanical seals in pumps, and for the production of stable diamond electrodes for water purification and disinfection systems.

DEPOSIT CONTROL

Pitch, occurring from natural resins in virgin pulp, and "stickies" in recycled paper fibers, pose a major challenge to pulp-and-paper producers because of their negative influence on papermaking productivity and

(Continues on p. 13)

Scaleup for the production of graphene oxides

Graphene-oxide-based materials are lamellar carbon compounds that are approximately 1-nm thick, and are expected to show excellent properties for various functional materials, such as innovative battery materials, lubricants, water-treatment membranes and catalysts. However, because these materials have been synthesized by the oxidation of graphite under severe conditions (requiring a strong oxidizing reagent and an acidic solvent), the mass production of these materials has been held back by major challenges.

Now, Nippon Shokubai Co. (Osaka and Tokyo, Japan; www.shokubai.co.jp) has resolved various problems associated with the oxidation reaction, making it possible to scale up production "several dozens of times" more than laboratory scale. The achievement, performed in collaboration with Okayama University and support from the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki City, Japan; www.nedo.go.jp), enabled the company to prepare materials in quantities sufficient for application development.

Three types of materials are available: hydrophilic graphene oxide as a water dispersion, with surface areas of 420 m^2/g; hydrophobic reduced graphene oxide as a solvent dispersion and powder, with conductivity of 2,900 Siemens per meter (S/m); and hydrophobic/hydrophilic modified graphene oxide as a solvent dispersion and powder.

Microwave-based emulsion technology featured in scaleup of sucrose esters

Construction has been completed on a 1,000-ton/yr facility to produce surfactants — mainly sucrose esters for use as additives in dairy products and beverages. The plant will be operated by TMT Co. — a joint venture (JV) established by Microwave Chemical Co. (MWCC; Suita City; www.mwcc.jp) and Taiyo Kagaku Co. (TKC; Yokkaichi City, both Japan) — and located at TKC's Yokkaichi factory. The facility will use a microwave-based emulsification process developed by MWCC, which was established as a venture company based on the technology originally developed by Osaka University.

With this technology, for which technical barriers to entry in the sucrose esters market were previously too high, it is now possible to manufacture products with higher quality and purity than before by directly heating molecules by microwave irradiation without using an organic solvent. Energy consumption is said to be cut in half compared to conventional heating.

The new facility is the culmination of a 2015 strategic alliance between TKC and MWCC to enter the Southeast Asian market. TKC aims to expand beverage-related products by optimizing the production system for sucrose esters. For MWCC, which aims to make microwave technology processes widespread through open innovation with chemical manufacturers, this will be the first time that they introduce their technology into a mass-production factory through a JV with a major company.

Debut of a coal-to-ethanol plant

China has successfully brought onstream the world's first demonstration plant that converts coal to ethanol, according to an announcement by the Chinese Academy of Sciences. Located at Shaanxi Yanchang Petroleum in China's Shaanxi province, the plant uses process technology that was jointly developed by the Chinese Academy of Sciences (Beijing; www.cas.cn), Dalian Institute of Chemical Physics in Liaoning province (Dalian; www.dicp.cas.cn) and Shaanxi Yanchang Petroleum (Xi'an; www.sxycpc.com).

The technology uses coal-based syngas as raw material, and a non-precious-metal catalyst, to produce anhydrous ethanol. The plant has the capacity to produce more than 100,000 metric tons of ethanol per year (m.t./yr), according to Liu Zhongmin, deputy director of the Dalian Institute. Liu says China produces 7 million m.t./yr of ethanol, but that does not satisfy the country's industrial and energy needs. He says China plans to build a plant that can produce 1 million m.t./yr by 2020.

Most countries produce ethanol from corn or sugar cane, but this is not a viable option for China, because of its huge population and the dearth of arable land. Turning China's abundant coal resources into ethanol will help safeguard the country's energy and food security, Liu says.

Zhu Fang, deputy director of information and marketing for the China Petroleum Chemical Industry Federation, says it is not certain the technology will make an impact. Whether the production of ethanol will prove advantageous depends partly on oil prices, he says. Oil prices have dropped so much that ethanol fuel is no longer cost-effective, compared with crude oil, adds Fang.

A catalyst for making H_2 from methanol

Polymer electrolyte membrane fuel cells (PEMFCs) running on hydrogen are an attractive proposition, particularly as a power source for motor vehicles. In situ release of the required H_2 from a stable liquid ensures its safe storage and transportation before use. Use of methanol is especially attractive because it can reform itself with water to release H_2. However, traditional reforming of methanol steam operates at relatively high temperatures of 200–350°C, and therefore the focus for vehicle and portable PEMFC applications has been on aqueous-phase reforming of methanol (APRM).

Now a group from Peking University (Beijing, China; www.pku.edu.cn) led by professor Ding Ma has reported a new catalyst — platinum atomically dispersed on α-molybdenum carbide (α-MoC) — enables low-temperature (150–190°C) base-free (avoiding the caustic hydroxide) H_2 production through APRM, with an average turnover frequency of 18,046 moles of hydrogen per mole of platinum per hour. Ma attributes this to the outstanding ability of α-MoC to induce water dissociation and to the fact that platinum and α-MoC act in synergy to activate methanol and then to reform it.

Ma says that a 50-L tank of methanol and catalyst with 6–10 g of platinum could power a Toyota Mirai for about 690 km. The methanol would cost about $15, and the platinum about $320, but the catalyst is potentially recyclable. Ma says that automobile catalytic converters now contain 1–4 g of recyclable noble metals, so 8 g of platinum is not a comparably large number.

The type of catalyst developed by Ma and co-workers could also be useful for other aqueous-phase reforming processes, such as those involving bio waste or ethanol. ■

paper quality. Packaging and tissue machines lose the equivalent of 4% of their output per day due to machine contamination and sheet breaks caused by deposits. They contribute to holes in the sheet, specks and printability issues, in addition to causing machine downtime and cleaning time.

To solve these problems, Archroma (Reinach, Switzerland; www.archroma.com) has introduced Cartaspers PLH liquid, a product that enables easy and highly effective control of pitch and stickies deposition, especially in soft-water pulp-and-papermaking environments. Pulp-mill tests already report easier application, better performance and significant cost savings compared to alternative deposit-control systems, says the company.

Cartaspers PLH is an anionic pale yellow, low-viscosity liquid that is very effective in attracting non-polar (hydrophobic) substances, such as stickies and natural pitch. It helps to passivate contamination and prevent agglomeration and deposition, without any impact on cellulosic material. The organic additive performs across all water-hardness levels and complies with food contact regulations such as BfR and FDA. Compared to talc powder, the liquid is easier to handle and to disperse. Cartaspers PLH does not cause scale deposits in evaporators or contribute to ash content in finished pulp, which reduces pulp quality. ❑

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Plant Watch

LyondellBasell announces HDPE technology license in Dalian

April 12, 2017 — LyondellBasell's (Rotterdam, the Netherlands; www.lyondellbasell.com) Hostalen ACP process technology was selected by Hengli Petrochemical (Dalian) Chemical Co. for a high-density polyethylene (HDPE) unit to be built in the Hengli Petrochemical Industrial Park in Dalian, Liaoning Province, China. The new plant's HDPE capacity will be 400,000 metric tons per year (m.t./yr).

Total-Hanwha JV to expand refining and petrochemicals platform

April 12, 2017 — Hanwha Total Petrochemical, a 50/50 joint venture (JV) between Total S.A. (Paris, France; www.total.com) and Hanwha (Seoul, South Korea; www.hanwha.com), will invest to expand its Daesan petroleum-refining and petrochemicals integrated platform. The planned $450-million investment will increase the site's ethylene production capacity by 30% to 1.4 million m.t./yr. The expansion project is set to be completed by mid-2019.

Mitsui Chemicals starts up electrolyte solution production facility

April 10, 2017 — Mitsui Chemicals, Inc. (Tokyo, Japan; www.mitsuichem.com) has announced the startup of its electrolyte solution production facilities, which have been built at the company's Nagoya Works site in Japan to accommodate growing domestic demand for lithium-ion batteries and their associated materials. The production capacity for the new plant is 5,000 m.t./yr.

Air Liquide to build nitrogen plant at plastics complex in Oman

April 6, 2017 — Under the terms of a recently signed supply agreement with Oman Oil Refineries and Petroleum Industries Co. (Orpic), Air Liquide (Paris, France; www.airliquide.com) will build a €20-million, 500-m.t./d nitrogen-production unit at Orpic's Liwa Plastics Industries Complex. The new unit is expected to start operations in the first quarter of 2019.

ExxonMobil Chemical announces global expansion of hydrocarbon fluid assets

April 6, 2017 — ExxonMobil Chemical Co. (Houston; www.exxonmobilchemical.com) announced the expansion of its global hydrocarbon-fluid assets by more than 250,000 m.t./yr at its petrochemical sites in Antwerp, Belgium, Baytown, Tex. and Jurong Island, Singapore. According to the company, more than 60% of the additional hydrocarbon-fluid capacity is already online, with the remaining amount expected by early 2019.

Cepsa expands production of linear alkylbenzene in Brazil

April 5, 2017 — Compañía Española de Petróleos S.A.U. (Cepsa; Madrid, Spain; www.cepsa.com) has completed a revamping project to expand production of linear alkylbenzene (LAB) at its Deten Química plant in Brazil. The plant improvement project involved an investment of €64 million and increased the plant's LAB production capacity to 260,000 m.t./yr.

Lanxess increases capacities for iron oxide pigments in Germany and Brazil

March 30, 2017 — Lanxess AG (Cologne, Germany; www.lanxess.com) announced two capacity-expansion projects for iron oxide pigments. In Krefeld-Uerdingen, Germany, production of red and black pigments will be gradually increased by around 23,000 m.t./yr, up from the current capacity of 280,000 m.t./yr, by 2019. Lanxess is also expanding its capacity for yellow pigments by 2,000 m.t./yr at its site in Porto Feliz, Brazil.

Dow completes construction of new Freeport ethylene plant

March 28, 2017 — The Dow Chemical Co. (Dow; Midland, Mich.; www.dow.com) announced the completion of the construction phase of its new ethylene production facility in Freeport, Tex. Dow's ethylene unit, which has a nameplate capacity of 1.5 million m.t./yr, is now progressing through the commissioning phase, with startup expected by mid-2017.

Mergers & Acquisitions

NOVA acquires U.S. Gulf Coast assets from Williams in $2-billion deal

April 17, 2017 — NOVA Chemicals Corp. (Calgary, Canada; www.novachem.com) has agreed to acquire selected U.S. Gulf Coast assets from Williams Partners L.P. (Tulsa, Okla.; www.williams.com) for $2.1 billion. The transaction includes Williams' 88.46% ownership stakes in the Geismar, La. olefins plant and Williams' interest in the Ethylene Trading Hub in Mt. Belvieu, Tex.

Ashland to acquire composites plant in France

April 10, 2017 — Ashland Inc. (Covington, Ky.; www.ashland.com) has made a binding offer to acquire a composites-resin manufacturing facility in Etain, France, from Reichhold Holdings International B.V. The transaction is expected to be completed by the end of June. The Etain facility manufactures unsaturated polyester resins (UPR) used in a variety of end markets. The proposed transaction is said to be integral to the closing of Reichhold's previously announced combination with Polynt.

BASF to sell Bleaching Clay and Mineral Adsorbents businesses

April 7, 2017 — BASF SE (Ludwigshafen, Germany; www.basf.com) will sell its Bleaching Clay and Mineral Adsorbents businesses, currently part of BASF's Global Catalysts division, to EP Minerals LLC. The transaction is expected to close in the third quarter of 2017. The divestiture includes a production site and a clay mine in Mississippi, and the mineral rights sublease associated with a mine in Arizona.

Butamax acquires ethanol business in Kansas

April 5, 2017 — Butamax Advanced Biofuels LLC (www.butamax.com), a 50/50 JV between BP plc (London, U.K.; www.bp.com) and DuPont (Wilmington, Del.; www.dupont.com) focused on bio-isobutanol, acquired Nesika Energy, LLC and its ethanol facility in Scandia, Kansas. Butamax will now start the detailed engineering work to add bio-isobutanol capacity to the facility, while continuing to produce ethanol before and after adding this capacity.

Flowserve to sell Gestra business to Spirax-Sarco

April 5, 2017 — Flowserve Corp. (Dallas, Tex.; www.flowserve.com) will sell its Gestra AG business unit to Spirax-Sarco Engineering plc (Cheltenham, U.K.) for an enterprise value of €186 million. In addition to Gestra's core manufacturing facilities in Bremen, Germany, the sale also includes several other smaller associated businesses. Flowserve obtained Gestra in 2002. as part of the acquisition of Invensys Flow Control.

DuPont and FMC announce pair of divestitures

March 31, 2017 — DuPont agreed to divest a portion of its Crop Protection business to FMC Corp. (Philadelphia, Pa.; www.fmc.com), and to acquire substantially all of FMC's Health & Nutrition business. The transaction, which is expected to close in the fourth quarter of 2017, includes consideration to DuPont of $1.6 billion to reflect the difference in the value of the assets.

Solvay to sell its polyolefin cross-linkable compounds business

March 30, 2017 — Solvay S.A. (Brussels, Belgium; www.solvay.com) has signed a definitive agreement to sell its polyolefin cross-linkable compounds business based in Roccabianca, Italy to Finproject S.p.A., a manufacturer of injection-molded foam, polyolefin-based compounds and polyvinyl chloride compounds. The transaction is expected to close in the second quarter of 2017. Solvay's polyolefin cross-linkable compounds are used in applications in the wire, cable and piping industries.

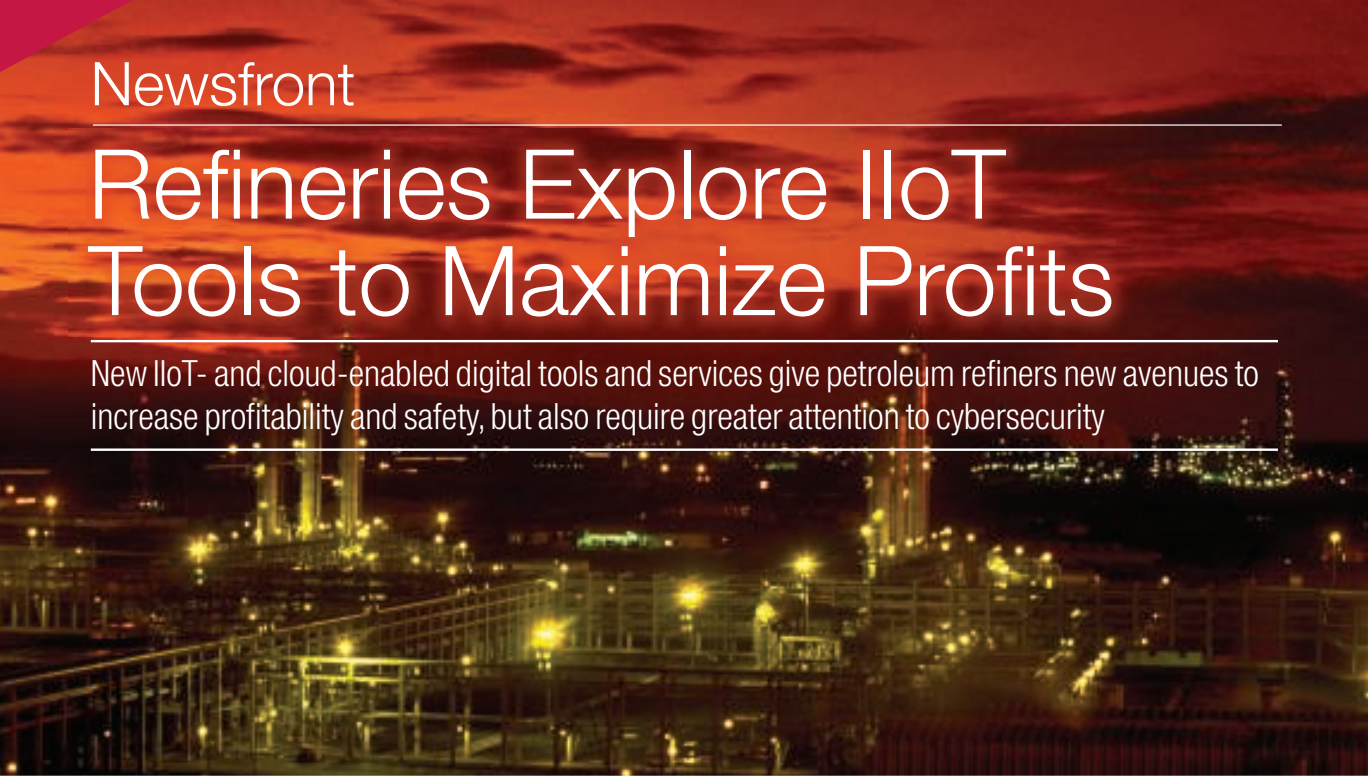
3M to buy Scott Safety from Johnson Controls for $2 billion

March 17, 2017 — Johnson Controls (Milwaukee, Wis.; www.johnsoncontrols.com) will sell its Scott Safety business to 3M Co. (St. Paul, Minn.; www.3m.com) in a transaction valued at around $2 billion. Scott Safety is a specialist in several product areas, including respiratory protection, gas and flame detection and thermal imaging.

Mary Page Bailey

Refineries Explore IIoT Tools to Maximize Profits

New IIoT- and cloud-enabled digital tools and services give petroleum refiners new avenues to increase profitability and safety, but also require greater attention to cybersecurity



IN BRIEF

While several forces are creating conditions in which U.S. petroleum refiners can thrive in 2017 and beyond, success and profitability are not guaranteed (see sidebar, p. 20). Refiners must address changing supply and demand for individual refined products, fluctuations in crude oil prices and dynamic geopolitical factors, all while pursuing the industry's ever-present imperative for efficient and safe operations. And refinery operations are taking place in an environment where the retirement of experienced workers is ongoing and the industry infrastructure is aging. The sum of these forces makes for a challenging environment for the nation's 139 active petroleum refineries.

To strengthen their chances of success, refiners are increasingly exploring digital tools that take advantage of the emerging Industrial Internet of Things (IIoT), as well as advanced software for data analysis that can optimize process operations and reduce downtime. A host of new offerings are becoming available, and several were discussed at the annual meeting of the American Fuel and Petrochemical Manufacturers (AFPM; Washington, D.C.; www.afpm.org), which took place in San Antonio, Tex. in late March.

IIoT opportunity

The historical approach to refinery operation has largely been characterized by a "run to fail" mentality, where abnormal conditions and malfunctions were detected only when alarms arose or when a component broke or failed. The IIoT enables operators, engineers and plant managers to capture and analyze data so they can predictively identify potential issues before problems arise. A plant enabled by IIoT is equipped with a combination of sensors, automation systems and cloud-based technologies that are integrated with its current systems and data analytics capabilities. Streaming data from sensors and instruments allow plants to quickly assess current conditions and identify warning signs for abnormal operations. Beyond that, digital tools that enable plants to access the benefits of the IIoT and cloud computing are becoming instruments for boosting profitability.

The recent proliferation of sensors and software, combined with advanced analytics capabilities, has allowed plants to move to a predictive-maintenance system, says Paul Bjacek, the chemicals and natural resources research lead for business consulting firm Accenture (www.accenture.com). "But we've also seen what we call a 'digital decoupling' in the chemical process industries (CPI) and elsewhere, in which digital technology, including IIoT tools, is becoming a primary driver of value that goes beyond being a system to improve conventional processes," Bjacek says.

According to proponents of IIoT-enabled digital systems and advanced analytics, the new tools can allow improved decision-making by aggregating data from multiple sources — cost-effectively generating data

not available previously. It can then allow pattern recognition and analytics to guide actions based on that wealth of data. Benefits of such IIoT-enabled tools are said to include the following:

- Increasing the rate of asset utilization by reducing unplanned downtime
- Minimizing small efficiency losses from sources that may not have been detectable previously
- Raising operating efficiency through improved monitoring of energy usage
- Improving operations by continuous monitoring and by providing instant access to information that supports decision-making
- Maintaining the effectiveness of control loops, controllers and models over time, so the benefits of advanced process control are sustained
- Lowering overall process risk, thus improving safety
- Reducing maintenance costs

Focus on economics

In order to realize these benefits, though, refineries need ways to transform all of the captured data into information within a real-world, operational context. A host of companies have been developing systems for providing tangible value for IIoT-related data collection and analysis.

Martin Turk, a global solution architect for industrial clients at Schneider Electric SE (Rueil-Malmaison, France; www.schneider-electric.com) says, "There is a need to begin with the problems that need to be fixed and to ask how these new [IIoT-related] technologies can help solve them, instead of starting with the tools and trying to find what problems they could address. At Schneider, we're taking a value-focused approach to IIoT, where the objective is to leverage the IIoT to make petroleum refiners more profitable," he says.

In February 2017, Schneider introduced patented software known as Profit Advisor (Figure 1), which uses data analytics to measure financial performance of industrial operations in realtime. Profit Advisor works with process data historians to mine both past and realtime operating data, and then crunches those data through proprietary segment-specific accounting algorithms, the company says, to determine realtime operational profitability and potential savings.

Developed in collaboration with Seeq Corp. (Seattle, Wash.; www.seeq.com), Schneider's Profit Advisor helps make economic-based decisions, in part by using continuous comparisons between designed performance and actual performance, Turk says. "It allows us to predict the impact of operator decisions on plant economics, making each operator more like a proprietor," he says.

Profit Advisor measures the realtime profit performance of each major plant asset and unit operation, and the whole plant, so it is a departure from current cost-accounting systems that only measure financial performance of the overall plant, Schneider Electric says. The product is designed to allow individual plant personnel to "see and understand the return-on-investment and business value of their actions . . . in realtime," the company adds, em-

powering them to make better decisions about operational profitability.

The system can also make it easier for workers to focus efforts on activities likely to provide the greatest financial returns and allows them to predict the profitability of possible changes before they are made, which can minimize risk and eliminate waste, Turk explains. For example, assessing the cost of a given period of downtime to fix a component could be compared to the costs of continuing to run a piece of equipment in a slightly degraded or suboptimal state for a certain period, Turk says.

Schneider Electric's Profit Advisor exists within a larger system of digital tools that includes Avantis PRiSM (process information signal monitoring), a predictive asset-analytics solution that can provide early notification of equipment health issues days, weeks or months before failure, and ARPM (automated rigorous performance monitoring). ARPM is a model-based online application designed to provide operators and engineers with realtime information about the performance of plant assets (for example, compressor efficiency) so that they can make better and faster decisions regarding what to do to correct for deviations from expected behavior.

PRiSM was originally designed for rotating equipment in other sectors, allowing operators to detect deviations and examine likely causes of problems, Turk explains, but his company is now moving this tool into refineries and adapting it to handle other equipment classes, such as heat exchangers and reactors.

Connected ecosystem

With all of the IIoT-related technology available, it has become relatively easy to collect data, but using those data thoughtfully to really make smart decisions about what to do with those data is what we are focused on, says Don Empie, communications director at Honeywell Process Solutions (HPS; Houston; www.honeywellprocess.com).

Honeywell is in the early stages of implementing its HPS Connected Plant initiative, which uses IIOT-enabled data collection and predictive analytics to enhance profitability across multiple facility sites, Empie says (Figure 2). To support the effort, HPS has created what it called "an ecosystem of OEMs [original equipment manufacturers]," each of which brings deep and specific expertise in different equipment classes. HPS Connected Plant is designed to harness the IIoT to tap into the deep knowledge of Honeywell and its network of suppliers and partners, Empie says, and by doing so, end-users are better able to make use of data enabled by IIoT systems.

FIGURE 1. Data analytics software that measures a plant's financial performance in realtime can unlock additional profits

A key part of HPS Connected Plant — and an example of how HPS is taking advantage of existing expertise — is Honeywell subsidiary UOP LLC's (Des Plaines, Ill.; www.uop.com) Connected Performance Service (CPS) offerings, which were launched in autumn of 2016. UOP's cloud-based software services continuously monitor streaming plant data and apply advanced analytics and machine learning to identify latent or emerging underperformance, alert plant personnel and make specific operational recommendations. The objectives include reducing unplanned downtime, increasing safety, raising efficiency and improving supply chain management.

Leveraging UOP process models and best practices, the CPS services create a "digital twin" of a plant that operates virtually in the cloud. "This 'digital twin' is kind of a utopia plant operating in the cloud that allows realtime comparisons between actual and simulated plant performance," explains Zak Alzein, Honeywell UOP vice president and general manager for CPS.

"We are offering a holistic approach to optimizing asset capabilities and maximizing uptime," Alzein adds, "by bringing together rigorous knowledge of process technology with new software tools." These IIoT-enabled tools take into account equipment inputs and feed properties and link them via cloud computing to maintain performance over time and provide a platform for continuous innovation and improvement, he says.

Two critical strengths for CPS services are their machine-learning algorithms and the open partnership between HPS and UOP. Since each petroleum refinery is unique, broad process technology experience is important. "Our fundamental knowledge of the chemistry is married to the data analytics and the machine learning," Alzein says. The UOP vice president thinks the technology world has reached an inflection point in machine learning, where these types of algorithms are found in many places, including in ordinary web browsing and smartphone applications. "Machine learning can eventually create almost a 'self-healing' plant that can use the IIoT to quickly introduce software updates and security patches, and proactively manage its own maintenance, for example," Alzein says.

Thus far, Honeywell UOP has announced three plants in which the services will be used, with more announcements forthcoming. The facilities announced to date are the Binh Son Refining and Petrochemical Co. Ltd. complex in Quang Ngai, Vietnam, the Delek Refining Inc. refinery in Tyler, Tex., and the Al Waha Petrochemicals Co. facility in Jubail, Saudi Arabia.

Honeywell-UOP

FIGURE 2. Digital tools that enable plants to take advantage of the Industrial Internet of Things and cloud computing are becoming pathways to higher profitability

"Adoption is slow in this industry, but the plants are recognizing the potential benefits of these tools and these approaches," remarks Alzein.

Remote process support

The March AFPM meeting also saw the launch of the KBC Co-Pilot Program, which is a service using simulation technology with IIoT and cloud computing tools to access the expertise of strategic and technical consultants at KBC Advanced Technologies (Walton-on-Thames, U.K.; www.kbcat.com). In Q3 2016, KBC became a wholly owned subsidiary of automation company Yokogawa Electric Corp. (Tokyo, Japan; www.yokogawa.com).

The Co-Pilot program is the initial manifestation of the KBC Production Core, which envisions automation of all aspects of production operations, with integrated technology and consulting best practices that leverage cloud computing and the IIoT.

The first release under the program is a Refinery Unit Performance Co-Pilot, says Jason Durst, Co-Pilot Program Manager at KBC, and is focused on driving value for clients by providing them with the tools and expertise to collaboratively maximize the potential from oil-refinery process units. Future releases will add Co-Pilot solutions for other asset types.

The Refinery Unit Performance Co-Pilot service monitors process operations at a facility in realtime to remotely support the plant with expertise and insight that supplements the plant's own capabilities and resources. It tracks data from multiple sources, including actual operating units and simulation programs, says Durst, and through Web-based dashboards, allows both clients and KBC subject matter experts to analyze the raw data and standardized unit performance indicators to make decisions to increase unit performance.

Co-Pilot is focused on bringing value to the client, Durst adds, and it is suited to process operations where the following may be true: managers are not confident that their operating plan is always realistic and achievable; an inexperienced workforce means the unit operation often misses plan; engineers lack the tools and knowledge to maximize profit or reduce risk; or operators do not always automatically know when they are deviating from plan.

Co-Pilot assures asset operators that their simulation and planning tools are up-to-date through the cloud, and that any adjustments made or recommended by their engineers result in optimal process performance and safe operation of equipment within recognized limits, KBC says.

Cybersecurity risks

The proliferation of internet-connected devices and sensors associated with IIoT technologies, coupled with increased use of cloud computing and data-as-a-service models, has further raised cybersecurity concerns for industrial control systems. Attention on the topic continues to grow and AFPM meeting organizers included a session about cybersecurity and automation systems. Among the themes explored by speakers was

U.S. PETROLEUM REFINING OUTLOOK

U.S. Dept. of Energy data indicate that U.S. refining capacity grew by almost 2% in 2016, and Chet Thompson, president of the American Fuel and Petrochemical Manufacturers (AFPM; Washington, D.C.; www.afpm.org), called 2016 a good — but not great — year for the petroleum refining industry, with exports of refined products robust at 3.3 million barrels per day (bbl/d) and demand projections remaining strong.

AFPM leaders commented on the positive outlook for their industry that has been set up with the new Trump Administration in the U.S. Greg Goff, who chairs the AFPM board of directors says, "We are at a tipping point for opportunity now, and we as an industry have to rise up with a sense of duty and be leaders. We have a business-friendly White House, we have executive branch agencies that are not hostile to our industry, and we have a center-right Congress."

Aside from the "seismic political shift" that led to Trump becoming President and the Republican Congress, Thompson pointed out that AFPM members have what he clearly sees as allies in Rick Perry (former Texas governor and new Secretary of Energy), Rex Tillerson (former ExxonMobil executive and new Secretary of State), and Scott Pruitt (former Oklahoma attorney general and new EPA administrator).

While no mention was made of addressing climate change concerns, Thompson and Goff both accepted the presence of Federal regulations for the industry. "Governmental regulations are not necessarily bad, but we need transparency in how they are made and how they are justified and how they are written," Thompson says. "We're not opposed to regulations as long as they are reasonable and cost-effective.

Thompson called on Congress and the Administration to bring about corporate tax reform and repeal the Renewable Fuel Standard (RFS), as well as expressed support for the White House America First Energy Plan (www.whitehouse.gov/america-first-energy). The document, which appeared shortly after Trump's inauguration has been criticized for failing to mention renewable energy, climate change and investment in utility grid infrastructure.

the need to merge the operational technology (OT) sector of the business with the information technology (IT) area, the traditional "home" to cybersecurity countermeasures (for more information, see *Chem. Eng.*, June 2014, pp. 30–35).

Eddie Habibi, founder and CEO of PAS Inc. (Houston; www.pas.com) spoke about the need for petroleum refineries and other CPI companies to undertake a comprehensive inventory of what he calls "cyber-assets," which includes all control-system sensors, input-output devices, computer workstations, mobile devices, and others. "You can't secure it if you don't know it exists," Habibi says. "If you have a complete inventory of cyber assets, you can identify vulnerabilities and determine if unauthorized changes have occurred," he notes (for more information, see *Chem. Eng.*, October 2016, pp. 60–64).

The traditional "IT-centric" view of cyber endpoints for industrial control systems neglects many parts of the distributed control systems (DCS) and programmable logic controllers (PLC) that exist below the level of information networks. That portion, which Habibi termed the "production-centric" cyber endpoints, consists of 80% of the assets that require inventorying, he says.

Aside from the comprehensive cyber-asset inventory, Habibi also recommended that companies conduct a prioritization exercise for the costs and consequences of various types of cyberattacks, or other incidents in which cybersecurity may be at risk unintentionally or non-maliciously. This can better ensure that resources are devoted to cybersecurity in a thoughtful way. In addition, attention should be paid to how cyber assets are backed up, and how recovery from a cyberattack would be accomplished.

According to Habibi and others at the meeting, the cyberattack "threat landscape" is growing, but so is the recognition of cybersecurity's importance at a grassroots level. It is important to realize that industrial control systems have characteristics of a living organism that continually changes, Habibi remarked, and also that eliminating the problem of cybersecurity will never be accomplished with a single solution.

Another speaker at the cybersecurity session was Gavin Mead, principal, cyber services for KPMG LLP (New York; www.kpmg.com/us). Mead also addressed the need for cybersecurity to extend into the OT world. Cybersecurity has been a hot topic in IT for several years, but the wave of interest in securing OT components from cyber threats has been more recent.

Mead pointed out several reasons for why the cybersecurity threat is growing. These include the fact that industrial automation systems are more sophisticated now, and that real-time business decisions are increasingly made with information from the control system. In addition, commoditized IT systems are common, and they support the OT system. Meanwhile, cyber attackers are increasingly sophisticated and well-funded.

The greatest risk to companies comes from failing to spend their financial resources for cybersecurity in the smartest way, Mead says. "We spend a disproportionate amount of money on assessing the problem and not enough on what the remediation will look like," he says. "That should come sooner in the process."

"The topic of cybersecurity is well discussed now, but there is still not enough sharing of information about cyberattack incidents," Mead says.

Jeff Melrose, principal technology strategist for cybersecurity at Yokogawa Corp. of America (Sugar Land, Tex.; www.yokogawa.com/us) added a new dimension to the AFPM session by discussing potential cybersecurity threats associated with drones. He says drone technology, even that available to hobbyists, has evolved to the point where their range is up to three miles, and they have the ability to maintain a stable hover or follow a target autonomously for 30 minutes more.

A drone equipped with electronic transmitters could theoretically follow a target and be directed remotely to disrupt wireless communications or surveil. Melrose suggested that refineries should begin instructing physical security personnel to look for drone activity near plants and should update procedures to include what to do if a drone approaches a facility. ■

Scott Jenkins

The Financial Benefits of Water Treatment

Due to the rising costs of water use and disposal, improved treatment technologies make economic sense

IN BRIEF

While chemical processors think of themselves as just that — makers of chemicals — they don't often consider themselves players in the water industry. However, due to a combination of drivers, such as water scarcity and pressure to clean up discharge water coupled with improved water treatment technologies and tools, it may be time to consider water treatment as more than a necessary method to improve water quality for process or discharge. In fact, experts agree that water treatment can also be an integral part of the chemical processing business and a way to boost the bottom line.

"No matter what business you're in, you're also in the water business, simply because of the fact that you can't manufacture anything without using water in the process industry," says Justin Mattingly, research manager with the Water Environment & Reuse Foundation (WE&RF; Alexandria, Va.; www.werf.org), which recently completed a project — Framework for the Successful Implementation of On-Site Industrial Reuse — that provides tools for industry to identify, evaluate and implement onsite water conservation and reuse opportunities.

And, as large consumers of water, processors need to be aware that water is quickly becoming a scarce resource in many regions around the world. Nanette Hermsen, global marketing director for reverse osmosis at Dow Water & Process Solutions (Edina, Minn.; www.dowwaterandprocess.com), cites statistics from UN-Water (the United Nations interagency mechanism on freshwater-related issues; www.unwater.org), which suggest that over the course of 50 years, from 2000 to 2050, the global manufacturing demand for water is expected to increase by 400%. "The increasing demand for water in industry combined with water scarcity issues means we have to use water effectively and get more out of every cycle, every loop and every drop of water so there's no waste," she says. "As such, industry has begun using more wastewater and more challenging waters as feed water, so there's been a strong push for designing technologies and processes to accommodate these more challenging streams, whether it's on the front end or the back end, because they are looking more and more alike these days. Water treatment in a circular economy approach means that your back end often becomes your front end."

Water Planet

FIGURE 1. PolyCera membranes from Water Planet offer a ceramic-like combination of high hydrophilicity, permeability and robustness, but at 10 to 20 times lower cost

The financial case for treatment

Mattingly agrees, and adds that it is also possible for processors to financially benefit from water treatment and water reuse. "While drivers for water treatment, specifically water reuse, are usually water shortages or discharge restrictions, it's becoming more important for industry to peel back the onion on water use and identify opportunities on investments that allow them to not only treat water for their needs, but also to reap some significant financial

Dow Water & Process Solutions

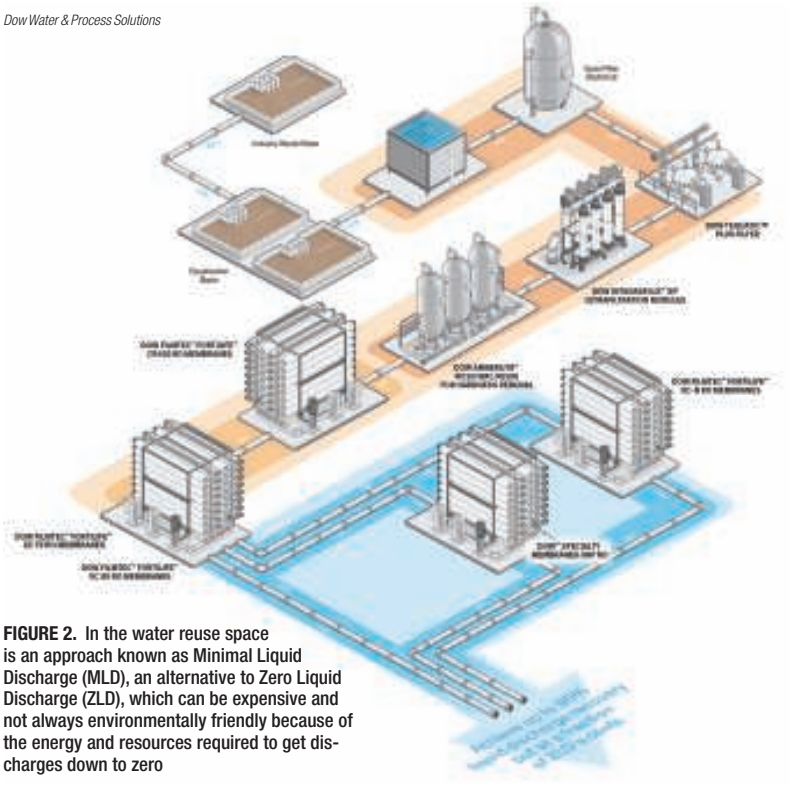


FIGURE 2. In the water reuse space is an approach known as Minimal Liquid Discharge (MLD), an alternative to Zero Liquid Discharge (ZLD), which can be expensive and not always environmentally friendly because of the energy and resources required to get discharges down to zero

awards by doing so," he explains.

How so? According to Eric Hoek, CEO of Water Planet (Los Angeles, Calif.; www.waterplanet.com), the cost of purchasing and disposing of water has gone up to the extent where water is a major expense for industry, but treating and reusing that water reduces those costs. "Due to water scarcity, the cost of sourcing fresh water for industrial purposes has increased. At the same time, the cost of disposing of water, either by treating wastewater to a very high level for sewer disposal or paying someone to accept it, has climbed. So we have a situation where going the traditional route of buying water from the local municipality and treating for disposal has become very burdensome," explains Hoek. "However, today's water-treatment technologies have gotten to the point where they are more effective and less expensive, which creates a situation where treating and recycling that water for reuse is a straight up reduction in costs."

He says, in most cases, a return on investment for the technology needed to treat water for reuse can be seen in less than five years. "Even when there is a need for advanced treatment technologies, water reuse offsets the costs dramatically."

As a matter of fact, WE&RF is working on a second project — Scorecard for Evaluating Opportunities in Industrial Water Reuse — which aims to develop a user-friendly return on investment (ROI) calculator for onsite water reuse. "We're trying to make visible the full cost of water to help industry get a more accurate calculation of the cost of water, which includes how much you pay per gallon of water, the volume of water used, the energy needed to heat and treat that water for process, the energy used to treat that water for disposal and the cost to dispose of the water, as well as water supply availability and the costs associated with risk of water shortage," explains Mattingly. "Only by understanding the full cost of water, can you get an accurate calculation for the ROI of onsite reuse technology and water efficiency."

He adds, however, that initial capital investment is just one point that may deter facility decision makers. "We also need to educate them on today's available treatment technologies and the concept of reuse because they need to have the confidence that the water being produced will be suitable for their needs." In an effort to boost confidence in water-treatment technologies, the organization includes a section in its first report with a full survey of the available technologies, how they operate and their capabilities in meeting treatment needs.

Some of the newest technologies are discussed below.

Dow Water & Process Solutions

FIGURE 3. In an effort to promote MLD and reuse, Dow's Filmtec Fortilife line consists of new elements designed to meet these needs. Fortilife XC70, XC80 and XC-N offer advantages for plants looking to reduce costly concentrate waste, lower operating expense and achieve MLD goals

Water reuse technologies

Membrane technology has long been used for water treatment because it's very compact and highly automated. However, until recently, available membrane technologies — polymeric and ceramic membranes — had drawbacks. Hoek says polymeric membranes foul quickly, requiring frequent cleaning, while ceramic membranes are more robust but extremely expensive. "It created a paradigm where everyone would like to use membranes, but found them too expensive or unreliable."

To alleviate this problem, Water Planet created a membrane material that can handle fouling, is easy to clean and is more chemically and thermally robust than conventional polymeric materials, but is still a polymer (Figure 1). "The result is PolyCera, which offers polymer economics with ceramic performance," says Hoek. "It is a low-cost alternative to ceramics, but reliable enough to be deployed in difficult-to-treat industrial wastewaters."

Available as flat sheets or in spiral

TOOLS OF THE WATER TRADE

When it comes to water treatment, many processors think they have to make concessions. "They believe complying with regulatory legislation concerning water discharge will negatively impact operations or yield. But, this isn't really the case," says Peter Macios, executive product manager with GE Water & Process Technologies (Trevose, Pa.; www.gewater.com). "One of the things that's unique to water process technologies is that we can provide chemical processors with the equipment, services and tools that give them the opportunity to make operational excellence and environmental priorities inclusive of each other."

As previously noted, the newest water-treatment technologies provide both treated water and economic benefits. These benefits can be further increased through the use of currently available tools, as well. "I hear from plants around the world that they want to know what's going on with their water at all points in the system from the front end, during operations and then within the discharge," says Macios. "This isn't limited to flow and velocity. They also want to know about water quality. And, they want it in digital format — almost like a fitbit for water treatment."

As a result, GE Water & Process offers its InSight management solution. "Water and process applications generate operating data that, properly managed, can play an integral part in lowering the total cost of operation. Effective water operations depend on data that are transformed into meaningful and actionable information, and the InSight software solution provides the ability to diagnose problems, find opportunities for improvement, report on key performance indicators and alarms on events or trends before they threaten asset or production integrity. "InSight can be applied along with water treatment technologies so that it's no longer just chemistry, but also a very strong digital component that helps analyze and optimize performance of the water treatment," says Macios. "We armed the 'water doctors' with better tools, which allows processors to more easily meet the goals of both environmental and operational excellence."

Similarly, MilliporeSigma provides instruments that help processors become more profitable in their water treatment. "There's always been a common theme in industry about cutting costs and maximizing production yield so that, at the end of the day, the facility is profitable," says Steve Kuchenberg, global segment lead — environmental testing with MilliporeSigma (Billerica, Mass.; www.milliporesigma.com). "And because water plays such a critical role in chemical processing, it becomes part of the equation of profitability."

He says challenges exist around getting water that is useable and of the correct composition to safely flow through process equipment, coolers and boilers and then handling it as it become discharge water or water for reuse. While each processor has different water-based concerns depending upon where they source their water, what they do with it and how they handle it after the process, it is always important to measure and monitor the composition of the water to ensure that it meets process needs, won't cause premature wear on equipment and meets disposal criteria.

"While continuous monitoring systems are excellent tools for this, alone they aren't always enough," says Kuchenberg. "There should be some checks in place to ensure that the monitors are working, and that requires manual and point-of-use testing."

One of the most recent tools for this is MilliporeSigma's Spectroquant Prove 600. It is a spectrophotometer designed for process water analysis. Offering high-resolution optics with cuvettes of up to 100 mm, the compact device is suitable for complex kinetics or spectral measurements. Prove 600 is preprogrammed for the sensitive silicate and chloride tests, so users can detect the lowest analyte concentrations, and avoid damages to cooling- and boiler-water systems.

Making these instruments easier to use and more sensitive goes a long way to making sure process water, no matter where it comes from, is of the correct composition to avoid process upsets and associated costs, says Kuchenberg. ❑

monolith elements, PolyCera membranes offer a ceramic-like combination of high hydrophilicity, permeability and robustness, but at 10 to 20 times lower cost. The spiral monolith elements leverage benefits in a ceramic-like crossflow, back-washable filtration module. "Our testing shows operating expense savings og up to 40% relative to commodity polymer membranes and 80% relative to ceramic membranes," says Hoek. "It allows our customers to stop doing nothing and start choosing to recycle and reuse their water."

In the water reuse space is an approach known as Minimal Liquid Discharge (MLD), an alternative to Zero Liquid Discharge (ZLD), which can be expensive and not always environmentally friendly because of the energy and resources required to get discharges down to zero (Figure 2). "Some industrial and municipal users are turning to MLD to achieve up to a 95% liquid-discharge recovery, but at a fraction of ZLD cost," says Hermsen. "MLD is attractive because they aren't paying for water intake and water disposal via the use of a combination of different technologies." In an effort to promote MLD and reuse, one of Dow's newest product lines, Filmtec Fortilife, consists of new elements designed to meet these needs. Fortilife XC70, XC80 and XC-N offer advantages for plants looking to reduce costly concentrate waste, lower operating expense and achieve MLD goals (Figure 3).

Dow's IntegraFlux Ultrafiltration Modules with XP fibers are meant to handle the challenging demands of closed-loop water systems and are typically used in conjunction with reverse osmosis (RO) in systems using an MLD approach, says Hermsen.

Recognizing the systematic approach to cleaning up water for reuse, as well as treating river or alternative water sources for use, another player in the water treatment industry has also tweaked existing technologies to provide higher efficiencies. "As we look to alternative water sources, such as river water and resource recovery, we, as treatment providers, have invested in research to develop technologies that are more efficient and robust so that our users can employ alternative sources and reuse effluent to improve their own efficiencies," says Ben Moore, business development manager with Veolia Water Technologies (High Wycombe, U.K.; www.veoliawatertechnologies.com.uk). As a result, the company has made improvements to many of its traditional treatment methods. For example, Veolia offers Actiflo, a high-rate, compact water-clarification process in which water is flocculated with microsand and polymer in a draft tube (Figure 4). The microsand enhances the formation of robust flocs and acts as a ballast, significantly increasing their settling velocity. The resulting microsand ballasted flocs allow for clarifier designs with very short retention times, high rise rates and extremely compact footprints. "On the back of that, our Rapide Strata twin-bed deionizers help produce high-purity water, while offering savings of up to 40% on running and effluent costs compared to conventional ion-exchange systems. The improved technology offers regeneration in 30 to 45 minutes, minimizes downtime, enhances bacterial control and improves chemical usage

FIGURE 4. Actiflo is a high rate, compact water clarification process in which water is flocculated with microsand and polymer in a draft tube. The microsand enhances the formation of robust flocs and acts as a ballast, significantly increasing their settling velocity. The resulting microsand ballasted flocs allow for clarifier designs with very short retention times, high rise rates and extremely compact footprints

efficiencies," notes Moore. He also cites improvements to the company's Sirion Mega RO system for industrial process water, wastewater and water reuse applications. It can be used alone or in combination with processes such as ion exchange in applications where total dissolved solids (TDS) concentrations in water must be reduced. The RO membrane also acts as a very fine filter, removing 99% of suspended and colloidal solids, bacterial and organic molecules. This makes the process attractive in applications where treated water not only has to be low in TDS but also of high clarity and free from bacteria, such as in food processing and pharmaceutical manufacturing. "All these systems from deionizers to RO are becoming more and more efficient and can reliably recover more water to improve efficiencies and costs," says Moore.

FIGURE 5. Chemical free, UV disinfection has been proven to improve well integrity and reduce operational costs for over 20 years. Now seen by operators as an OPEX saving technology, UV disinfection is gaining prominence in the upstream oil-and-gas industry

More efficient water treatment

Thanks to technology adaptations, water treatment for applications other than reuse has also become more efficient and cost effective. For example, in the oil-and-gas industry, there are a number of problems associated with controlling microorganisms via chemicals. "Companies in this sector need to use a form of disinfection technology to avoid a range of negative consequences in the well, the equipment and the piping systems that can be caused by uncontrolled colonies of bacteria," explains Paul Hennessey, oil, gas and energy business manager with atg UV Technology (Lancashire, U.K.; www.atguv.com). "For the last 30 or 40 years, that has been done using chemicals. However, there are not only transportation and storage issues associated with using chemicals in offshore applications, but also issues related to chemical-induced byproducts that have to be taken down to undetectable limits before wastewater can be discharged into the ocean. This required extra equipment, time and expense," he says. "So it became necessary to take a holistic approach to avoid putting something in on the front end that has to be removed on the back end."

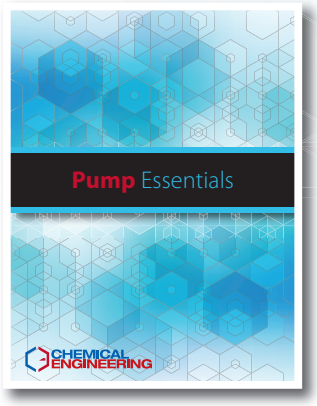
The solution turned out to be ultraviolet (UV) technology — an existing technology with a new use (Figure 5). "We use the same technology that's been used in municipal drinking and wastewater treatment for years, but packaged it in a different way and designed it to target oil field microorganisms," says Hennessey. "It is chemical free, so there's no toxicity, no need to transport, store or handle chemicals and it creates no residual byproducts that need treatment."

Here, too, tweaks to an existing technology have created a solution that is not only more efficient, but also less expensive. "Treatment chemicals weren't inexpensive and to properly treat these applications, you needed a whole cocktail of chemicals applied at different stages," he says. "So when you take the whole chemical solution and treatment process and compare it to UV, UV is much less expensive." He says one oil-and-gas major company used to spend £200,000 ($251,000) a year on treatment chemicals, but moved to UV technology, with a consumable cost of the UV system equipment and energy to run it of £15,000 ($18,800) a year. "That's a savings of £185,000 ($232,200) a year when using UV as opposed to traditional chemical treatment," says Hennessey.

Clearly, treatment technologies have improved, allowing users to see significant economic benefits. "A lot of these technologies have been available for decades, but they are more advanced, more energy efficient and cost effective than ever before," says Dow's Hermsen. "This provides significant advancements in water and wastewater treatment, recovery and reuse and affords users better sustainability and cost benefits, which is what we're all striving for in a water-strapped environment." ■

Joy LePree

Pump Essentials



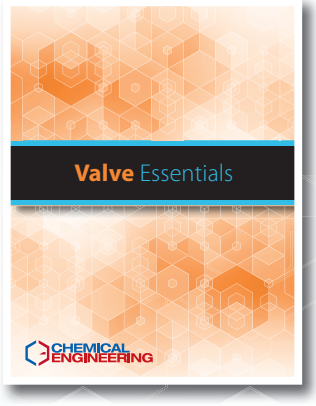
Most engineers would agree that pumps represent the workhorse component in any chemical process industries (CPI) facility. Every day, countless decisions must be made related to the proper selection and specification, sizing and installation, operation and maintenance, and troubleshooting of these critical machines.

This *Chemical Engineering* reference book provides a wealth of practical engineering guidance on the proper use and operation of several different types of pumps. Articles focus on the sizing and selection of centrifugal pumps, and tips for managing the impact of pumps whose operation deviates from the best efficiency point (BEP). Others provide engineering tips for understanding and optimizing magnetically driven and sealless pumps, and guidance for calculating net positive suction head (NPSH).

Included is detailed information on condition monitoring and maintenance of pumps, recommendations for designing and operating safe and accurate pressure-relief systems, and selecting variable frequency drives (VFD) for centrifugal pumps.

Text also encompasses data related to lifecycle cost analysis, construction-cost indices for CPI equipment, and budget considerations for capital-intensive CPI operations.

Valve Essentials



Engineers are routinely challenged when it comes to the proper selection, specification and sizing, and installation, operation and maintenance, and troubleshooting of valves to control fluid flow while ensuring overall reliability and safety.

This resource provides engineering articles which focus on the proper selection and operation of control valves and control valve positioners and sensors. Included is information provide sizing calculations for pressure-relief valves and related systems, plus tips for using pressure-relief valves with rupture disks.

Guidance is offered on reducing fugitive emissions and troubleshooting valves in the field, as well as engineering recommendations related to material selection, planning for plant revamps, improving operability, and managing challenges associated with hygienic operation.

Powder and Bulk-Solids Handling

Material Transfer

Outotec

Elcan Industries

Bulk-bag discharge unit has low headroom requirements

This patented system (photo) is custom designed for the safe discharge of product into the user's process. It features several stainless=steel features, including the Flo-Lock discharge spout-closure system, which is said to quickly halt material flow and allow for partial-bag discharge. The Seal-Master bag-spout access chamber is designed for easy operator access, and the Sure-Seal bag spout-clamping system is designed to minimize dust escape. The system also includes the Flo-Master bag-massaging system to enhance powder flow, and pneumatic piping with rigid 304 stainless-steel air lines. — *Material Transfer, Allegan, Mich.*

www.materialtransfer.com

The process of relining grinding mills just got easier

The process of relining a grinding mill can be challenging, even for the most experienced crew, says this company, due to confined spaces, hot environments and complex tasks. The 7-Axis Beam Mill Reline Machines (MRM; photo) can be maneuvered using a conventional rail arrangement or tire-drive system, providing increased flexibility for transport around the mill deck. Its traveling liner cart can be maneuvered for rotating liners, and a crane with seven degrees of freedom for manipulation of the liners inside the mill ensures safe, efficient and reliable operation, says the company. Safety features include remote control operation, state-of-the-art electro-hydraulic proportional control blocks with advanced fault detection, safe machine design and safety-rated components and systems, says the manufacturer. — *Outotec Oyj, Helsinki, Finland*

www.outotec.com

Advanced screeners can handle many particle sizes

Partnering with German manufacturer Rhewum GmbH, this company offers the Rhewum line of screening equipment (photo). The latest addition to this company's advanced screening equipment family are large, rectangular screening machines that incorporate direct excitation of the screen cloth to achieve high throughput at lower micron size, says the company. The customized machines are available in numerous sizes and can have multiple decks to enable the production of several products at the same time. The machines feature electromagnetic elements mounted on the side of the screen housing, which directly transfers energy into the screen mesh while the machine body remains static. — *Elcan Industries, Tuckahoe, N.Y.*

www.elcanindustries.com

Sanitary, high-lift dumper handles powders in boxes

Constructed of stainless steel that is finished to food, pharmaceutical or industry standards, the Tip-Tite High-Lift Box/Container Dumper (photo, p. 32) discharges dust-free into vessels that are 6 to 10 ft above the plant floor. The containers are loaded at the floor level and hydraulically sealed against a discharge hood. The assembly is then hydraulically elevated and tipped, causing the discharge hoot spout to seat against a gasketed receiving ring installed on any receiving vessel or process equipment. Opening a pneumatically actuated slide gate valve at the spout outlet allows controlled, dust-free discharge, while closing it allows partially empty boxes to be returned to the plant floor. The unit accommodates Gaylords and other boxes from 36– 48 in. (915–1,220 mm) side length, and 39–44 in. (990–1,117 mm) overall height. It can also be constructed

Note: For more information, circle the 3-digit number on p. 90, or use the website designation.

in carbon steel, and optional receiving hoppers can be configured with mechanical or pneumatic conveyors to transport discharged materials to any plant location. — *Flexicon, Bethlehem, Pa.*
www.flexicon.com

These level sensors handle a range of particle types

The full line of bulk-solids level sensors (photo) from this company includes probes for a variety of applications. The DJ Series handles products ranging from low-density flakes and powders to heavy granules and pellets. The GJ Detector is constructed to handle problem applications that have a tendency to pack or bridge. The GSS sensor operates successfully with consistent results on difficult product applications, such as precipitated powders, fine, low-density powders and materials as light as 0.5 lb/ft^3, says the company. All level indicators are available as a sealed and suspended model, when a side-wall mount is not practical, says the company. The level probes rhave no moving parts — *Automated Products, Dynatrol Div., Houston*
www.dynatrolusa.com

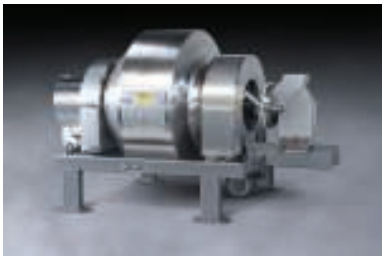
This batch unit provides rapid, thorough sanitary mixing

The Model 700-TH-40-SS sanitary rotary batch mixer (photo) blends batches of ingredients in parts as small as one ppm with 100% uniformity in less than 3 min, evacuates 100% of the batch, and can be sanitized rapidly with no tools, says the manufacturer. It is intended for industrial applications involving contamination-sensitive materials and those requiring frequent product changeovers. The unit has a rotating drum with proprietary mixing flights that tumble and fold materials gently, imparting minimal energy to the batch, regardless of disparities in bulk densities, particle sizes or variable flow characteristics of the ingredients, and its retractable inlet enables easy, thorough washdown. The mixer has a useable batch capacity of 40 ft^3 (1.132 m^3), total capacity of 80 ft^3

Flexicon

Automated Products

Munson Machinery



Best Process Solutions

(2.27 m^3) and weight capacity of 4,000 lb (1,814 kg), and is equipped with a spray line for liquid additions. — *Munson Machinery, Utica, N.Y.*
www.munsonmachinery.com

Manage the storage and emptying of bulk bags safely

This company's new bulk-bag filler with wooden pallet dispenser (photo) automatically places an empty pallet under a bulk bag before filling. Between 14 and 16 pallets can be loaded for staging into the pallet dispenser. Controls automatically remove the bottom pallet from the stack and place it below the bulk bag before filling occurs. Once the bulk bag is filled, a power roller discharges the filled bulk bag and pallet onto an accumulation conveyor (not shown) for transport to warehouse. — *Best Process Solutions, Brunswick, Ohio*
www.bpsvibes.com

Level-detection system is immune to steam and buildup

The GWR-2000 guided microwave level transmitter (photo; p. 33) is used for inventory management and level detection in silos and provides continuous level measurement in vessels up to 100 ft tall with accuracies of ±0.08 in. (2 mm). It uses time-domain reflectometry (TDR) to continuously measure the distance, level and volume of powders or solids in bins, tanks and silos. This sensor features hazardous location approvals, a very small upper dead zone, and assures highly accurate level measurement in low-dielectric materials down to 1.3. It has 4–20-mA and Modbus RTU communication options, making it compatible with a human-machine interface or programmable logic controller, as well as the company's eBob LAN-based software program or BinView cloud-based monitoring. It excels in challenging conditions such as vessels with high dust and air movement or excessive noise, says the company. — *BinMaster, Lincoln, Neb.*
www.binmaster.com ■

Suzanne Shelley

New Products

Use these pumps in applications with fluctuating feedrates

The V-AN Series of self-regulating centrifugal pumps (photo) features a control system that independently adapts to changing feedrates, meaning that when media flows into a vessel, the liquid level rises until the inflow and outflow of the vessel balance out — without any type of mechanical or electrical regulation equipment. All V-AN pumps are dry-running, self-ventilating, operate free of cavitation and boast a low NPSH (less than 0.1 m). The pumps are suitable for applications with fluctuating flowrates, as well as those that require pumping boiling or gaseous media. Furthermore, the suction pressure can be lowered to the boiling condition as needed. The V-AN Series also allows for the reduction in feed-vessel diameters, saving investment costs, says the manufacturer. — *Paul Bungartz GmbH & Co. KG, Düsseldorf, Germany*

www.bungartz.de

Paul Bungartz

Monitor benzene with this targeted gas detector

The TA-2100 benzene gas detector utilizes advanced photo-ionization sensor technology to provide fixed, continuous monitoring in both indoor and outdoor installations in demanding industrial environments. The detector provides low-ppm detection limits as a critical part of an early warning system. A self-calibration feature adjusts the span monthly, based on the sensor life curve, and offsite sensor calibration is also possible with the sensor's embedded memory chip. The device can operate at temperatures ranging from –20 to 55°C, and in relative humidity up to 95%. — *Mil-Ram Technology, Inc., Fremont, Calif.*

www.mil-ram.com

Safer changeouts with these filter elements

VertexCore coalescing filter elements (photo) have a fixed extension that is welded to the element end cap, which allows maintenance staff to easily remove and replace elements without exposing their head, shoulders, torso or legs to a confined space. This design feature eliminates the widespread behavior of climbing into or reaching into filtration pressure vessels to remove or replace elements. The VertexCore extensions and hold-down rods, while facilitating element replacement, also provide a barrier to prevent operator entry, a positive reinforcement to confined-space safety regulations. The multi-layer elements feature removal efficiencies of 99.98% for particle sizes down to 0.3 µm with maximum carryover of 0.1 ppm. VertexCore elements can be retrofitted to existing pressure vessels to eliminate carryover created by inadequate element spacing of standard elements. — *Clark-Reliance Corp., Strongsville, Ohio*

www.clark-reliance.com

Clark-Reliance

Quiet, low-vibration pumps for sensitive applications

The Ecodry plus (photo) is a vacuum pump designed specifically for applications in the transition area between small laboratory equipment and large-scale industrial machines, in the size class ranging from 40–60 m^3/h. Ecodry pumps' quiet operation — the average noise level is just 52 dB — is achievable due to insulation that is integrated into the pump housing, as well as an optimized silencer in the exhaust. Because there is no dust or oil contamination, these pumps are suitable for installation with large-scale accelerator systems. The non-contact rotor design is not only designed for quiet operation, but also for low vibration. This is especially beneficial in applications that require the production of high-resolution images, such as in electron and scanning microscopy, because the transmission of vibrations from a pump can hinder these results. — *Leybold GmbH, Cologne, Germany*

www.leybold.com

Leybold

Air-quality monitoring with many connectivity options

The OnGuard Smart corrosion-monitoring device incorporates a room pressure sensor and WiFi capabilities to provide a complete picture of the environment's air quality with multiple connectivity options. In addition to measuring room pressure,

the OnGuard Smart also monitors temperature and relative humidity. Most importantly, copper and silver corrosion corresponding to ISA Standard 71.04-2013 is measured via this company's Quartz Crystal Microbalance (QCM) sensors. The OnGuard Smart can also alert an operator to a potential failure of electronics so action can be taken before failures occur. Data-logging and reporting capabilities provide diagnostic data to pinpoint problem areas or times so that issues can be resolved quickly. System data are captured in real-time, and are accessible remotely. — *Purafil, Inc., Doraville, Ga.*
www.purafil.com

Gas metering for extruded plastic foam production

The Plastinum DSD 400 gas-metering system (photo), designed for extruded-plastic-foam manufacturing, provides precise amounts of liquid CO_2 or gaseous N_2 during the extrusion process to help optimize foaming and reduce density. The system's ability to quickly react to constantly changing pressure fluctuations at the extruder enables stable extrusion processes and delivers consistent foam structures during continuous extrusion foaming, says the manufacturer. This allows users to minimize, or sometimes even eliminate, the use of flammable hydrocarbons. The DSD 400 handles pressures up to 5,081 psi (400 bars) and can pump liquid CO_2 through the control valve at a constant rate at speeds up to 66 lb/h (30 kg/h). The system features a high-performance compressor, mass flowmeters and a dynamic control valve, and its lightweight and compact design simplifies installation. — *Linde LLC, Bridgewater, N.J.*
www.lindeus.com

Linde

This new NOx analyzer has an internally cooled sensor

The accuracy of an NO gas sensor, the primary component of NOx, can be compromised when exposed to ambient temperatures above 86°F (30°C) and significantly more so above 104°F (40°C). To help prevent this temperature effect on the NO sensor, the E8500 Cooled NOx portable emissions analyzer (photo, p. 33) keeps the NO sensor cooled with an internal cooling system. The analyzer measures, displays and records the NO sensor temperature to make it easier to comply with conditional test methods. The E8500 Cooled NOx also comes standard

E Instruments International

with this company's Sample Conditioning Unit (SCU), which cools and dries the stack gas at the probe handle to minimize the time that the gas has in contact with the condensate. — *E Instruments International, LLC, Langhorne, Pa.*
www.e-inst.com

A plastic piping system for very low temperatures

The ecoFIT polyethylene (PE) piping system (photo) provides chemical

GF Piping Systems

resistance, abrasion resistance and high impact strength, even at low temperatures. The ecoFIT product line consists of a complete range of system components, including valves and connections. Other performance characteristics include operating temperatures ranging from –58 to 140°F, low weight, ultravoilet (UV) radiation and weather resistance and high mechanical strength. The products are available in standard sizes in both inches (2 to 23 in.) and millimeters (20 to 250 mm). The impact resistance of ecoFIT components are particularly beneficial in applications where low temperatures would typically degrade or limit the physical properties of plastic materials. — *GF Piping Systems, Irvine, Calif.*
www.gfps.com

Recover caustic materials with these nanofiltration systems

Causti-COR nanofiltration systems are specifically designed to recover and purify caustic for reuse in food, beverage and industrial applications. The systems can recover up to 95% of caustic from solutions used to clean process equipment in industrial applications, says the manufacturer. Patented spiral-wound filter elements allow purification of up to 20% sodium or potassium hydroxide at solution temperatures up to 70°C (160°F). Six models of Causti-COR systems are available to handle flowrates up to 32 m^3/h. There are three batch-mode systems for processing feed flowrates between 1 and 15 m^3/h and three continuously operated systems for processing feed flowrates be-

Honeywell Safety and Productivity Solutions

KD Scientific

Asahi/America

Andritz Separation

tween 4 and 32 m^3/h. Custom-engineered systems are available to treat larger or application-specific flowrates. — *Koch Membrane Systems, Wichita, Kan.*
www.kochmembrane.com

Anti-fog lens coating available on more eye-protection products

This company has expanded the availability of its Uvex HydroShield anti-fog lens coating to include seven new eye-safety offerings, including the clear Flex Seal Goggle (photo), and three lens tints each for the Stealth OTG and Livewire product lines. Uvex HydroShield eliminates fog and resists scratching, even in extremely hot, wet and otherwise demanding conditions. Its performance significantly exceeds EN166, the most stringent anti-fog standard in the world, according to the manufacturer. The dual-action coating is permanently bonded to the lens to withstand extended wear and repeated washings without wearing off. Most HydroShield anti-fog coated products meet ANSI Z87.1-2015 and are certified to the requirements of the CSA Z94.3 standards. All Uvex lenses offer 99.9% UV protection. — *Honeywell Safety and Productivity Solutions, Smithfield, R.I.*
www.uvex.us

Dual-rate pump combines two syringe pumps in a single device

The Gemini 88 Plus dual-rate syringe pump (photo) provides two independent pumping channels linked through hardware and software, combining two individual syringe pumps into one instrument. The syringe pump can infuse simultaneously at different rates, or infuse with one syringe and withdraw with the other. When combined with a valve box, it provides the continuous delivery of a peristaltic or piston pump with the accuracy, absence of pulsation and low flowrates of a syringe pump. This functionality allows continuous infusion or withdrawal, with both high- and low-pressure operation possible. The system is compatible with a wide variety of syringes. — *KD Scientific, Holliston, Mass.*
www.kdscientific.com

These thermoplastic ball valves feature improved ergonomics

The new design of the Omni Type-27 compact ball valve (photo) includes a smooth ergonomic handle with open/shut indication. The rugged, injection-molded one-piece body features a single-threaded and sealed end carrier, and double-stem O-ring seals provide added leak protection. The Omni Type-27 ball valve is available with socket or threaded end connections in sizes from 3/8 through 2 in. Available body materials are PVC and CPVC, both with EPDM seals and PTFE seats. NSF-61 certified and rated for 150 psi at 70°F, the Omni Type-27 can be electrically actuated with this company's Electromni Series 83 electric actuator. — *Asahi/America, Inc., Lawrence, Mass.*
www.asahi-america.com

A high-speed mixer delivers 40,000 L/h

The DynaShear inline high-speed emulsifier disperses gums, stabilizers, proteins and sweeteners in a single pass, delivering batch times as low as 3–5 min., with less air entrainment and the ability to run continuously. With flowrates up to 40,000 L/h, it delivers smooth product with no agglomerates, says the company. The two-stage rotor/stator action allows processors to run longer and clean-in-place (CIP) less frequently. The DynaShear prevents clogged strainers and extends the life of pumps, valves and seals. — *Admix Europe ApS, Allerod, Denmark*
www.admix.com

This filter press is driven by compressed air

The new SP series (photo) is a so-called "air-over-oil" filter press driven exclusively by compressed air. Air-over-oil filter presses are used where power connection is not available or possible in a process line. By deliberately dispensing with electrical equipment, the SP series is a cost-effective alternative to conventional machines and a further development of filter presses that are designed for manual operation only. The heart of the new press is the hydraulic unit operated by compressed air. Once supplied with air (6–8 bars), the pneumatically

driven high-pressure pump generates up to 400 bars of hydraulic pressure. The inflowing hydraulic oil then moves the cylinder that generates the locking force required to close the press securely. After completion of the filtration process, the operator relieves the pressure. Units are available with filter areas of 6.5 to 226.4 m^2 and volumes of 69.4 to 2,401 L. — *Andritz Separation GmbH, Graz, Austria*
www.andritz.com

A compact ultrasonic sensor with IO-Link

A new variant of this company's Compact Series of ultrasonic sensors (photo) has an IO-Link output. Users can use IO-Link for the process values or continue to use the switching output of the sensor. The switch point is taught via IO-Link or via a teach adapter. The benefits of IO-Link include inexpensive wiring, intelligent data retention for predictive maintenance and a special mute function feature. This enables the selective switching on or off of the sonic transducer via the IO-Link master. This simplifies the synchronized or staggered operation (multiplex) of several sensors via the controller. Synchronous or multiplex operations were previously only possible by using complex wiring solutions. — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
www.turck.com

Reduce downtime with this diagnostic app

This new Diagnostic Tool application — available on Apple, Android and Windows mobile devices — is a quick and simple way for users of Control Techniques' drives to solve any error codes that the drive may show. Built within the app are easy-to-use wiring diagrams for first-time setup, plus links to the relevant manuals that provide the most comprehensive drive data and information. The app also has full contact details of the technical support teams around the world

Hans Turck

DMN–Westinghouse

to aid operators with any technical problems. Currently, the app has full information for all drives within the Unidrive M, Powerdrive F300, Elevator drives, Unidrive SP, Commander SK, Digitax ST and Mentor MP ranges. — *Emerson Industrial Automation, Eden Prairie, Minn.*
www.emerson.com

This high-pressure valve is now available in the U.K.

This company's new high-pressure (HP) rotary valve (photo) is now available in the U.K. The valve's design reduces product degradation and also greatly reduced axial air leakage — up to one-third less air leakage than other standard high-pressure valves is possible. The HP valve is able to run at pressures up to 3.5 barg. The HP valve bodies and the 12-bladed, standard full-end disc rotor are manufactured from 316 stainless steel, while the end covers are made from aluminum in order to reduce wear. The HP rotary valves are available in three sizes: 200, 250 and 300 mm. Standard conveying rates range from 8.3 to 30 L per complete rotor revolution at 100% filling. The standard models are suitable for handling products up to a temperature of 80°C. — *DMN–Westinghouse, Noordwijkerhout, the Netherlands*
www.dmnwestinghouse.com

IDEC

Enclosures and control stations for hazardous locations

The EC2B Series (photo) is a new line of enclosures, control stations and accessories for hazardous-location applications. These standard and custom control stations utilize the company's EU2B line of hazardous location pushbuttons, pilot lights, selector switches, key selector switches, emergency stop switches and analog meters. All EC2B and EU2B products are UL certified for use in Zone 1 and 2, and are also certified for use in hazardous locations by IECEx (Global), ATEX (Europe) and TIIS (Japan) to meet the strictest safety standards. The enclosures and fully-sealed pilot devices are rated IP65 and Type 4X for protection against water and corrosion, and are available with exposed or finger-safe IP20 screw terminals. The enclosures are constructed of 304 stainless steel to provide long service life in hazardous and corrosive areas. — *IDEC Corp., Sunnyvale, Calif.*
www.idec.com/hazloc

Endress+Hauser

A pH electrode for hygienic and sterile applications

Memosens CPS171D pH electrodes (photo) can be sterilized and are autoclavable for use in bioreactors, fermenters and other hygienic and sterile applications. The CPS171D measures the full pH range of 0–14 and operates in temperatures from 32 to 284°F. The CPS171D is IECEx and ATEX approved for use in hazardous locations; has IP68 protection; and has FDA, USP and ISO approvals for biocompatibility regarding cytotoxicity and bioreactivity. The CPS171D pH probe has a unique reference gel and glass membrane that when combined, can improve the longterm stability for reliable and accurate measurement, even after multiple clean-in place (CIP) and sterilize-in-place (SIP) cycles. The probe is suitable for CIP and SIP operations up to 284°F. — *Endress+Hauser, Greenwood, Ind.*
www.us.endress.com/cps171d

This clamp-on flowmeter enables flexibility in installation

The TransPort PT900 (photo) is a portable, ultrasonic flowmeter for liquid flow measurement. The TransPort PT900 features an all-new transmitter and clamping fixture, as well as an app-driven user interface on an Android tablet. The clamp-on design allows for the measurement of flow from outside a pipe, so there is no requirement for the process to be shut down for installation. Its portability allows it to be moved easily from location to location for temporary or spot flow measurement or check metering. The transducers are compatible with most pipe sizes and materials and can handle a wide range of liquids, including ultrapure to extremely dirty water, refined hydrocarbon liquids and crude oil. Other features include Bluetooth communication between the transmitter and tablet, 4 GB of memory for storing large data logs and accuracy of ± 1% of reading. — *GE Oil & Gas, Billerica, Mass.*
www.gemeasurement.com

GE Oil & Gas

Stainless-steel flanges now available on these AODD pumps

The Husky line of corrosion-resistant stainless-steel air-operated double diaphragm (AODD) pumps (photo) has been expanded to include stainless-steel ANSI/DIN welded flanges. The flanges are available in vertical and forward-facing orientations, and feature a rotatable design that simplifies connection to process piping. Husky AODD pumps range from 1/4 to 3-in. connections and produce flowrates up to 300 gal/min. Configurable in a wide variety of pump body materials and wetted elastomers, Husky AODD pumps are compatible with challenging fluid characteristics, such as extreme temperatures, abrasives and caustic or corrosive materials. — *Graco Inc., Minneapolis, Minn.*
www.graco.com

This respirator hood is certified for an extended service life

The Parat 4920 escape-hood respirator (photo) recently received approval by the National Institute for Occupational Safety and Health (NIOSH) for an extended service life of 16 years, provided that the filter is exchanged after eight years. Replacing the filter halfway through the hood's lifecycle not only prolongs the service longevity, but also greatly reduces the total cost of ownership and longterm maintenance costs. The 4920's high-performance combination filter protects against a variety of toxic industrial gases, vapors and particles. The multi-gas filter is approved according to NIOSH 42 CFR Part 84 for Respiratory Protective Devices for escape from ammonia, chlorine, chlorine dioxide, hydrogen chloride, hydrogen fluoride, hydrogen sulfide, methylamine, organic vapors, sulfur dioxide and particles. Additionally, the filter is independently tested and provides some levels of protection against formaldehyde, hydrogen cyanide and mercury vapors. — *Dräger Inc., Houston*
www.draeger.com
Mary Page Bailey and Gerald Ondrey

Graco

Dräger

Pressure-Based Level Measurement

Department Editor: Scott Jenkins

Liquid-level measurement in storage tanks or other vessels is important for avoiding spillage and process upsets. One class of technologies for liquid-level measurement involves measuring the pressure exerted on a gage by the weight of the liquid, and this one-page reference provides information about various devices from this category.

The two main types of hydrostatic pressure sensors are head-pressure transmitters and air-bubbler units. Each measures liquid level by detecting the pressure exerted by the weight of the liquid. Hydrostatic pressure sensors are either externally mounted or submersible pressure sensors made for liquid-level applications. Since these sensors are a contact measurement technology, they can be affected by changes in the environment. They should not be used if there are variations in the density of the fluid being measured. Also, error is introduced if the probe is not stationary.

Externally mounted sensors. Externally mounted pressure sensors are attached to the bottom or side of a tank. The measurement is based on the distance from the bottom of the tank, the pressure exerted by the liquid in the tank, and the reference pressure from the air above the liquid in the tank. There may be a need to measure the air above the liquid with another sensor if the tank is pressurized. The built-in circuitry correlates the pressure into a 4–20-mA output signal proportional to the liquid level.

Submersible sensors. Submersible pressure sensors can be used in open-air applications, where the sensor cannot be mounted to the bottom of the tank. The sensor is specially designed to seal the electronics from the liquid environment. For this type of sensor, using chemically compatible materials is important to assure proper performance. Submersible pressure sensors can reach extreme depths for measurements, but are not especially accurate, particularly if the sensor is not fixed in place.

Differential pressure

More than one pressure sensor can be used for differential pressure (DP) measurement. DP sensors calculate the measurement based on each sensor's input, enabling higher accuracy and the ability to measure mass, density and volume. Since these sensors measure increasing pressure with depth and because the specific gravities of liquids are different, the sensor must be properly calibrated for each application. In addition, large variations in temperature cause changes in specific gravity that should be accounted for when the pressure measurement is converted to level.

DP devices are a common means of continuous level measurement in the chemical process industries (CPI) because of their ease of use. The high-pressure side of a differential pressure instrument is connected to the bottom of a tank, while the low-pressure side is connected to the vapor space at the top of the vessel (Figure). The measured pressure differential is the pressure of the liquid column in the tank. This provides a true level reading if the fluid density is constant. If not, changes in the liquid composition or temperature will change the specific gravity and create a false reading. Any changes in density, such as those caused by a change in temperature, necessitate recalibration.

DP devices offer the advantage of easy installation in liquid applications that are relatively clean and free of suspended solids. Drawbacks include the requirement to seal fluid in pressurized vessels, difficulty of calibration and technical difficulties related to density and temperature.

Air-bubbler systems. Pneumatic-based air-bubbler systems contain no moving parts, making them suitable for measuring the level of sewage, drainage water, sludge or water with large quantities of suspended solids. The only part of the sensor that contacts the liquid is a bubble tube, which is chemically compatible with the material to be measured. Since the point of measurement has no electrical components, the technique is a good choice for classified "hazardous areas." The control portion of the system can be safely located, with the pneumatic plumbing isolating the hazardous from the safe areas.

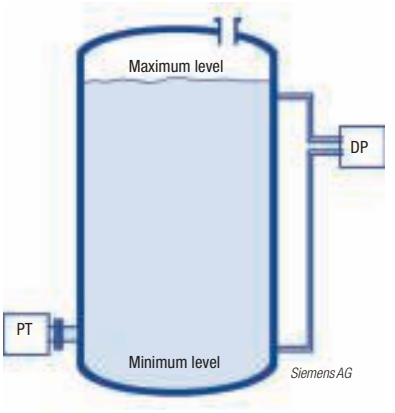


FIGURE 1. The measured pressure differential of the liquid column in a tank provides a true measure of the level if the fluid density is constant

The air-bubbler system works by introducing air into a pipe. The pressure created in the pipe returns to the sensor where it can be displayed visually or converted into an electrical signal. The pressure in the pipe is equal to the pressure exerted by the water and effectively measures the same as the other hydrostatic pressure sensors. In tanks with no vents, an additional line is needed to prevent the bubbler from building pressure inside the tank. The pressure in the pipe has to be considered in the level calculation depending on the air pressure above the liquid, the size and shape of the tank, and the distance from the bottom to the pipe.

Air-bubbler systems are a good choice for level measurement in open tanks at atmospheric pressure, and can be built so that high-pressure air is routed through a bypass valve to dislodge solids that may clog the bubble tube. It is highly recommended for applications where ultrasonic, float or microwave techniques have proved undependable. ■

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1. Schmidt, K., Level Measurement Technologies for the CPI, *Chem. Eng.*, July 2008, pp. 34–37.
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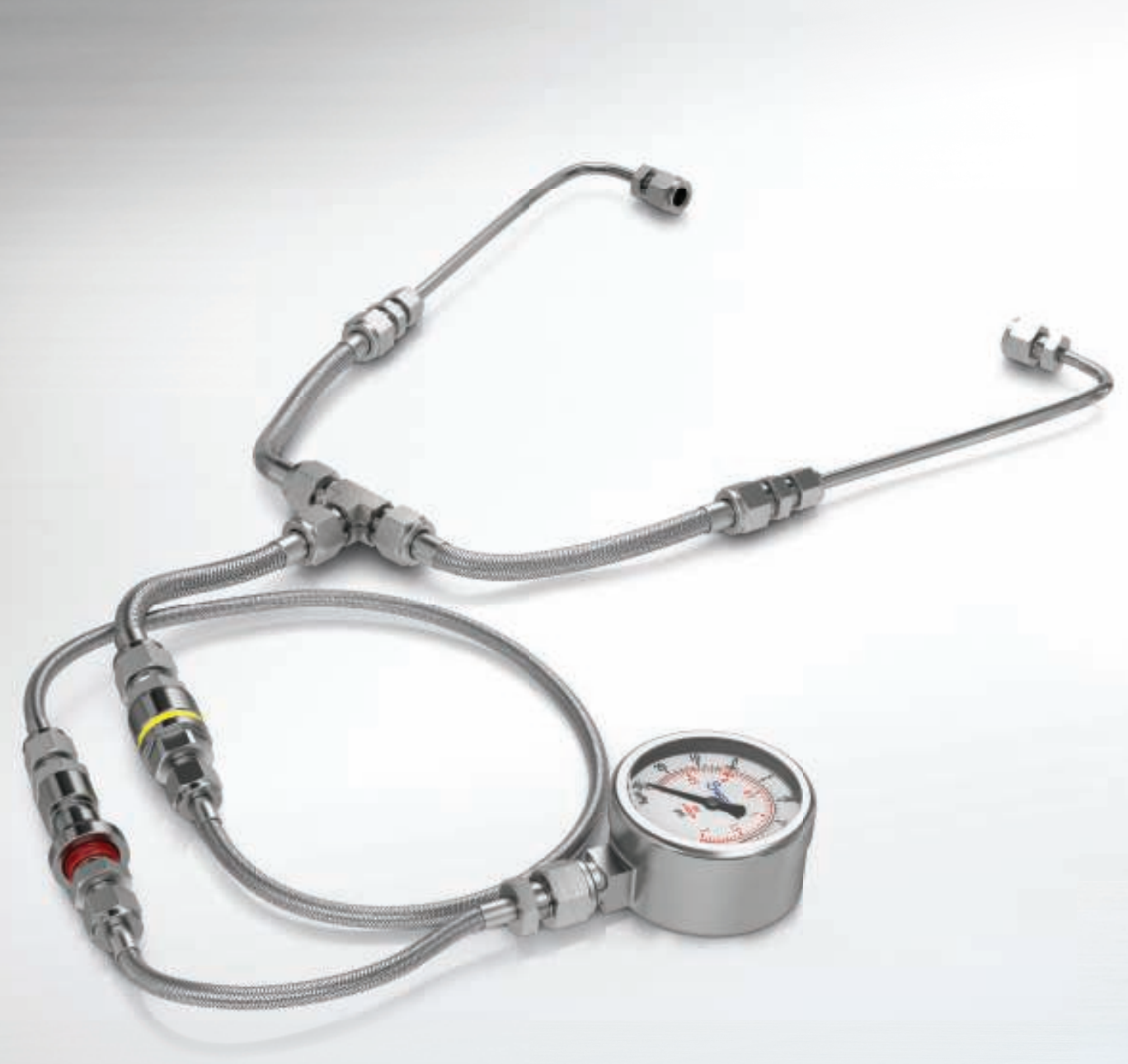

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Ammonia Production from Natural Gas

By Intratec Solutions

Ammonia (NH_3) is among the most important industrial chemicals, produced by reacting nitrogen and hydrogen in a 1:3 stoichiometric ratio. This world-class commodity chemical is used in a myriad of applications, from fertilizers to wood pulping and drugs.

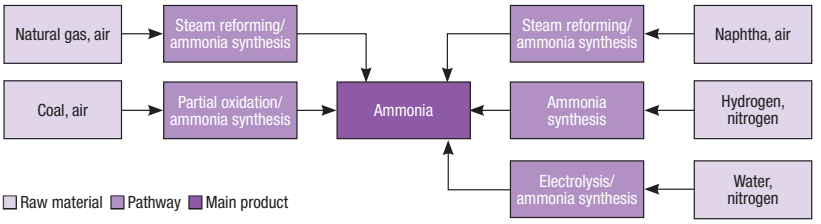

FIGURE 2. Ammonia production pathways

The process

The process described in the following paragraphs is similar to the KBR Purifier process, in which ammonia is synthesized following production of synthesis gas (syngas) from natural gas via steam reforming (Figure 1).

Natural-gas steam reforming. After being compressed and desulfurized, natural gas is mixed with steam for primary steam-reforming reactions. In a tubular fired heater filled with a nickel-based catalyst, the methane is reacted with steam, generating a crude syngas mixture composed mainly of carbon monoxide (CO) and hydrogen (H_2). The partially reformed natural gas is fed to the autothermal reformer (ATR), where the remaining methane is converted to CO and H_2. The effluent from the ATR is cooled, generating steam.

Raw syngas purification. The outlet from the ATR is fed to a two-stage, high- and low-temperature reactor, where the bulk of the CO is converted into carbon dioxide (CO_2) and H_2. The shifted gas is then cooled in a boiler-feed-water exchanger, generating steam, and a cooling water exchanger, in such a way that water present in the gas condenses and is removed in a knockout drum. The gas stream is sent to the CO_2 absorption unit, which utilizes a methyldiethanolamine (MDEA) wash to remove CO_2. The gas stream, free from CO_2, is heated and fed to the methanator, where residual carbon oxides are converted to methane in the presence of methanation catalysts. After being cooled and dried in molecular sieves, the syngas is fed to the syngas purifier, composed of a feed-effluent exchanger, a low-speed expander and a rectifying column. In the syngas purifier, excess nitrogen, methane, most of the argon and other impurities are condensed, to be further vaporized and used as fuel.

Ammonia synthesis. The purified syngas is compressed, heated and fed to the ammonia reactor, an intercooled horizontal converter. The cooled reactor outlet is then directed to a multi-stream heat exchanger that causes the ammonia to condense, using recycled gas and boiling ammonia as refrigerant. Residual gases are recycled to the syngas compressor upstream.

Ammonia production pathways

Since it was developed by Fritz Haber and Carl Bosch, the catalytic synthesis of ammonia from nitrogen and hydrogen has not changed significantly. Because of this, most of the different ammonia manufacturing routes are related to different sources of the two elements, especially H_2. In this context, two main ammonia production routes are based on steam reforming. Different pathways for ammonia production are presented in Figure 2.

Economic performance

The operating variable costs (raw materials and net utilities cost) estimated for a facility producing ammonia from natural gas operating in the U.S., using data from the second quarter of 2013, would be about $94 per ton of product.

This column is based on "Ammonia Production from Natural Gas – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/ammonia-production-cost. ■

Edited by Scott Jenkins

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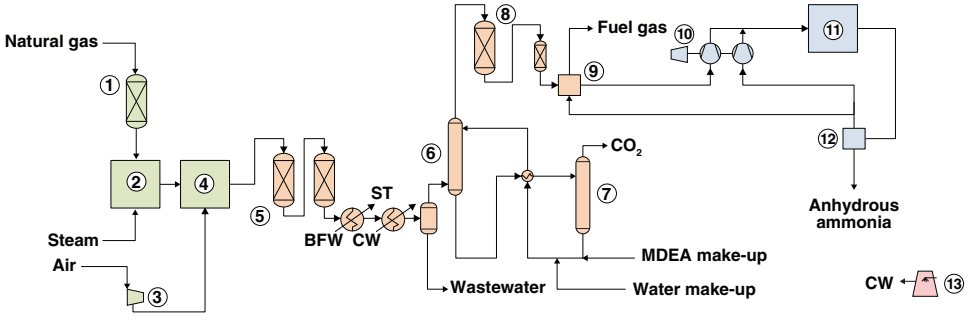

1. Desulfurization
2. Steam reformer
3. Air compressor
4. Autothermal reformer
5. CO shift reactors
6. Absorption column
7. Regeneration column
8. Methanator
9. Syngas purifier
10. Syngas compressor
11. Ammonia reactor
12. Ammonia recovery
13. Cooling tower

BFW Boiler feed water
CW Cooling water
ST Steam

FIGURE 1. Process similar to KBR purifier for ammonia production from natural gas

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Part 1

Implementing an 'Integrity Operating Window' Program

An effective Integrity Operating Window (IOW) program — which establishes safe operating limits and acceptable limits of process variation before an asset begins to degrade — can help operators stay ahead of potential repairs and reduce risk

Russ Davis
MISTRAS Group

IN BRIEF

System	Description	Color	API 570 Pipe Class	Corrosion rate, mil/yr	Damage mechanism	Limits
100	Ammonia vapor		1	0.5	NH_3 SCC*	Carbon steel in aqueous ammonia non-PWHT*
101	Ammonia liquid		2	1	Ammonium chloride corrosion	Concentration of ammonium salts and temperature
102	Ammonia, CO_2, H_2O vapor, ammonia recycle High-pressure streams		2	3	NH_3 SCC	Carbon steel in aqueous ammonia non-PWHT
300	Tail gas		2	3	CO_2 corrosion	<300°F
						Liquid phase where CO_2 condenses from vapor phase
500	Natural gas		2	0.5	CO_2 corrosion	<300°F
						Liquid phase where CO_2 condenses from vapor phase
501	Fuel gas		2	0.5	CO_2 corrosion	<300°F
						Liquid phase where CO_2 condenses from vapor phase
502	Hydrogen line		2	0.5	CO_2 corrosion	<300°F
						Liquid phase where CO_2 condenses from vapor phase

FIGURE 1. Damage mechanisms are established to identify the key controllable monitoring parameters, or variables that can be effectively adjusted to bring the process back within safe operating limits (*SCC = stress corrosion cracking; PWHT = post-weld heat treatment)

A comprehensive asset-integrity management (AIM) program is essential to ensuring process integrity and reducing risk of operations to as low a level as practicable. Historically, these programs are based on a given set of operational parameters that were established during the implementation of the program. To develop these programs, process conditions — such as the various chemical components present in the process streams, temperature, pressure, and flowrates — are analyzed by mechanical integrity (MI) subject matter experts (SMEs). These experts identify the potential damage mechanisms associated with anticipated operating conditions, and help to establish inspection methods and testing frequencies. In the subsequent management of the AIM program, reliability and MI groups rely on these parameters and testing method-

ologies that were established during the program's development.

But over time in a process facility, operational parameters change, and the rate of equipment degradation may change as well, causing the asset-integrity program to become ineffective. This can shorten equipment lifespans, raise costs, and greatly enhance potential risk to personnel, assets and the environment.

To maintain the integrity of process equipment in petroleum refining and petrochemical facilities, a comprehensive process safety management (PSM) system is required. Currently, most of these systems are oriented toward a rigorous mechanical integrity program that predicts or prevents failures of pressure equipment. Beyond this, however, the optimal PSM support systems include implementation of so-called integrity operating windows (IOWs; defined below) and management-of-change (MOC) programs, which are designed to monitor and control process variables that can impact the likelihood of failure.

The implementation and management of an effective IOW program is complex. It requires a multi-disciplinary team of engineering SMEs, with advanced knowledge of mechanical, corrosion, reliability and materials engineering disciplines; a multitude of inspection and maintenance services; and plant data-management software to store and trend data over the program's lifetime. With such a wide range of SMEs and competencies required, operating companies may partner with an experienced third-party service provider with expertise in the full scope of asset-protection solutions, including inspection, engineering, maintenance, condition-monitoring, and mechanical integrity data management software. Through such a partnership, the stakeholders can develop, implement and manage an effective program.

Defining integrity operating windows

As defined by the American Petroleum Institute's (API) RP 584, integrity operating windows are established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined length of time [*1*]. In short, IOWs

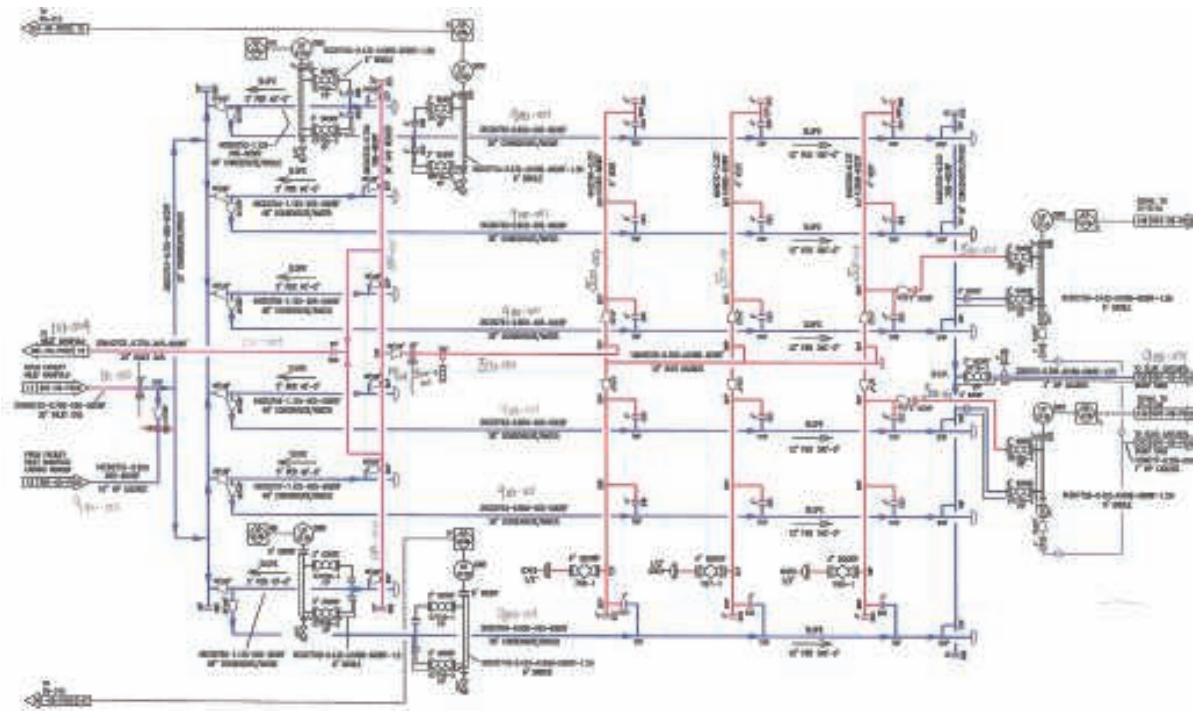


FIGURE 2. As shown in this sample process flow diagram, process flow streams and control groups are often color-coded in accordance with the colors assigned to them on the damage-mechanism analysis table shown in Figure 1

establish acceptable limits of process variations before an asset begins to incur damage.

The purpose of defining an IOW is to establish, implement and maintain a program to identify any potential damage mechanisms that may adversely affect the process, and then use that information to create a system where parameters can be modified as processes evolve over time. IOWs identify safe operating limits with the express purpose of avoiding equipment degradation that could lead to a loss of containment. The ultimate goal of IOWs is to lower the risk of operating plant process equipment.

Integrity operating windows are typically defined by their criticality. API RP 584 divides IOWs into three categories:

1. IOW critical limit
2. IOW standard limit
3. IOW informational limit

IOW critical limit. An IOW critical limit would be one that, if exceeded, could lead to rapid deterioration of process equipment. A critical limit requires immediate operator action to return the process variable to a predetermined parameter in order to prevent potential equipment damage in a short time frame. An example of a critical limit could be a pH excursion in a process stream, as an extremely low pH could quickly damage pressure equipment and could reasonably lead to loss of containment in a short time.

IOW standard limit. An IOW standard limit is an integrity parameter, which, if exceeded over a specific time frame, could cause increased corrosion rates or eventually lead to cracking or other damage to materials of construction. Standard limits are typically very time-based, in that the time required for equipment to be adversely impacted generally defines the response to a standard limit IOW. The consequence of damage to the equipment associated with the IOW will also influence an SME's response to the parameter being exceeded. An example of a standard limit IOW could be an elevated temperature on a heater tube skin, which could lead to tube failure over time.

IOW critical limit. IOW informational limits are generally used by SMEs to predict the long-term integrity of equipment, or to analyze impact on the asset-integrity program. Informational IOWs are parameters that may or may not be affected by operations. These IOWs do not typically require operational responses but may be utilized to assess future repairs of turnaround and shutdown frequencies. Informational IOWs can be used to evaluate the process assumptions used to establish risk-based inspection (RBI) programs. An example of an informational limit would a temperature rise due to process creep, which could indicate to facility operators that the parameters that were defined during the AIM program development are misaligned with current

operating processes.

These terms vary across companies and industries. Critical limit IOWs may also be referred to as safe operating or safety critical limits. Standard limit IOWs have been referred to as key operating limits or reliability limits, and informational limit IOWs may also be referred to as corrosion control limits, depending on the industry in which they are used.

IOW program-development overview

Step 1. The first step to developing an IOW program is to identify all potential damage or corrosion mechanisms that may adversely impact the process equipment. A diverse team of engineers will evaluate the operating parameters of each process condition to understand their potential corrosivities, and will evaluate their impacts on equipment materials of construction. The SME team will develop a damage or corrosion map, which will be used again later to evaluate what indicators are currently provided to detect exceedance of an IOW limit. SMEs can then define the IOW limits for each damage mechanism.

Step 2. After all damage mechanisms have been identified, the consequence of failure and the likelihood of failure need to be analyzed and understood. Consequence of failure data can be gathered from process hazard analysis (PHA) data or by consequence modeling. The equipment failures are then risk-ranked.

Step 3. The third step in IOW program development is typically an evaluation of alarms, indications, and procedures necessary to recognize exceedance of the IOW limit.

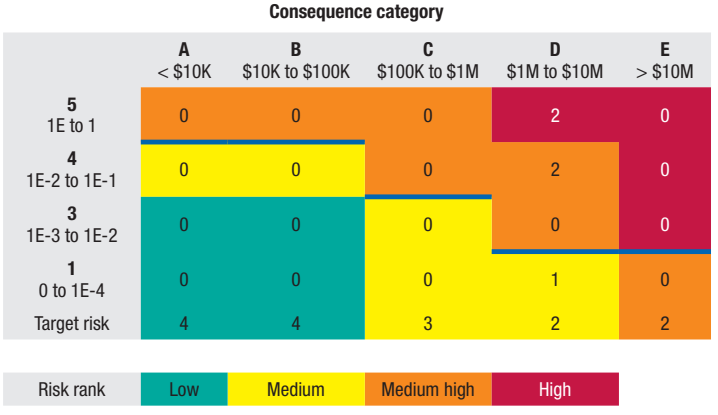
Step 4. Step four is to define the criticality of the operating limit and define the priority of the IOW limit. This is where SMEs determine whether the IOW is critical, standard or informational.

Step 5. The next step is the documentation of each IOW, and the development of proper responses to IOW alarms and notifications. Procedures or work instructions should define the roles and responses necessary to return the process to a reliably safe state, or to further assess the response to limit exceedance, depending on criticality.

Step 6. After IOWs and procedures have been properly documented, all personnel involved in the process operation must be trained in IOW implementation and timely responses to IOW indicators and alarms.

Step 7. Step seven is integrating the IOW program into the rest of the plant operations, maintenance and reliability programs, and plant data-management software. This is an essential step, to ensure that IOW program procedures are being uniformly practiced throughout a facility, and that any change to a process parameter is being catalogued alongside the rest of the facility's integrity data.

Step 8. Finally, the last step to an IOW program is the revalidation of



Bold line indicates target risk

FIGURE 3. Risk-ranking data can be used to categorize the IOW limits, as shown here. High-risk events will require a Critical IOW. Events with medium risk may require a Standard IOW, and low-risk events may be categorized as requiring an Informational IOW only

the IOWs, which consists of reviewing each IOW for effectiveness and avoidance of spurious alarms and notifications.

Damage or corrosion analysis

A comprehensive analysis must be performed by an engineering team with knowledge of the relevant processes, operating parameters, corrosion analysis and damage mechanisms. This team assesses potential damages that can adversely affect the equipment based on the material of construction. They will also assess the operating parameters of process conditions, such as temperature, stream constituents, pressure, vibration, abrasiveness and more. Once the team has identified potential corrosive streams and the equipment materials of construction, the limits associated with the damage mechanism are identified. The team may have an output report such as that shown in Figure 1.

Once the potential damage mechanisms associated with the various process systems and limits have been identified, these data can be depicted on plant process flow diagrams (PFDs), such as the one shown in Figure 2. Process flow diagrams typically contain all major pieces of process equipment, identified by a unique number; all process flow streams, identified by a number and their chemical compositions; and control loops, or groups of equipment and piping with similar materials, operating conditions and degradation mechanisms.

Risk ranking

Risk profiles should be developed for each equipment item that has a potential influence on process safety. The risk-ranking process consists of analysis of the consequence of failure, and the probability of failure for the equipment within each system. Consequence-of-failure data may come from process-hazard analysis (PHA) data or consequence modeling, and analysis may be performed as an element of the risk assessment. Once a risk analysis is completed, ranking can be performed and the risk rank associated with each system or subsystem can be documented.

The risk-ranking data will be used to categorize the IOW limits, as shown in Figure 3. High-risk events will require a Critical IOW. Events with medium risk may require a Standard IOW, and low-risk events may be categorized as requiring an Informational IOW only.

Evaluating alarms

By understanding the limits associated with potential damage mechanisms that may affect the equipment, SMEs can perform an evaluation of what alarms, alerts and notifications will be required for operations, reliability and mechanical integrity groups to recognize exceedance of an IOW limit.

Alarms are the typical indicators for critical limit IOWs, usually coming in the form of horns and flashing lights in the control room to denote that immediate action must be taken. Alerts and notifications can span from visual or audio signals to simple emails to operations and technical personnel, informing them that an IOW has been exceeded but without any urgent need for time-sensitive action to be taken.

The engineering team typically assesses process parameters such as the following:

- Temperature
- Pressure
- Flow
- Stream constituents
- Water content
- Chlorides
- Sulfur
- pH

Defining the IOW criticality

At this step, operators must determine IOW criticality limits and priorities, depending on potential damage severity and the expected time constraints before serious damage occurs.

- Critical IOW — An alarm requiring a timely response by a facility operator or SME to bring the process back within IOW parameters
- Standard IOW — Typically includes an alert to operations personnel and to the reliability SME. Standard IOWs usually

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have a timeframe associated with them. If an integrity limit is exceeded for a set time, equipment will suffer damage
- Informational IOW — Information conveyed from field-gathered data to the reliability SME. This information may require changes to the RBI assumptions, frequency of inspection, or nondestructive evaluation (NDE) methodology considerations

Documentation and training

Just like every other aspect of a process safety program, documentation is critical. The IOW program must include documentation of each IOW and the proper response to IOW alarms, alerts and notifications. This information should be incorporated into the facility's operating procedures as well as reliability program documentation.

When process changes occur, the asset-integrity group may not always be informed, or may be using an outdated frame of reference from the program's original development.

Once all necessary IOW information has been documented, the facility must properly define the roles and responsibilities for operations, engineering, reliability and mechanical integrity personnel. All of this information should be proceduralized, and all responsible personnel should be trained in IOW implementation and the proper, timely response to IOW alarms, alerts and notifications.

IOW integration

The IOW program must be fully integrated into the plant's operations and maintenance, reliability and mechanical integrity programs, and engineering processes. Changes in feedstock, temperatures and flow characteristics that impact individual assets can have an impact on the entire asset-integrity program. It is critically important for a facility to fully understand the information returned from the IOW program and to recognize the effects that changes in one process parameter can have on other equipment, as this information should inform operations from purchasing all the way through post-production.

This step can be time-consuming and meticulous. In order to maximize its effectiveness, an IOW program must be as integrated into plant operations as possible. Utilizing a comprehensive mechanical-integrity data-management software program, in which inspection, corrosion, and integrity data, MOC activities, RBI management and more are stored, organized, trended and analyzed — helps to ensure that IOW program data are centrally located and consistently updated.

Closing thoughts

Getting the longest, safest reliable life from each equipment component in the plant is critical to the profitability of any chemical process operation. Process safety is an evergreen management program, and changes that affect the program design must be monitored and properly responded to in order to maintain a risk rate that is as low as practicable.

When process changes occur, the asset-integrity group may not always be informed, or may be using an outdated frame of reference from the program's original development. For example, a slight temperature elevation can raise a corrosion rate significantly. Changes in sulfur content in a crude stream can lead to sulfidation damage in areas the MI group had not anticipated.

The key for any facility is to control these variables before they start harming equipment and people. An effective IOW program — one that is fully integrated into plant processes, and implemented and managed by properly trained personnel — helps facilities to be informed when variables become unsafe, and lets them know the actions that must be taken to quickly reduce risk. An integrated IOW program is an essential component of any mechanical integrity program. ■

Edited by Suzanne Shelley

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Part 2

Rethinking Maintenance: Transitioning to a Proactive Approach

Deploying well-timed audits and properly training employees are among the steps companies can take to realize maintenance strategies that are proactive rather than reactive

Larry Bouvier and Rob Levandoski
Fuss & O'Neill Manufacturing Solutions, LLC

IN BRIEF

PROACTIVE STRATEGY

ACTING TODAY

Chemical manufacturing plays an essential role in society, both economically and in our day-to-day lives. The economic impact of the chemical process industries (CPI) is indisputable, but like any industrial sector, it is susceptible to the vagaries of the global economy. That is why it is essential for CPI manufacturers to constantly look for ways to operate more efficiently and profitably.

One of the keys to achieving optimum operations is asset management. All too often, our observations reveal that the industry struggles to adequately recognize the condition of the equipment and infrastructure on which they rely every day. As a result, many manufacturers frequently experience lower throughput, reduced equipment reliability, higher accident rates and increased expenses to meet regulatory obligations. One underlying cause is that manufacturers take a reactive approach to maintenance, waiting for equipment failures or accidents to occur before taking action. Instead, companies should be proactive, creating integrated asset-management and maintenance programs designed to regularly assess and monitor equipment while also reviewing the operator skills and workplace conditions (Figure 1).

FIGURE 1. An effective maintenance program integrates not only a survey of equipment performance, but also the behavior of operators and the overall workplace conditions

The problem is widespread. In the authors' experience working with manufacturers across various industries, only about one in ten companies has an effective and comprehensive maintenance and equipment management program in place to keep systems operating efficiently and safely. The financial implications are extraordinary: American businesses lose more than $500 billion dollars every year to equipment breakdowns or inefficiencies and the inevitable loss of productivity that comes with those breakdowns.

Proactive strategy

Many companies treat maintenance as a line item to be minimized rather than an essential element of the company's operations. While skimping on maintenance may provide temporary savings, it always winds up costing companies much more in the end.

Having an effective maintenance and

asset management strategy isn't just smart business — it's crucial. Effective maintenance keeps equipment running properly, keeps production schedules on target and provides a safer work environment. When it comes to the bottom line, maintenance can actually help companies realize significant cost savings by avoiding equipment repairs or replacement losses caused by production shutdowns or slowdowns, not to mention unnecessary worker injury costs. Data show that it typically costs companies five to ten times more to react to breakdowns than to implement a proactive maintenance program.

However, many companies with a commitment to maintenance still struggle because of personnel issues. One of the most troublesome challenges facing manufacturers of all types is that there simply are not enough experienced and qualified maintenance professionals, both managers and technicians, to go around. As a result, more than 90% of all American maintenance workers today have not been formally trained.

The problem has been a long time in the making and can't be turned around in a week or a month. At the height of America's manufacturing preeminence in the 1950s, 1960s and 1970s, companies offered formal apprenticeship programs through which maintenance managers and experienced maintenance staff taught their craft to the next generation of maintenance professionals. These apprenticeship programs were demanding and comprehensive, and often lasted as long as five years. However, at the end of the program, participants had the expertise and experience they needed to take care of their companies' maintenance needs.

Unfortunately, these apprenticeship programs are largely a thing of the past. One reason is that both time and technology changed. Organizational culture changed. Companies have cut back on training and skills development, and as a result, the technical competence of the maintenance professional has suffered. We are now at a time where the last generation's trained professionals are approaching retirement age, and there are too few trained and experienced people available to take their place.

Some companies recognize this shift and are already taking steps to correct this shortcoming, partnering with local technical and

FIGURE 2. Maintenance audits that assess equipment condition are an excellent initial step toward implementing longterm proactive practices

community colleges to develop formal curricula that can be implemented into their long-term maintenance programs. This is a good first step. However, because of the complexity of the equipment and software systems that are in use at most manufacturing sites today, many companies won't reap the benefits of these training programs for a few years.

Acting today

Obviously, companies cannot wait five or ten years for their new training programs to get up and running. Companies need answers to their manufacturing challenges today, not some undeterminable date in the future. But what can they do today?

The first step is to focus on one aspect of asset management and conduct a maintenance program audit. The audit permits companies to evaluate the effectiveness of their current efforts against a world-class maintenance standard. The audit includes a broad range of equipment lifecycle topics, and typically starts with a visual evaluation of the equipment condition. The audit continues and assesses how the company plans, schedules and monitors equipment functionality, further assessing the record-keeping and information management to monitor how it is operating. The evaluation also looks at failure-planning asset-condition monitoring. The audit can be conducted either by in-house maintenance managers or experienced consultants who are experts on the maintenance process (Figure 2).

Depending on the scope and diversity of the operation, it is often only necessary to monitor the equipment for a few hours to get a good sense of how well it is working and where potential issues can be found, both in terms of both short-term and longterm operations.

Once the evaluation is completed, a short-term plan needs to be developed for fixing problems identified during the audit phase. The plan should be created with the goal of getting equipment fully operational as quickly as possible. Incomplete solutions and "band aid" approaches don't work, and they typically lead to new problems down the road while hindering productivity in the short-term.

However, while these initial steps represent progress, they are still reactive. The goal of every manufacturer should be to have a proactive maintenance program in place. This doesn't happen overnight; many companies find that they need to implement 3- to 5-year plans to move from reactive to proactive maintenance. Lifecycle plans are created by establishing production goals for equipment and then determining maintenance best practices that will lead to that equipment being able to achieve those goals. Every company, facility and piece of equipment is different, and the plans for meeting those goals must be built around the unique characteristics and challenges presented by the company and its equipment. Experienced maintenance managers who are familiar with the equipment that is being used and its capabilities should have no trouble creating a workable and effective maintenance plan.

The question is, where do these experienced managers come from? As stated earlier, in many areas, experienced and accomplished maintenance professionals are in short supply. Companies with inadequate maintenance resources can follow one of two routes for acquiring the experience they need to create and implement a maintenance program. The first is the human resources route: recruiting talent from other companies. This can be an excellent strategy for finding talented maintenance managers. However, it is a seller's market due to the shortage of experienced managers, so companies should expect to pay a premium for the best managers. One advantage of this approach is that it provides a longterm solution, since the manager is likely to stay on with the company during not just the program's development, but its ultimate implementation.

The second route may be to retain a main-

tenance consultant on a short-term contract. The consultant can create a maintenance plan and coordinate training for the company's maintenance staff to implement that plan. The advantage of this approach is that companies can typically gain access to much more experienced maintenance professionals at a more affordable cost. The longterm success of this approach rests on the ability of maintenance staff to implement the program after the consultant has left.

Companies that take a proactive approach to maintenance can save millions of dollars by avoiding expensive equipment repair, productivity stumbles and safety-related losses. Those companies that do make a commitment to proactive maintenance do not just save money — they also create an improved work environment, produce a better product and gain a significant edge over their competitors. ■

Edited by Mary Page Bailey

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Storage Tanks: Heating and Cooling System Design

Various heating or cooling options are described here, along with the factors and design parameters that need to be considered. A sample calculation regarding coils is included

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IN BRIEF

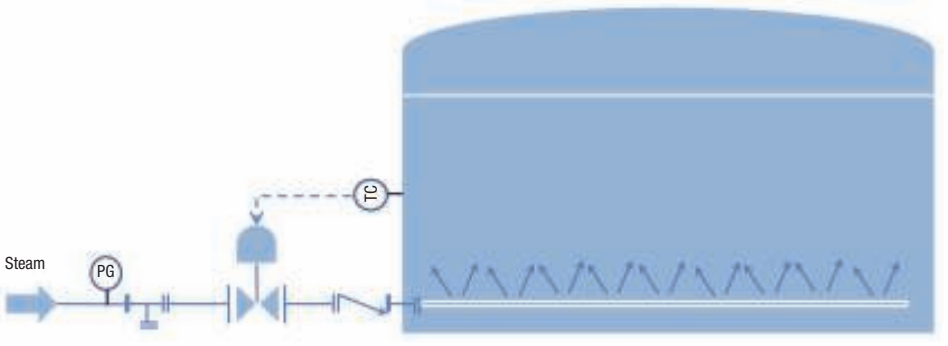

FIGURE 1. Direct steam injection is the simplest method for heating. Shown here is steam injected through a sparger in an open tank

Tanks constitute important equipment in the chemical process industries (CPI). Various types of liquids are stored in tanks and often these liquids are difficult to handle due to their high viscosities. Generally, increasing the temperature lowers the viscosity, resulting in ease of pumping. Therefore, temperatures inside tanks sometimes need to be maintained at elevated levels. In some cases, low temperatures must be maintained in order to avoid polymerization, undesired reactions or product degradation. In a nutshell, temperature control inside tanks may be required.

Designing a tank heating or cooling system involves two basic steps. The first step is to determine the heat loss from the tank to the surroundings (for hot liquids) or the heat gain by the tank (for cold liquids). The second is to design the system to compensate for the heat loss or gain. The purpose of this article is to provide an overview of the design procedure for tank heating and cooling systems for any given service to achieve the previously described objectives.

Types of heating and cooling systems

Tank heating or cooling systems can be implemented in a number of ways. The various options include direct steam injection or indirect heating. Indirect heating includes the following:

- Steam tracing
- Heating or cooling with internal coils
- Steam jacketing
- Electrical heating
- External heating or cooling by liquid circulation
- External cooling by vapor recompression

The above options have distinct differences and some even have limitations that make them suitable for certain applications, but unsuitable for others. A combination of the above methodologies is also possible. For example, steam heating coils and wall steam tracing often come in pairs.

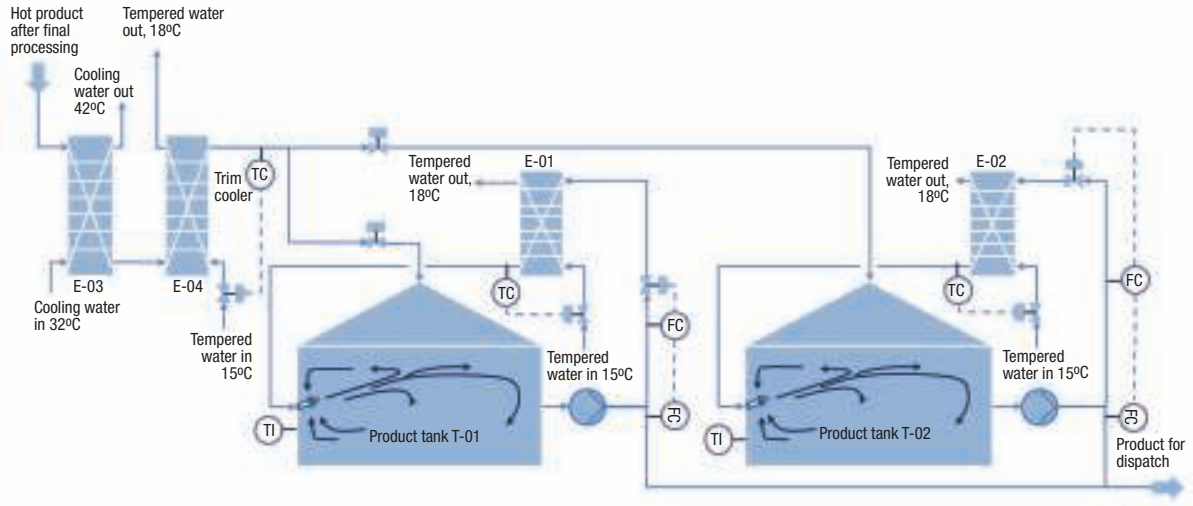

FIGURE 2. This diagram shows an external cooling arrangement for a pair of storage tanks

Direct steam injection. Direct steam injection [*1*] is the simplest method and can be a very efficient way for heat transfer since both the latent heat and the sensible heat are used for heating (Figure 1). It is appropriate only when dilution or an increase in liquid mass is acceptable and the process fluid is not sensitive to steam injection. Direct steam injection is the most widely used method for boiler-feed-tank heating. Various types of tank spargers are available for this purpose. However, in such cases, because the steam mixes with the process fluid, steam hammer and vibrations often occur, leading to higher maintenance costs.

Steam tracing. To provide a good heat distribution over the surface of the tank, steam tracing is carried out with 3/8- or 3/4-in. tubes that are made of copper or aluminum. Direct contact with the tank wall produces good heat transfer, but it is difficult to predict the performance since it is strongly dependent on the degree of contact. The tubes are wrapped around the tank manually, and hence the degree of contact with the tank wall is not very effective. As a result, the overall heat-transfer coefficients exhibited by steam tracing could be as low as 5–6 W/$m^{2.}$°C. The use of heat-transfer cement improves the performance, however with an added cost. As a rough estimate, the installed cost of tracer with cement is approximately double that of tracer alone.

Heating with internal coils. With internal coils, both the compensation for heat loss or gain and additional heat duty required for intermittent services (such as startup heating after a prolonged shutdown) are possible to meet. Coils placed at the bottom of the tank mainly target bulk heating. Coil assemblies placed close to the walls at different heights compensate heat loss through the insulated cylindrical wall. If the temperature of the fluid entering the tank varies, then agitation is needed to create a buffering effect and to limit temperature fluctuations within the tank.

As a heating medium, normally low-pressure steam is recommended, since high temperatures in the coils could cause severe corrosion. Such heating or cooling systems could be designed for a wide range of heating loads, a feature not associated with the other tank heating options.

Steam jacketing. Jacketing is often used for tanks needing frequent cleaning and for glass-lined vessels that are difficult to be equipped with internal coils. A storage tank for liquid sulfur is a typical application that involves jacketing. The heat-transfer coefficients on the steam side are normally high. The process side heat-transfer coefficient can be increased by agitation [*2*]. In terms of thermal efficiency, steam jacketing lies in between the submerged coil and steam tracing.

Electrical heating. The design of electrical heating systems is vendor specific. A typical application is the compressor lube-oil reservoir-heating system, which is applicable in cold locations. The low ambient temperatures in these areas cause a rise in the viscosity of the liquid as a result of natural cooling during long shutdowns, which renders pumping of the fluid very difficult.

External heating by liquid circulation. There are instances where leaks may develop from corrosion of coils due to scaling by high concentration inside the tank. In such cases, internal heating coils are not recommended [*6*], and heating or cooling through external exchangers could be used (Figure 2). A pumping arrangement with an external heater or cooler facilitates good mixing in the tank with the help of an eductor, thus promoting forced circulation. The heat generated by the circulating pump sometimes also adds to the heat input. However, for a cooling systems, this could be counterproductive.

External cooling by vapor recompression. Vapor recompression with an external heat exchanger is often used for refrigerated and semi-refrigerated liquids like ammonia, propylene, propane and so on. In such systems, the heat gain from the tank wall results in the generation of boil-off vapors (Figure 3). These boil-off vapors are recompressed, cooled to liquefy the vapors, and returned to the storage tank.

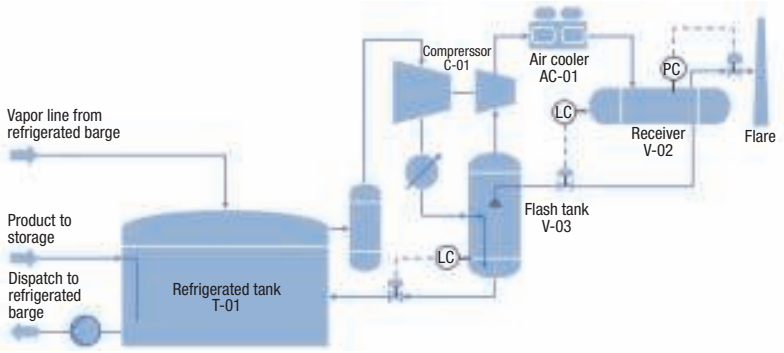

FIGURE 3. A typical vapor recompression system is shown here

Various design conderations

The system should be configured suitably, depending upon the goal. There is no general rule and every scheme must be carefully considered based on the availability of the heating or cooling medium. Factors like utility requirements, size of the hardware (heat exchangers, pumps and compressors), heat loss and so on are to be judged carefully along with the associated process systems.

Consider the example given in Figure 2. In this figure, the hot product from the upstream processing unit at a temperature of 50°C is required to be stored at a temperature between 18 and 22°C in two product storage tanks. A target operating temperature of 20°C is selected to be maintained inside the tanks T-01 and T-02. The product is cooled to 20°C in the two successive plate heat exchangers before sending it to the tanks T-01 and T-02. The exchanger E-03 uses cooling water (operating range 33–43°C) and E-04 uses tempered water (operating range 15–18°C). The minimum ambient temperature is 22°C (a typical equatorial site).

During normal operation, one tank is under the filling mode, while the other tank would be in emptying mode. The trim cooler E-04 is provided upstream of the tank and uses tempered water to cool it to 20°C. However, the tanks would gain heat from the ambient air, leading to a rise in temperature. Therefore, the tanks need to be equipped with exchangers E-01 and E-02 for external cooling and need to be operated continuously to maintain the target temperature of 20°C.

With regard to energy savings, the following case is interesting. Assume that the tank T-02 is under emptying. This means that the tank is not lined up with the exchangers E-03 and E-04 and therefore it is continuously receiving heat from the surroundings. Hence, exchanger E-02 needs to be kept under operation to remove the heat gained.

However, the tank T-01 is under filling and hence is lined up with the exchangers E-03 and E-04. Now, for the same fluid medium, the log-mean-temperature differences available in the heat exchangers E-01 and E-02 are lower than that available in the trim cooler E-04. If we can add a little extra surface area to E-04 to cool the incoming liquid to tank T-01 up to the temperature level of 18°C instead of 20°C, then the operation of the external cooling heat exchanger E-01 can be switched off and normal operating cost can be saved. Design of a similar type of intermediate storage tank heating or cooling system is explained by Catani [*3*].

In some services, the possible maximum temperature of the heating medium does not have any adverse affect on the contents of the tank. In such cases, a precise control of the flow of this heating medium may not be necessary or economical. For instance, if the heating medium is steam, a steam trap alone can serve the purpose.

The tank may have total or partial insulation. The presence of insulation, ambient temperature and the holding temperature affects the heat loss to the ambient air. Again, the tank surface in contact with the liquid phase has higher heat loss than that in contact with the vapor phase. Therefore, holding temperatures below 75–80°C, insulating the roof of the cone-roofed tank is not justified economically, since at such temperatures, there is very little heat loss from the vapor phase. Insulat-

TABLE 1. OVERALL HEAT-TRANSFER COEFFICIENTS FOR COILS*

Substance inside coil	Substance outside coil	Coil material	Agitation	Overall heat transfer coefficient kcal/h·m^2· ^{o}C
Steam	Water	Lead	Agitated	340
Steam	Sugar and molasses solution	Copper	Non-agitated	245–1,170
Steam	Fatty acid	Copper (pancake)	Non-agitated	470–490
Steam (7.5–10 barg)	Vegetable oil	Steel	Non-agitated	112.2–141.5
Steam	Vegetable oil	Steel	Various agitation	190–350
Cold water	Dilute organic dye intermediate	Lead	Turbo agitator at 95 rpm	1,460
Cold water	Warm water	Wrought iron	Air bubbled into water surrounding coil	730–1,460
Cold water	Hot water	Lead	Paddle stirrer 0.4 rpm	440–1,755
Cold water	Hot water	Copper	Non-agitated	510–880
Cold water	25% oleum at 60°C	Wrought iron	Agitated	100
Cold water	Vegetable oil	Steel	Various agitation	140–350
Water	Aqueous solution	Lead	Sleeve Propeller 500 rpm	1,220
Water	8% NaOH	Lead	Sleeve Propeller 22 rpm	755
Tempered water, 15.5°C	50% aqueous sugar solution	Lead	Mild agitation	245–290

*Note: This table is adapted from Perry [*7*]

ing the roof of a floating-roof tank is not usually done because of the difficulty in preventing water ponding and leakage into the insulation. The requirement of insulation is decided based on the heating or cooling arrangement. Keeping the operating philosophy and all the process constraints in mind, proper selection of the heating or cooling scheme is important before proceeding with the design.

Coils made of pipes of 2- and 2.5-in. diameter are commonly used for shop-fabricated tanks. On the other hand, those made of 1.5- and 2-in. diameter pipes are more commonly seen in field-fabricated tanks. In addition, other factors, such as the tube-side heat-transfer coefficient, higher pressure rating or layout problems also require the use of smaller diameter pipes. Closer spacing is not used for coils made of larger diameter pipes. In addition, closer spacing is not encouraged when the temperature difference between the tank fluid and the coil fluid is large.

For underground applications (like a liquid-sulfur pit), the steam-side entry and the condensate-side exit are located above ground while the coil itself is located below the ground. Such configurations, however, run the risk of condensate logging, waterhammer, noise and leaking pipe work, and therefore should only be used in such special cases.

Fins on the steam coil are not suitable if there is a possibility of scale formation. The condensate must be removed as soon as it is formed to keep the heating surface effective. Poor quality of steam, improper slope, longer coils and poor condensate drainage often lead to the problems of condensate hammering. For small tanks, this can be detrimental since the contents are not enough to create a buffering effect. External factors, such as condensate collection and steam trap arrangement, become important.

Designing the system

Inputs. Typically, the input requirements for the design of heating or cooling systems are listed below:

1. Construction details of the tank, such as tank diameter, wall thickness, material of construction, insulation and so on
2. Temperature of incoming fluid
3. Holding temperature
4. Ambient temperature (minimum and maximum values)
5. Wind velocity
6. Soil temperature (for heat loss calculations)
7. Temperature and pressure level of the heating or cooling medium
8. Whether the operation of the tank is continuous or intermittent, that is, whether the tank heating is intended to maintain a particular temperature, or only used during startup/shutdown mode at different seasons
9. The properties of the tank content, for instance, fouling factor and so on
10. Availability of utilities, such as cooling water, tempered water, steam, hot oil and so on

Estimating the duty. In a heating system, the design heat load is arrived at by considering the minimum ambient temperature, resulting in a conservative estimate of the requirement of utilities, such as steam. Many references are available for calculating the tank heating or cooling loads [*4, 5*]. The requirement of surface area of the heating coils should be considered assuming the lowest operating steam temperature. If the tank is provided with an agitator to facilitate uniform mixing, then the case of failure of agitation should also be considered while estimating the surface area.

Factors, such as heat added by agitators and through external pumping systems, heat losses through the auxiliary systems of the tank (like external cooling or heating pipe network, vapor equalization line, vapor recompression system), should be carefully evaluated to optimize the tank heating or cooling requirements.

Apart from the heat losses or gains from the surroundings (including the soil), the total heating or cooling load must consider the requirements, if any, of the temperature rise of the incoming fluid and the tank material to the desired holding temperature of the tank.

Calculation procedure for heating coils. The following description illustrates a step-by-step calculation procedure for heating coils using steam.

Step 1. Determine the heating (or cooling) duty to be served by the coil.

Step 2. Determine the overall heat-transfer coefficient between the medium inside the coil (in this case steam) and the bulk fluid. Typical overall heat-transfer coefficient values can be taken from Table 1 [*7*]. Otherwise, the values can be calculated empirically from Nusselt's correlations for specific systems [*4*]. Such heat-transfer coefficients are experimentally derived. The coefficients could also be cross-checked using commercially available heat-exchanger design software.

In addition, application of agitation (in situ heating) or an eductor system (Figure 2) with external pumped recirculation allows further improvement in the rate of heat transfer.

Step 3. Determine the temperature difference between the steam and the process fluid.

Step 4. Determine the heat transfer area required.

Step 5. Select the diameter and determine the length of the pipe that forms the coil. Because of the difficulties in providing accurate values of the overall heat-transfer coefficient and the non-availability of effective heat-transfer surface area due to condensate flow, it is typical to add a margin to the above calculated heat-transfer area.

Step 6. The maximum recommended steam velocities passing through the heating coils are in the range of 20–25 m/s. For higher steam loads and heat-transfer areas, the steam path could be divided into several parallel paths to reduce the steam-side velocity and temperature variation. In very long coils, a significant pressure drop occurs along the length of the coil. In such cases, the

TABLE 2. TYPICAL LENGTH OF THE COIL INSIDE THE TANK PER LAYER		
Tank diameter (D), m	Typical length of coil per layer	Passes
$D < 5$	$5.5D$	1
$15 > D > 5$	$10.5D$	2
$50 > D > 15$	$15D$	4
$D > 50$	$23D$	4

coil temperature used in the calculation should be carefully evaluated. However, in any case, the temperatures should not exceed the levels that affect the thermal stability of the stored material.

Step 7. Determine the number of layers of coil required. Refer to Table 2, which could serve as a guide. The diameter of the pipe that forms the coil should be selected to provide sufficient length of the coil for uniform heat distribution. Depending upon the application and shape of the vessel, several configurations are possible. Some of the configurations are illustrated in Figure 4, .

Step 8. Depending upon the number of parallel paths, the number of inlet and outlet nozzles for the fluid in the coil is decided. Larger diameter tanks are generally equipped with a higher number of parallel paths for better distribution (one pass, two pass, four pass from left-to-right in the bottom of Figure 4).

Sample calculation for coils

Let's consider an intermediate product (a type of vegetable oil) storage tank that has a continuous inflow rate of 8 m^3/h at 80°C. At the same time, the liquid outflow rate from the tank is 8 m^3/h and the downstream needs to be fed at 85°C. The properties of intermediate product are :

- Specific heat: 0.431 kcal/kg°C
- Density: 870 kg/m^3

The compensation for the heat loss from the tank to the environment, as well as the heating of the tank contents, can be achieved by a suitable design of the steam coils inside the tank. The governing case for coil design will be as follows:

- Tank inventory is full (that is, the maximum rate of heat loss)
- Ambient is at minimum temperature (that is, the maximum rate of heat loss)
- The process is continuous (that is, both the inflow and outflow are at steady state)

Let's consider the following:

- Diameter of the tank = 12 m
- Heat loss from the tank = 95,000 kcal/h (this includes heat loss to the atmosphere, heat loss to the soil and so on. Detailed calculations are not being provided to keep the example simple).

The energy required to raise the temperature of the incoming fluid from 80°C to 85°C = 8 m^3/h × 870 kg/m^3 × 0.431 kcal/kg°C × (85 – 80)°C = 15,000 kCal/h.

Therefore, total heat load of the coil = 15,000 + 95,000 kcal/h = 110,000 kcal/h.

Refering to Table 1 [*7*], the minimum heat-transfer coefficient for a non-agitated system of vegetable oil

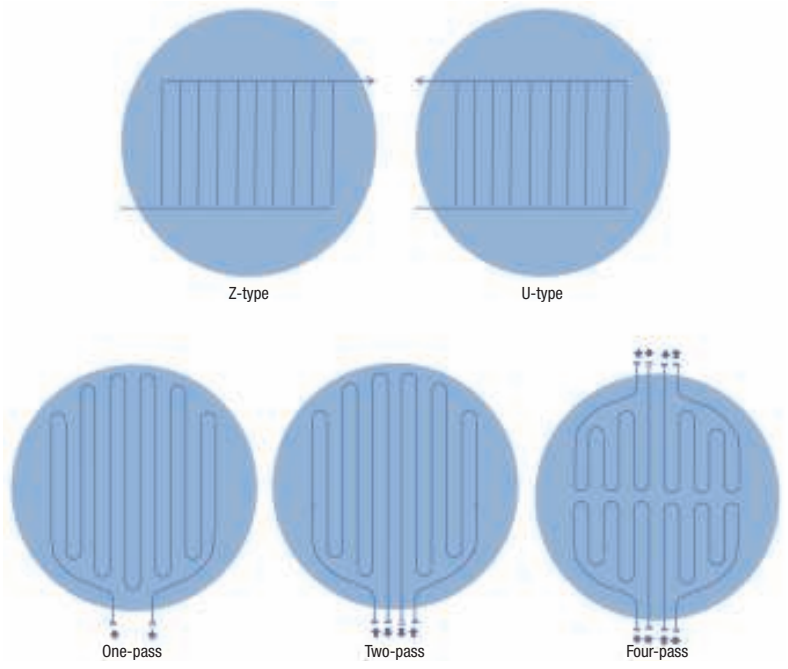

FIGURE 4. Coil arrangements can be Z-type (top left) or U-type (top right). The coils can be arranged to be one-, two- or four-pass (bottom, left to right)

with steam is 112 kcal/h·m^2·°C.

Assume saturated steam is available at 4 bars(a) (temperature of 143.63°C).

Latent heat of condensation of saturated steam at 4 bars(a) = 509.5 kcal/kg

Therefore, the steam consumption rate (normal value) = 110,000/509.5 = 215.9 kg/h

Temperature difference between the coil inside fluid and outside fluid = (143.63 – 85)°C = 58.63°C.

Coil surface area required = 110,000 kcal/h/(58.63°C × 112 kcal/h·m^2·°C) = 16.75 m^2.

With a coil formed by a pipe of 25-mm nominal diameter (outside diameter of 33.4 mm), the surface area for a 1-m long coil works out to 3.142 × 0.0334 m × 1 m = 0.106 m^2/m.

Therefore, length of the coil required = 16.75/0.106 m = 160 m (approximately).

With a tank diameter of 12 m, from Table 2, one layer of coil can accommodate a coil length of 12 × 10.5 m = 126 m.

This is lower than the required 160-m length as calculated above. This means two layers of coil need to be considered.

Two layers of coil will have a surface area of 126 m × 2 layers × 0.106 m^2/m = 27 m^2 (approximately).

Maximum duty of the coil = 27 m^2

× 58.85°C × 112 kcal/h·m^{2}·°C = 177,960 kcal/h.

Maximum steam consumption in the coil = 177,960 kcal/h/509.5 kcal/kg = 350 kg/h.

Maximum load of steam to each layer of coil = 350/2 kg/h = 175 kg/h.

Having selected two layers of coils, let us now come to the selection of the number of coil passes in each layer. If one pass arrangement in each coil layer was used, then the maximum velocity of steam in 25 mm coil works out to 46 m/s, which is rather high. Therefore we should have two layers of coils, each having two passes (as in Figure 4, bottom).

Concluding remarks

This article emphasizes the need for heating or cooling in storage tanks. For certain highly viscous liquids, temperatures inside some tanks sometimes need to be maintained at elevated levels for ease of pumping, while in some cases, lower temperatures are required to avoid polymerization, exothermic reactions or product degradations.

The various options available for heating or cooling have been described. The factors to be considered while selecting the right option are also described. The various design parameters to be considered during design are explained. A sample calculation is also illustrated. The finer aspects of coil design and engineering are also presented.

Note: The content of the article is based on the authors' personal views and their own published research. ■

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Proper Use of Conventional PRV Discharge Coefficients

In order to correctly size pressure relief valves (PRVs), a robust understanding of discharge coefficients for vapor, liquid and two-phase flow is crucial

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A pressure relief valve (PRV) is used to prevent the pressure in a process vessel from exceeding the allowed pressure rating of the vessel. The required PRV orifice area is determined by dividing an ideal nozzle orifice area by a valve discharge coefficient. Therefore, proper use of PRV discharge coefficients is very important for sizing PRVs and preventing potential overpressure of process vessels.

PRV manufacturers provide certified discharge coefficients that were determined experimentally for liquids and vapors. Certified PRV discharge coefficient values are reported in the Pressure Relief Device Certifications, NB-18 [*1*] from the National Board of Boiler and Pressure Vessel Inspectors. The certifications are based on isentropic ideal nozzle-flow equations for incompressible flow of water and compressible flow of air and steam. However, there is no certified discharge coefficient for two-phase flow. As many others have noted in the literature, the authors have found that the discharge coefficient for gases is significantly greater than the discharge coefficient for liquids.

The authors have revisited a previous theory on PRV discharge coefficients and investigated manufacturers' information and experimental data readily available in the literature. This article presents a new theory for explaining the significant difference between liquid and vapor discharge coefficients. This article also provides guidelines for the proper use of PRV liquid and vapor discharge coefficients for liquid, vapor and two-phase flow.

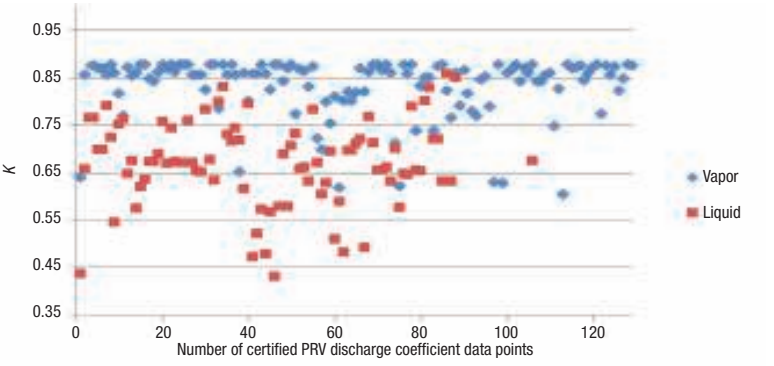

FIGURE 1. PRV discharge coefficient values (*K*) are certified according to ASME Section VIII for vapor and liquid

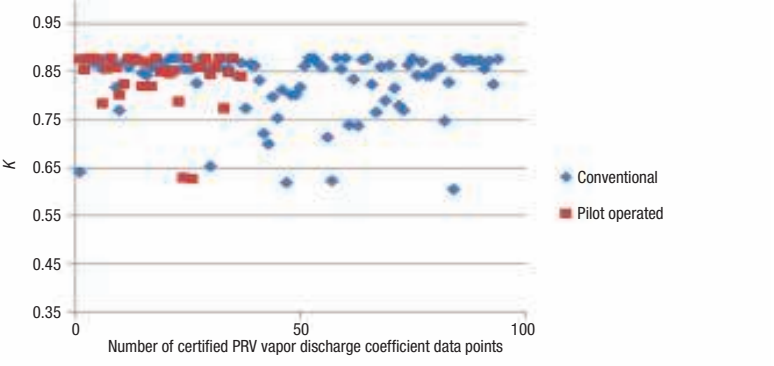

FIGURE 2. Due to their differing closing mechanisms, conventional and pilot-operated PRVs exhibit slightly different *K* values

PRV nozzle discharge coefficient

A theoretical flow model assumes frictionless isentropic flow. In reality, the actual measured flow capacities of PRVs deviate from the calculated theoretical ideal nozzle-flow capacities. The discharge coefficient accounts for the difference between the mass flux in the actual valve and that calculated by the theoretical flow model. The coefficient of discharge is given in Equation (1), which defines the discharge coefficient (*Kd*) of a PRV as the ratio of the measured flow capacity through the valve (G_M) to its theoretical ideal nozzle-flow capacity (G_T).

$$Kd = G_M/G_T \quad (1)$$

Thus, the discharge coefficient is dimensionless and normally less than 1. The PRV sizing standard API 520 recommends the typical value of 0.975 for sizing PRVs for vapor service. On the other hand, the typical value of 0.65 is recommended for sizing PRVs for liquid service. For sizing PRVs for two-phase service, there is no typical value recommended by API 520 or by valve manufacturers.

National Board PRV certifications

NB-18 (Relief Device Certifications) provides a complete listing of and information pertaining to pressure-relief device designs that are certified by the National Board. The capacity of a PRV is certified by one of two ASME methods — the slope method or the coefficient method. The authors have reviewed the ASME Section VIII Div.1 PRV certified values that were determined by the coefficient method. The publication includes the discharge coefficients for vapor and liquid flows. The ASME theoretical flow capacity for water (incompressible fluid) and air (compressible fluid) are defined by Equations (2) and (3), respectively. This article only considers two equations for water and air. Das [*2*] presented all the details of the ASME discharge coefficients in his article. The measured coefficient of discharge defined by Equation (1) is multiplied by 0.9 (derating factor) to obtain the ASME-certified discharge of coefficient *K* defined by Equation (4).

$$W = 2{,}407 \cdot A \cdot [(P - P_d) \cdot w]^{0.5} \quad (2)$$

$$W = 356 \cdot A \cdot \mathrm{P} \cdot (M/T)^{0.5} \quad (3)$$

$$K = 0.9 \cdot Kd \quad (4)$$

Where:
W = theoretical flow capacity, lb/h
A = nozzle throat area, in.^{2}
P = Set pressure × 1.1 + atmospheric pressure, or set pressure + 3 psi + atmospheric pressure (whichever is greater), psia
P_d = pressure at discharge from device, psia
w = water density at device inlet conditions, lb/ft^3
M = molecular weight
T = absolute temperature at device inlet conditions, R
Kd = actual (or measured) coefficient of discharge
K = ASME certified coefficient of discharge (derated)

Figure 1 shows all *K* values of PRVs that were certified as per ASME Section VIII. As can be seen, the distribution of the *K* values for liquid (water) is widely spread. On the other hand, there is a relatively high distribution of *K* values for vapor (air) that are greater than 0.85. It is apparent that certified vapor discharge coefficients (average: 0.833) are greater than liquid discharge coefficients (average: 0.671). If a valve is certified for both liquid and vapor, the liquid *K* is generally smaller than the vapor *K*.

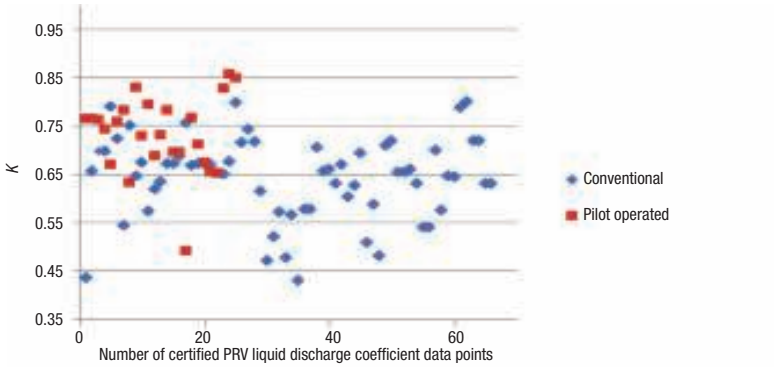

FIGURE 3. For liquids, the certified *K* values of pilot-operated PRVs are generally larger than those for conventional-type PRVs

Figure 2 shows all vapor *K* values of conventional and pilot-operated PRVs that were certified as per ASME Section VIII. The major difference between conventional and pilot-operated relief valves is that conventional relief valves use a spring to close the valve and pilot-operated valves use the inlet gas pressure to keep the valve closed. Therefore, the top area of the piston for pilot-operated valves is designed to be larger than the inlet, and there is a constant force difference keeping the valve closed. As seen in Figure 2, the lowest certified discharge coefficient is 0.604. A few vapor *K* values are not greater than the average certified liquid *K* value. Both types have a highest value of 0.878. The certified vapor discharge coefficients (average: 0.839) for pilot-operated PRVs are slightly greater than the vapor discharge coefficients (average: 0.830) for conventional devices.

Figure 3 shows all liquid *K* values of conventional and pilot-operated PRVs that were certified as per ASME Section VIII. The lowest liquid discharge coefficient is 0.431. The highest liquid discharge coefficient is 0.857. A few liquid *K* values are greater than the average vapor certified *K*. The certified liquid discharge coefficients (average: 0.733) for pilot-operated PRVs are greater than the certified liquid discharge coefficients (average: 0.644) for conventional PRVs.

Review of existing knowledge

For single-phase flow, the certified values of discharge coefficients are available from valve manufacturers and are used for sizing PRVs. Darby [*3*] states that the vapor discharge coefficient is significantly greater than the liquid discharge coefficient, because vapor flow is measured under choked conditions. Since vapor flow under subcritical conditions and liquid flow do not choke, the entire valve affects the mass flux, resulting in a lower discharge coefficient value.

For two-phase flow, the certified values of discharge coefficients are not available from valve manufacturers. Two-phase discharge coefficients were reviewed by Lenzing [*4*], Leung [*5*] and Darby [*6*]. Equation (5) is generally used for the estimation of the two-phase discharge coefficient. However, there is no appropriate flow model that can accurately predict two-phase flow in PRVs. Darby suggested that the vapor discharge coefficient be used for choked two-phase flow and the liquid discharge coefficient be used for non-choked two-phase flow.

$$Kd_{TP} = a \cdot Kd_G + (1 - a) \cdot Kd_L \quad (5)$$

Where:
Kd_{TP} = Two-phase discharge coefficient
a = Vapor volume fraction
Kd_G = Vapor-phase discharge coefficient
Kd_L = Liquid-phase discharge coefficient

The present guidelines on the proper use of discharge coefficients for PRVs can be summarized as shown in Table 1.

Why Kd_G is greater than Kd_L

Comflow (Compressible Flow) and TPHEM (Two-phase Homogeneous

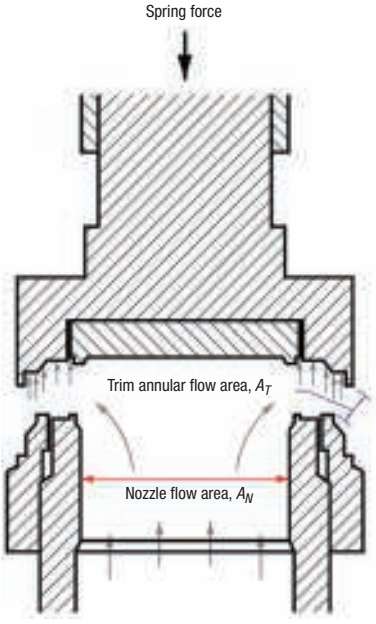

FIGURE 4. PRV nozzle flow area and trim flow area are important parameters to consider for mass flux calculations

TABLE 1. PRESENT GUIDELINES FOR CONVENTIONAL PRV DISCHARGE COEFFICIENTS

Fluid	Choked conditions	Unchoked conditions	High backpressure ratio
Single liquid flow	Liquid *Kd*	Liquid *Kd*	Liquid *Kd*
Single vapor flow	Vapor *Kd*	Liquid *Kd*	Not available
Two-phase flow	Vapor *Kd*	Liquid *Kd*	Not available

TABLE 2. MASS FLUX CALCULATIONS FOR AIR AND WATER FOR IDEAL NOZZLES

	60°F air	60°F water without exit loss	60°F water with exit loss
Theoretical mass flux, lb/s-ft^2	419	7,976	5,640
Valve inlet pressure (P_0), psia	124.7	124.7	124.7
Pressure at nozzle (P_1) or trim, psia	65.7, choked	14.7	14.7
$P_0 - P_1$, psi	59	110	55
Velocity head at nozzle or trim, psi	46.3	110	55
Exit loss, psi	0	0	55

TABLE 3. A SUMMARY OF MASS FLUX CALCULATIONS FOR SUBCRITICAL FLOW

	Equation (6)	Equation (8)
Inlet pressure, psia	124.7	124.7
Inlet temperature, R	520	520
Molecular weight	29	29
Ratio of specific heat	1.4	1.4
Backpressure, psia	94.7	94.7
Backpressure correction factor	N/A	0.87 [1]
Actual Kd_G for choked flow	0.95	0.95
Actual mass flux, lb/s-ft^2	347.6	346.6
Theoretical mass flux, lb/s-ft^2	365.9	364.8
Note 1: From Ref. [*8*], Figure 36, $r = 0.76$		

Equilibrium Model) are computer programs used to estimate flowrate and pressure changes in ideal nozzles and piping systems. These programs are available with the Center for Chemical Process Safety (CCPS) guideline book [7]. The help files on these programs recommend that the pipe exit loss for vapor (compressible) and two-phase flows should not be considered. This is because there is generally no pipe exit loss for compressible fluid. On the other hand, exit loss should be considered for liquid (incompressible) flow.

Figure 4 presents PRV details showing the area of the smallest nozzle cross-section (A_N, nozzle flow area) and the area of the trim cross-section (A_T, trim annular flow area) determined by lift. Table 2 is a summary of mass flux calculations for air and water for ideal nozzles. All calculations assume that there is no friction in the valve. The pressure drop from the nozzle throat to the valve trim affects the valve discharge coefficient. It is also assumed that both the effective nozzle area and trim area are identical. So if there is an exit loss for water (incompressible fluid), the available differential pressure for mass flux will be 50% of the total available differential pressure.

For air (compressible fluid), the velocity head (46.3 psi) at the nozzle or trim is much smaller than the available differential pressure (59 psi). Generally, all available differential pressure is supposed to be converted to the velocity head at the nozzle. However, there is a significant gap (12.7 psi) between the values, because of significant changes in compressible fluid density during an expansion process. The authors consider no exit loss for compressible flow, because this pressure gap is able to move fluid forward without exit loss. On the other hand, the velocity head for incompressible flow is equal to the total available differential pressure. This means that the incompressible fluid needs some extra pressure to exit the valve. This extra pressure is the valve exit loss for incompressible fluids. As can be seen in Table 2, the exit loss for incompressible flow significantly influences the mass flux, resulting in a liquid discharge coefficient (5,640/7,976 = 0.707) that is lower than the vapor discharge coefficient.

Kd_G for subcritical flow

The authors have revisited the calculation methods for gases under subcritical conditions to check the actual coefficient of discharge for superheated air at 124.7 psia and 60°F. The theoretical mass flux for subcritical vapor flow can be determined using either Equation (6) or (8) below.

$$W = 735 \cdot A \cdot F \cdot \sqrt{\frac{M \cdot P_0 (P_0 - P_2)}{T}} \quad (6)$$

$$F = \sqrt{\frac{k}{k-1} \cdot r^{\frac{2}{k}} \left[\frac{1 - r^{\frac{k-1}{k}}}{1 - r} \right]} \quad (7)$$

$$W = 356 \cdot A \cdot K_b \cdot P_0 \sqrt{\frac{M}{T}} \quad (8)$$

Where:
W = valve flow capacity for air, lb/h
A = nozzle throat area, in.^{2}
F = coefficient of subcritical flow
M = 29, molecular weight, g/mol
T = 520, absolute temperature at device inlet conditions, R
P_0 = upstream relieving pressure, psia
P_2 = backpressure, psia
k = 1.4, ratio of the specific heats for an ideal gas at relieving temperature
r = ratio of backpressure to upstream relieving pressure
K_b = backpressure correction factor

Equation (8) is necessary to account for the backpressure effect on

the mass flux. The backpressure correction factor is normally provided by valve manufacturers. The mass flux at subcritical conditions is less than the choked mass flux because the compressible fluids reach a maximum flow at choked conditions.

Table 3 shows the mass flux results determined by Equations (6) and (8). Both calculations assume a valve discharge coefficient of 0.95 and a backpressure of 94.7 psia. As can be seen, the two calculation results for subcritical flow are in good agreement. This indicates that there is negligible pressure drop downstream of the valve nozzle. If the backpressure correction factor is smaller than 1 at a lower backpressure ratio than the choked conditions (r = 0.53), then there is pressure drop downstream of the valve nozzle. Therefore, the API 520 [*8*] backpressure correction factor is based on a negligible pressure drop downstream of the valve nozzle.

Figure 5 plots the values of the calculated discharge coefficient for two conventional PRV models: Consolidated 1900 (Valve 1; Kd_G = 0.95; Kd_L = 0.744); and Pentair JLT-JOS (Valve 2; Kd_G = 0.967; Kd_L = 0.729) based on their backpressure correction factors [*9*,*10*]. Leung [*5*] has presented that Kd_G coincides with Kd_L at an absolute backpressure ratio of 1.0. As can be seen, the calculated discharge coefficients of Valve 1 are constant, except at the backpressure ratio of 0.95. The vapor Kd_G is generally constant and independent of the backpressure ratio. This means that the valve is designed with negligible pressure drop downstream of the valve nozzle. The vapor discharge coefficient for subcritical conditions and high backpressure ratios is determined by the corresponding pressure drop ($P_1 - P_2$) downstream of the valve nozzle and the actual mass flux per unit pressure driving force (*MPUP*), defined as the actual mass flux divided by the difference between P_0 and P_1. The *MPUP* variation is inherent for compressible flow. The final Valve 1 *Kd* value (at the backpressure ratio of 0.95) decreases slightly because it has the highest *MPUP*, as shown in Table 4. Although Valve 1 is designed with negligible pressure drop, the high *MPUP* results in a small pressure drop downstream of the valve nozzle, which leads to a slightly lower *Kd* value. For Valve 2, the *Kd* value varies with the backpressure ratio. As shown in Table 5, Valve 2 is designed with significant pressure drop downstream of the valve nozzle, so the discharge coefficient for subcritical conditions decreases as the backpressure ratio increases. However, the vapor *Kd* at the backpressure ratio of 0.95 is smaller than the liquid discharge coefficient. Therefore, there is probably no link between Kd_G and Kd_L. Compressible fluids are essentially different from incompressible fluids.

For incompressible flow, the *MPUP* is constant regardless of the backpressure ratio, so the liquid *Kd* value remains constant. Interestingly, the liquid *Kd* value of 0.744 is much smaller than the vapor *Kd* value. Thus, the liquid *Kd* value of 0.744 only can be explained by the valve

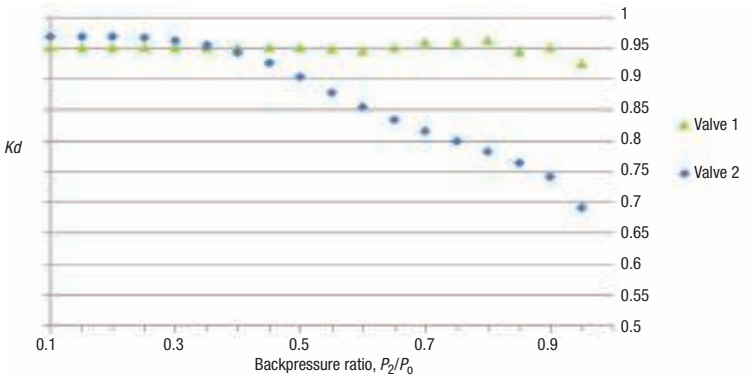

FIGURE 5. This plot of Kd_G variation with backpressure ratio for conventional PRVs shows how different valve models are impacted by backpressure ratio

TABLE 4. A SUMMARY OF VALVE 1 PERFORMANCE EVALUATION DETAILS

Backpressure ratio, P_2/P_0	ΔP in nozzle downstream, psi	$\Delta P/(P_0 - P_1)$	Actual/theoretical mass flux, lb/s-ft^2	Mass flux/$(P_0 - P_1)$, lb/s-ft^2/psi	*Kd*
0.55	1.60	0.029	397 / 419	6.74	0.948
0.65	0.06	0.001	385 / 405	7.75	0.950
0.75	–1.86	–0.027	355 / 370	9.23	0.958
0.85	0.29	0.016	290 / 307	12.74	0.944
0.95	0.35	0.059	174 / 188	22.12	0.924

TABLE 5. A SUMMARY OF VALVE 2 PERFORMANCE EVALUATION DETAILS

Backpressure ratio, P_2/P_0	ΔP in nozzle downstream, psi	$\Delta P/(P_0 - P_1)$	Actual/theoretical mass flux, lb/s-ft^2	Mass flux/$(P_0 - P_1)$, lb/s-ft^2/psi	*Kd*
0.55	22.23	0.656	368 / 419	10.85	0.878
0.65	17.47	0.667	338 / 405	12.90	0.834
0.75	12.69	0.686	296 / 370	15.99	0.798
0.85	7.91	0.732	235 / 307	21.73	0.764
0.95	3.14	1.012	130 / 188	42.02	0.691

exit loss required for incompressible (liquid) flow. If there is significant pressure drop downstream of the valve nozzle without an exit loss, the PRV will not function properly. The significant pressure drop may close the valve. However, the exit loss does not affect the function of valve opening and closing.

Tables 4 and 5 summarize the calculation details for Valve 1 and Valve 2 under subcritical conditions. All the calculations are based on the assumption that the certified actual *Kd* value is valid up to the valve nozzle throat.

HOMOGENOUS EQUILIBRIUM EQUATIONS

$$G = 68.07\sqrt{\frac{P_{ec}^{\beta+1}}{\alpha\beta P_0^{\beta} v_0}} \quad (9)$$

$$P_{ec} = \left[-2\alpha\beta P_0^{\beta}\left(\alpha\left(\frac{P_0}{P}\right)^{\beta} - \alpha + 1\right)^{-2}\left(\frac{\alpha P_0^{\beta}}{1-\beta}\left(P^{1-\beta} - P_0^{1-\beta}\right) + (1-\alpha)(P - P_0)\right)\right]^{\frac{1}{\beta+1}} \quad (10)$$

$$\frac{v}{v_0} - 1 = \alpha\left[\left(\frac{P_0}{P}\right)^{\beta} - 1\right] \quad (11)$$

Where:
P_{ec} = Pressure at equivalent choked (critical) conditions, psia
G = Mass flux, lb/s-ft^2
v = Specific volume, ft^3/lb
α, β = Parameters for a pressure-specific volume correlation

Review of experimental data

Lenzing and others [*4*] presented both air-water and steam-water experimental data for the ASME-certified PRV model Leser DN25/40 441. The authors have reviewed the experimental data to evaluate the discharge coefficients for single flow, non-flashing two-phase flow and flashing two-phase flow using Equations (9) through (11), which are shown in the box below.

Equation (9) was used to estimate the theoretical mass flux (G) for all flows in terms of P_{ec}, the pressure at equivalent choked (critical) conditions, which is defined by Equation (10). The theoretical mass flux was obtained by integrating Equation (11) for homogeneous equilibrium flow based on three data sets of specific volume versus pressure relationships from the stagnation pressure P_0 at the vessel to the valve nozzle pressure P at the throat. Kim and others [*11*] developed the flow model based on homogeneous equilibrium. The authors consider the homogeneous equilibrium model (HEM) to be the most appropriate and conservative model for relief valve sizing currently available.

Using a pressure-specific volume relationship, such as Equation (11), in nozzle flow calculations can greatly simplify the complexity of the flow calculations. Equation (11) requires three specific-volume data points at P_0 (vessel pressure) and P_1 (middle pressure, $(P_0 + P_2)/2$) and P_2 (atmospheric pressure) to solve for the parameters α and β. Equation (11) gives outstanding fits of the data for gases and two-phase systems. The specific volume data sets are generally obtained by isentropic flash calculations. Equation (11) is used to predict specific volumes during the isentropic expansion process in PRVs.

Figure 6 shows the measured discharge coefficients for the Leser DN25/40 441 valve for air-water flow at 72.495 psia (5 bars). The air-water data covers a limited set of data points in the range of $0.0001 \leq x_0 \leq 1$, where x_0 is the inlet air quality in weight fraction. The theoretical mass fluxes are based on isentropic flow in thermal equilibrium. The certified actual discharge coefficients of vapor and liquid are 0.777 and 0.579,

EXAMPLE CALCULATIONS

Example 1

Example 1 considers an air-water system (inlet air mass fraction = 0.0001) at 72.495 psia (5 bar) and 77°F. The stagnation pressure of the fluid entering the Leser type 441 valve nozzle is 72.495 psia. The stagnation temperature is 77°F. The backpressure on the relief valve is 14.644 psia. All physical properties used and the results calculated with the universal mass flux equation are listed in the summary table.

Step 1. Calculate the P_{ec} using Equation (10) at the system backpressure of 14.644 psia and the data given in Table 6. This yields a P_{ec} of 11.53 psia. The flow is unchoked because the calculated P_{ec} is not greater than 14.644 psia.

Step 2. Calculate the mass flux at the P_{ec} of 11.53 psia using Equation (9). This gives a value of 5,404 lb/s-ft^2.

Step 3. Calculate the valve coefficient of discharge using Equation (1). Dividing the measured flux (3,170) by the theoretical flux from the previous step (5,404) results in a *Kd* of 0.587. This flow appears to be incompressible flow based on the measured *Kd* value.

A SUMMARY OF EXAMPLE 1 CALCULATIONS

	Air-water (air 0.0001 weight fraction)
v_0 (ft^3/lb) at 72.495 psia	0.016337
v_1 (ft^3/lb) at 43.570 psia	0.016523
v_2 (ft^3/lb) at 14.644 psia	0.017465
α value	0.01673
β value	1.02207
Choked pressure ($P_{ec} = P$), psia	Not choked
Measured mass flux, lb/s-ft^2	3,170
Theoretical mass flux, lb/s-ft^2	5,404
Certified actual Kd_I	0.579
Measured actual Kd_L	0.587

Example 2

Example 2 considers an air-water system (inlet air mass fraction = 0.00126) at 72.495 (5 bar) and 77°F. The stagnation pressure of the fluid entering the Leser type 441 valve nozzle is 72.495 psia. The stagnation temperature is 77°F. The backpressure on the relief valve is 14.644 psia. All physical properties used and the results calculated with the universal mass flux equation are listed in the summary table.

Step 1. Calculate the P_{ec} using Equation (10) and the data from Table 7 at the system backpressure of 14.644 psia. This results in a P_{ec} of 24.86 psia. The flow is choked because the calculated P_{ec} is greater than 14.644 psia.

Step 2. Repeat Step 1 to seek the choked pressure by substituting the previous approximation (P_{ec}) as *P* into Equation (10) until the P_{ec} is approximately *P*. In this example, the fourth trial resulted in a P_{ec} of 28.24 psia.

Step 3. Calculate mass flux at the choked pressure of 28.24 psia using Equation (9). For this example, the mass flux is 3,713 lb/s-ft^2.

Step 4. Calculate the valve coefficient of discharge using Equation (1), which gives a *Kd* of 0.844. This flow appears to be compressible flow based on the measured *Kd* value.

A SUMMARY OF EXAMPLE 2 CALCULATIONS

	Air-water (air 0.00126 weight fraction)
v_0 (ft^3/lb) at 72.495 psia	0.019619
v_1 (ft^3/lb) at 43.570 psia	0.022028
v_2 (ft^3/lb) at 14.644 psia	0.034252
α value	0.17845
β value	1.02829
Choked pressure ($P_{ec} = P$), psia	28.24
Measured mass flux, lb/s-ft^2	3,135
Theoretical mass flux, lb/s-ft^2	3,713
Certified actual Kd_G	0.777
Measured actual Kd_G	0.844

Example 3

Example 3 considers air at 72.495 psia (5 bar) and 77°F. The stagnation pressure of air entering the Leser type 441 valve nozzle is 72.495 psia. The stagnation temperature is 77°F. The backpressure on the relief valve is 14.644 psia. All physical properties used and the results calculated with the universal mass flux equation are listed in the summary table.

Step 1. Calculate the P_{ec} using Equation (10) at the system backpressure of 14.644 psia. The calculated P_{ec} is 27.23 psia. The flow is choked because the calculated P_{ec} is greater than 14.644 psia.

Step 2. Repeat step 1 to seek the choked pressure by substituting the previous approximation (P_{ec}) as *P* into Equation (10) until the P_{ec} is approximately *P*. The fifth trial gave a P_{ec} of 38.23 psia.

A SUMMARY OF EXAMPLE 3 CALCULATIONS

	Air
v_0 (ft^3/lb) at 72.495 psia	2.734388
v_1 (ft^3/lb) at 43.570 psia	3.926934
v_2 (ft^3/lb) at 14.644 psia	8.534917
α value	0.99559
β value	0.71352
Choked pressure ($P_{ec} = P$), psia	38.23
Measured mass flux, lb/s-ft^2	179.9
Theoretical mass flux, lb/s-ft^2	240.3
Certified actual Kd_G	0.777
Measured actual Kd_G	0.749

Step 3. Calculate mass flux at the choked pressure of 38.23 psia using Equation (9). The calculated mass flux is 240.3 lb/s-ft^2.

Step 4. Calculate the valve coefficient of discharge using Equation (1). Here, the calculated *Kd* is 0.749, indicating that the flow is compressible. ❑

respectively. The flow behaves as if it were incompressible when the air quality is 0.0001. The flow behaves as if it were compressible when the air quality is greater than 0.001. The incompressible-compressible transition occurs at $0.0001 < x_O < 0.001$. Although the measured values are generally greater than the certified discharge coefficients, all data points except two (at x_O = 0.00236 and x_O = 0.0045) are in relatively good agreement with the certified actual discharge coefficients. These two data points may suggest some experimental problem.

Figure 7 shows the measured discharge coefficients for the Leser DN25/40 441 valve for 153.74 psia (10.6 bars) steam-water flow. The steam-water data covered a limited set of data points in the range of $0.0011 \leq x_O \leq 1$. The theoretical mass fluxes are based on the isentropic flow in thermal equilibrium. The certified actual discharge coefficients of vapor and liquid are 0.777

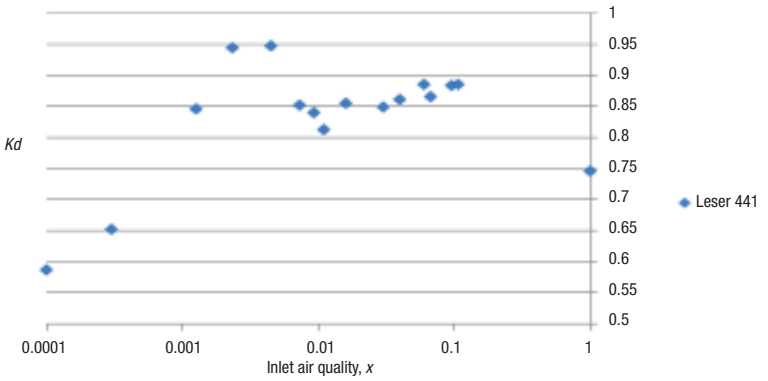

FIGURE 6. Measured *Kd* values of the Leser 441 PRV for air-water data at 72.495 psia are shown

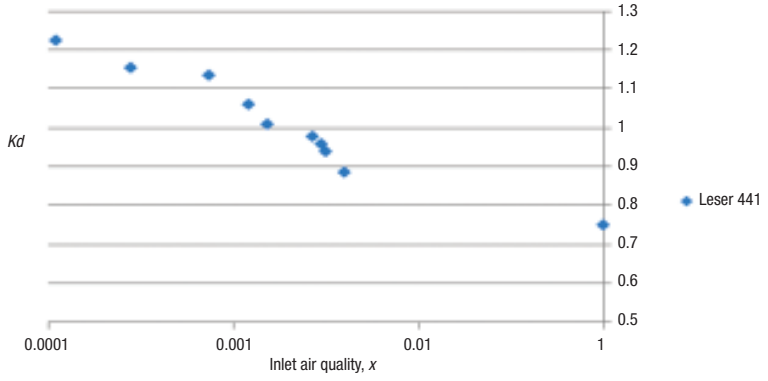

FIGURE 7. Measured *Kd* values of the Leser 441 PRV for steam-water data at 153.74 psia are shown

TABLE 6. NEW GUIDELINES FOR CONVENTIONAL PRV DISCHARGE COEFFICIENTS

Fluid	Choked conditions	Unchoked conditions	High backpressure ratio
Single liquid flow	Liquid *Kd*	Liquid *Kd*	Liquid *Kd*
Single vapor flow without pressure drop downstream of nozzle	Vapor *Kd*	Vapor *Kd*	Vapor *Kd*
Single vapor flow with pressure drop downstream of nozzle	Vapor *Kd*	Corrected Vapor *Kd*[1]	Corrected Vapor *Kd*[1]
Incompressible two-phase flow	Liquid *Kd*	Liquid *Kd*	Liquid Kd
Compressible two-phase flow	Vapor *Kd*	Vapor *Kd*[2]	Vapor *Kd*[2]
Note 1: Corrected based on manufacturer's backpressure correction factor. Note 2: Requires further work.			

and 0.579, respectively. All the flashing two-phase data points lie significantly outside of the upper tolerance of the vapor discharge coefficient. Thermal non-equilibrium effects would be the main cause of a higher measured *Kd* value than the certified actual vapor *Kd*. The non-equilibrium effect diminishes with increasing inlet vapor mass fraction. The equilibrium flow model under-predicts mass flux over all of the flashing two-phase data points.

To help clarify the calculation process and concepts, three example calculations for liquid flow, vapor flow and two-phase non-flashing flow are shown in the box on p. 67. The example data were selected from an experimental data set of Lenzing and others [*4*].

Final recommendations

Based on the data and calculations presented in this article, the authors recommend the following as a guide to proper use of conventional PRV discharge coefficients. These guidelines are also summarized in Table 6.

Single liquid flow. Size a PRV based on the ASME-certified liquid discharge coefficient that was determined experimentally. The liquid *K* is constant regardless of the backpressure ratio.

Single vapor flow. Size a PRV based on the ASME-certified vapor discharge coefficient that was determined experimentally for choked flow. The vapor *K* can vary significantly with the backpressure ratio if the valve is designed with pressure drop downstream of the valve nozzle. Therefore, the backpressure correction factor provided by the valve manufacturer should be used to size the PRV if the backpressure correction factor is less than 1.0 at lower backpressure ratio than choked conditions.

The vapor discharge coefficient for subcritical conditions and high backpressure ratios is determined by the actual *MPUP* and the corresponding pressure drop downstream of the valve nozzle. The changes in *Kd* are due to a variation in the *MPUP*. The *MPUP* variation is inherent for compressible flow. For incompressible flow, the *MPUP* is constant regardless of the backpressure ratio, so the liquid *Kd* value remains constant.

On the other hand, the vapor *K* for choked conditions can be used to size the PRV if the backpressure correction factor is not less than 1.0 at lower backpressure ratio than choked conditions. The vapor *K* for the valves designed with negligible pressure drop in the downstream of the valve nozzle is generally independent of the backpressure ratio.

Two-phase flow. Unlike single liquid and vapor flows, valve manufactures do not provide any discharge coefficient value for two-phase flow. However, PRV sizing should be based on the ASME-certified discharge coefficient for vapor if the fluid behavior is compressible flow. If the fluid behavior is incompressible flow, the ASME-certified discharge coefficient for liquids is recommended to size PRVs. However, many empirical two-phase discharge coefficients are much greater than the vapor *Kd*. Thermal non-equilibrium is known to be the main cause of such high values. But there is also no accurate flow model that accounts for non-equilibrium. Although this article does not present the non-equilibrium flow model, the authors are developing the non-equilibrium correction factor and the discharge coefficient for transitional

flow between compressible flow and incompressible flow. The discharge coefficient of transitional flow may lie between the liquid *Kd* and vapor *Kd*.

Finally, the authors propose an exit loss theory to explain why the liquid discharge coefficient is normally smaller than the discharge coefficient of vapor. The exit loss yields a lower liquid discharge coefficient, however, there is no exit loss for vapor flow and two-phase flow with a significant change in density. No exit loss can result in a high certified vapor discharge coefficient maximum of 0.878. ■

Edited by Mary Page Bailey

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Powder Testing:
Tips for Assessing Alternative Options

The advantages and limitations of three powder-testing techniques are reviewed here

Tim Freeman
Freeman Technology

Powder testing is deployed to characterize products including pharmaceuticals, foods, metal powders, powder coatings and cement — at every stage of the product lifecycle. The resulting data-support product development and formulation, equipment and process design, optimization of day-to-day operations, and troubleshooting. It also ensures the quality of raw materials, intermediates and final products.

When choosing a new powder tester, engineers must evaluate competing options and consider the ability of each to answer the needs of the application for which it is required. This article reviews the strengths and limitations of three powder-testing techniques — uniaxial shear testing, biaxial shear testing and dynamic testing — and provides guidance to support a rigorous assessment of their relative merits for different powder-testing requirements.

Defining testing requirements

Maximizing the return on investment in a new powder tester relies on choosing an instrument with capabilities and features that are optimally suited to the site-specific requirements. For instance, a tester with limited functionality may be unable to provide the information needed, while one that is over-specified for a relatively simple task may incur unnecessary expense and, as a result, deliver a poor financial return. Considering a range of practical and technical issues, engineers should set some reasonable criteria for assessing the technology available. For example:

- Who will carry out the testing? Will there be a single dedicated expert or will there be multiple analysts carrying out testing alongside other activities?
- How important is the speed of measurement? Is the value of the resulting information directly dependent on how quickly it can be generated?
- Is automation a primary requirement or would manual operation be acceptable or desirable?
- Are you looking for a simple but reliable indicator of differences between powder samples, or do you need to develop a more-detailed understanding of how your powder behaves under a range of different process conditions?
- Do you just need a technique that provides relatively coarse sample differentiation, or do you need to be able to detect very subtle differences, because of the sensitivity of the product or process performance?
- How much is it worth to solve the problem that you are looking to address with powder-testing data? Can a significant investment be justified or is spending necessarily restricted?

The practicalities of measurement have a major impact on the use and acceptance of any given technique and the ongoing cost of measurement. Ultimately, it is often the quality and relevance of the data generated that is the deciding factor when it comes to final tester selection. Therefore, it is essential to understand the information that an instrument can deliver, and assess its relevance when developing a solution for the problem(s) being addressed.

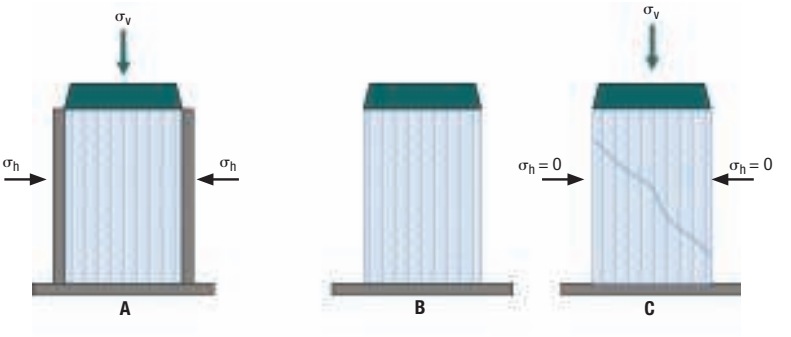

FIGURE 1. Uniaxial testing involves the construction and subsequent fracture of a consolidated powder column, to directly measure uniaxial unconfined yield strength (uUYS) for competing materials (σ_h = minor consolidation stress; σ_v = major principal stress)

The first and most important goal for a powder test is that it must provide information that relates directly to the issue under consideration, and yield sufficient insight to advance toward a solution. This may seem obvious, but the ability to establish operational relevance is the area where many test methods fail.

Assessing the options

The challenge of meeting industrial requirements for characterizing powders has given rise to a significant number of different powder-testing methods and an array of associated powder-tester designs. Methods and instruments vary substantially in terms of reproducibility, repeatability, practicality, level of automation, sensitivity and equipment cost. In terms of information delivery, many techniques measure just a single number, while others provide more comprehensive quantification. Here we focus on three techniques that exemplify the capabilities of powder testers across the cost-capability spectrum — the recently commercialized technique known as uniaxial testing, and the traditional options of biaxial shear testing and dynamic testing.

Uniaxial shear testing

Uniaxial testing is a simple and intuitive technique that involves measuring the normal stress required to break or fracture a free-standing, consolidated powder column. The parameter measured is the uniaxial unconfined yield strength (uUYS), as a function of a preconsolidation stress (Figure 1), and from which the flow function (*FF*; a factor that is required for hopper design) can be derived. Cohesive powders have relatively strong interparticulate forces, which encourage the particles to bond strongly, resulting in a relatively high uUYS.

By contrast, in a more free-flowing powder sample, the tensile forces between particles tend to be much weaker, and consequently, the uUYS values are lower. Uniaxial shear testing provides an effective way to directly rank the flowability of powders.

In terms of output, uniaxial shear testing is similar to biaxial shear testing, which also generates values for UYS, albeit less directly. A uniaxial powder-testing device can also be used to measure bulk density and compressibility, providing further insight into powder behavior.

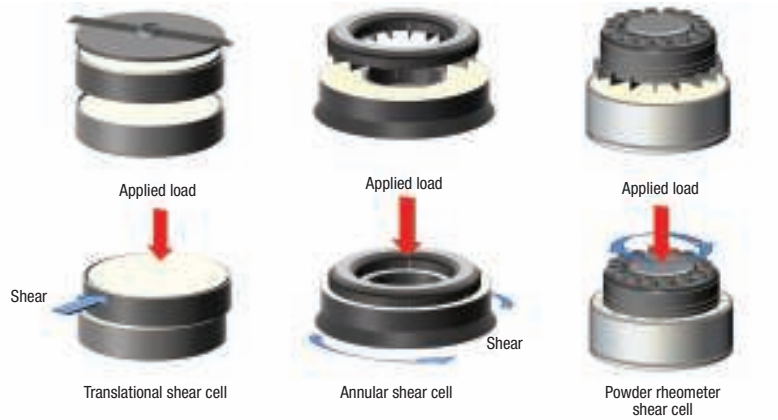

FIGURE 2. Biaxial shear cells measure the forces required to shear one consolidated powder plane relative to another to quantify UYS and determine values for *FF* and *ff*

Uniaxial testing is simple and fast — measurement times are on the order of just a few minutes — and equipment costs are relatively low compared to many other devices. Robust automated instrumentation costs approximately $15,000, while a manual equivalent can be purchased for around half this price.

Testing is more difficult with relatively free-flowing powders, since such materials are less easily consolidated to form a free-standing column. Nonetheless, the latest design is able to offer highly repeatable measurements for a wide range of powders. However, as noted, the need for consolidation at relatively

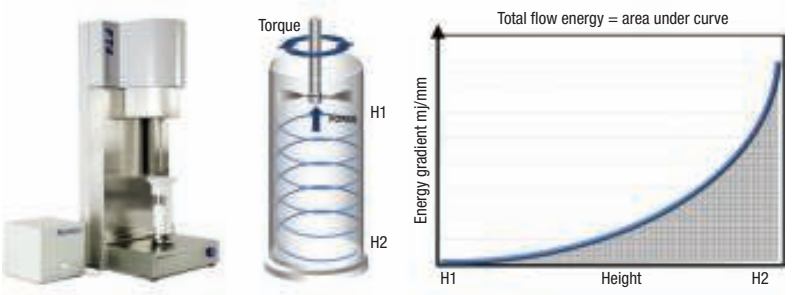

FIGURE 3. Dynamic testing measures the powder in motion and can be applied to samples in a consolidated, moderate stress, aerated or even fluidized state

high stress means that there is little flexibility to test powders under a range of stress conditions, which can be a limitation for using this method for certain applications.

Areas of application for uniaxial testing. Uniaxial testing can be viewed as an "entry level" technique for ranking flowability, with sufficient repeatability for reliable application. It is particularly useful to powder processors who currently rely on test methods that are failing to provide sufficient differentiation, or that are dependent on particle property measurement (such as particle size data) to infer bulk powder properties.

Uniaxial testing is well-suited for quality assessment and quality control (QA/QC), for rapid assessment of the consistency of a raw material or finished product. It provides a choice that is accessible (from both an ease-of-use and cost standpoint) for process optimization and troubleshooting when exploring the causes of problems such as variable fill weight or erratic hopper discharge. However, the consolidation applied during testing makes the technique less relevant to processes where the powder is in a relatively low-stress or aerated state, and this approach may cause sample damage or attrition if the particles are especially friable.

Biaxial shear cell testing

Biaxial shear cell testing was developed specifically to generate the parameters required for understanding powder behavior in hoppers, and to support the application of hopper-design methodologies. This method involves measuring shear stress — the forces required to shear one consolidated powder plane relative to another — at a range of applied normal stresses (Figure 2). A process of extrapolation of the yield loci data, and the application of Mohr stress circles is required to derive the UYS.

Shearing the powder against a coupon of an actual or potential material of construction produces wall friction data, via a similar technique. These two data sets, along with information about powder density, enable values for the flow function (*FF*) and flow factor (*ff*) to be determined, two parameters that are required for hopper design.

A range of different shear cells are commercially available (shown in Figure 2), including translational, annular and rotational designs, but all operate according to these same basic principles. Instruments vary in their level of automation and cost, which typically runs from around $20,000 to $50,000.

The most precise versions enable highly repeatable measurement and good control over the applied experimental conditions. However, as with uniaxial testing, relevance is limited by the need for sample consolidation, and by the fact that measurements are less differentiating between free-flowing powders (For instance, high-stress test results may not be relevant for low-stress operations). Measurement times are on the order of 5–15 minutes, but shear cell testing requires a certain level of expertise for effective application and data processing.

Areas of application for biaxial testing. Biaxial shear cell testing remains a core technique during hopper design and other hopper-related applications for determining whether existing equipment is suitable for a new product, for example, and for troubleshooting erratic or sub-optimal discharge. More generally, biaxial shear cell testing is useful for assessing the ease of transition of consolidated powders from the static to the dynamic state under moderate- to high-stress conditions, and it is routinely applied for process optimization. It can be an effective technique within this context, but it is vital to recognize the limitations with regard to predicting the behavior of free-flowing powders, and performance in a low-stress or dynamic environment.

Dynamic powder testing

Dynamic powder testing involves measuring the axial and rotational forces acting on an impeller as it rotates through a powder sample, along a precisely defined path. A crucial difference between dynamic testing and both forms of shear testing is that the powder does not have to be consolidated ahead of measurement. Dynamic testing can be used to quantify the flow properties of powders that are under moderate stress, are aerated or are even fluidized, as well as those that are consolidated, to comprehensively characterize behavior across a complete range of process-relevant conditions. The properties measured include basic flowability energy (*BFE*), a parameter that quantifies how easily a powder flows under forced, confined conditions; and specific energy (*SE*), an analogous property that is measured under unconfined conditions. All dynamic parameters are based on measurements of the powder in motion, a feature that enhances the process relevance of the data generated.

Dynamic test methodologies are well-defined and inherently more sensitive than other powder-testing techniques. This advantage, coupled with precision-engineered, highly automated instrumentation, makes dynamic testing the most powerful technique for differentiating samples that exhibit only subtle differences, but nevertheless perform differently as a product or in a process. Measurement times can be less than other techniques for a basic assessment of flowability — in the region of 2–5 minutes — but dynamic testing also permits longer, more in-depth investigations that may take up to 20 minutes.

Testers that offer dynamic powder characterization also enable measurements of shear and bulk properties, making it possible to measure as many as 25 to 30 different properties and to build a comprehensive database of powder properties that quantifies all aspects of behavior. The desire to access these capa-

bilities will mean a higher upfront investment, as such testers are more costly — around two to three times more expensive than a basic biaxial shear cell. However, the value returned is often similarly magnified due to their relevance to a range of applications. Dynamic results have proven relevance in the optimization of process and product performance and can therefore deliver substantial cost savings.

Areas of application for dynamic powder testing. A dynamic powder tester provides a wealth of information to accelerate product and process development, and to troubleshoot effectively. However, it can be equally valuable in QA/QC, where the ability to detect a small change in raw material or product may be crucial to manufacturing efficiency and company reputation. The ability to directly characterize the response of a powder to air, up to and beyond the point of fluidization, is a unique benefit. Such characterization is particularly helpful for the optimization of, for example, pneumatic conveying, fluidization processes and dry-powder inhaler applications.

An investment in dynamic testing is often triggered by a failure to understand poor performance, but over the long term, dynamic testing equipment delivers further benefit in the form of variable cost gains and substantial improvements in product quality. This is especially true for those developing novel powders for demanding applications, such as continuous tableting or additive manufacturing.

Making a selection

Choosing a powder tester that suits the site-specific requirements is the key to ensuring a good return on any investment. The introduction of new options in powder testing, such as the introduction of a commercial instrument for uniaxial shear testing, makes it timely to review the options to ensure a "fit for purpose" selection. An instrument that provides more information than needed may bring an unhelpful level of complexity and cost.

In some applications, fast and simple may be the prime requirement for certain applications. However, over the long term, testers with more sophisticated functionality can ultimately yield a far greater return, providing that the information they produce is relevant to the process need, and therefore is of practical and commercial value. Rigorously reviewing what a tester can deliver against what is required is the key to an optimized choice. ■

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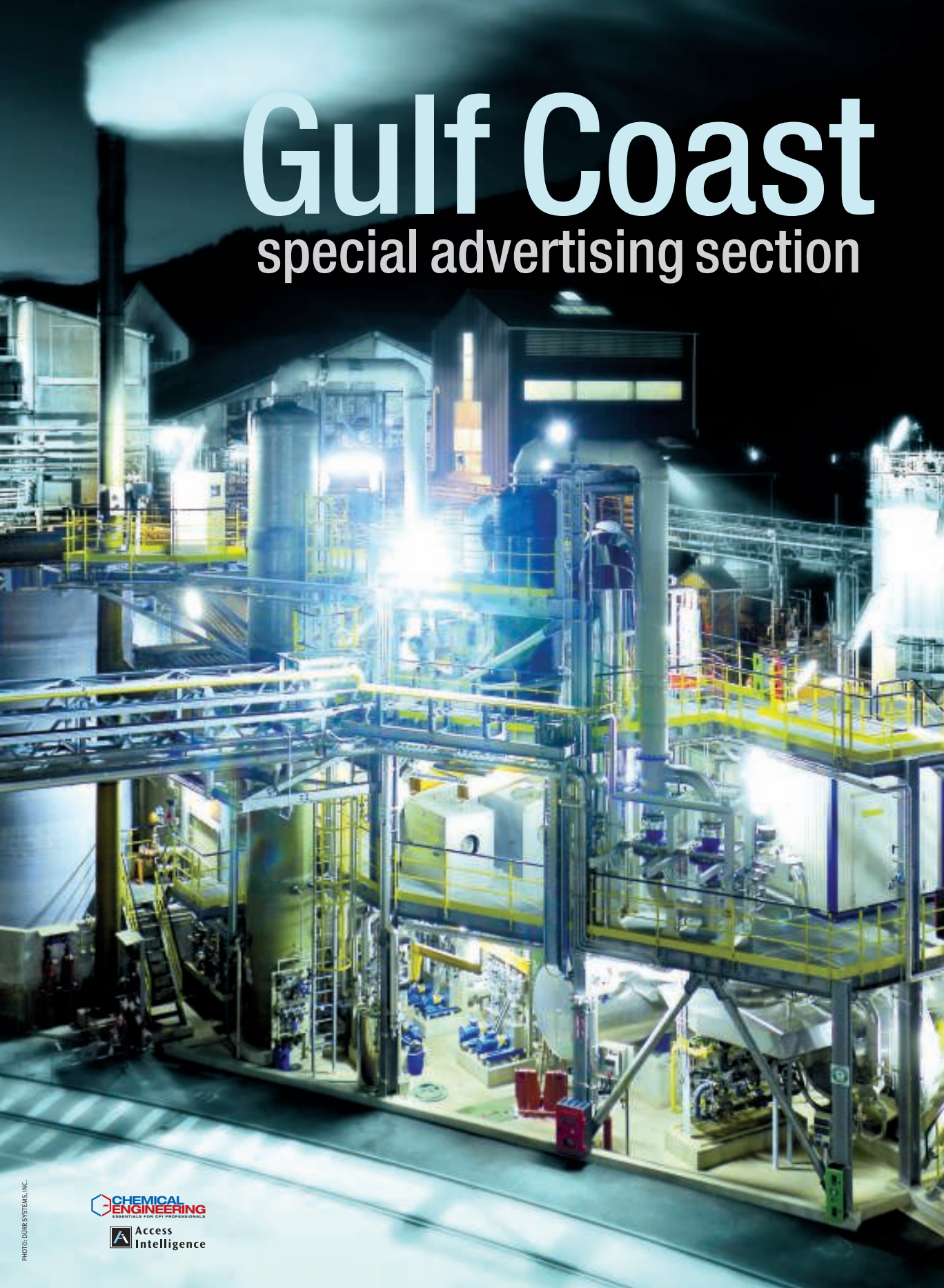

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Inside:

Two new columns for chemical park

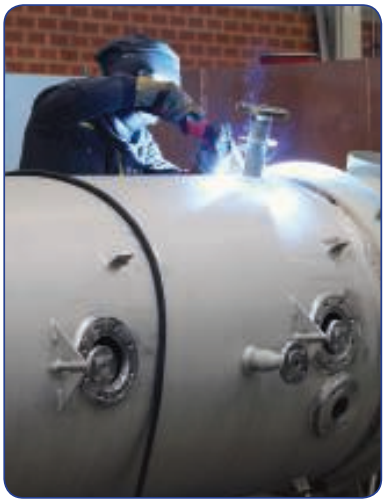
German supplier BUTTING shows off its expertise in tower fabrication on a complex job involving special fittings

Fabrication and pipework specialist **BUTTING** was recently able to demonstrate its long-standing experience by producing two columns for a German chemical park. The columns required special internal fittings and many external nozzles.

The columns were prefabricated in Butting's Knesebeck factory. Both were manufactured in two parts for ease of transport and installation. The first column was 25 m long and 1,400 mm in diameter, while the second was 15 m long and 1,000 mm in diameter.

Robert Lenz, Spools & Plant Construction, explains: "A large number of branches were welded on one side. In so doing, very tight tolerance requirements had to be complied with, in order to guarantee the parallelism of the inner fittings."

The columns left Knesebeck at the end of February in several parts on a total of four lorries. The high degree of prefabrication benefited the customer. Once on the construction site the joints did not have to be welded, but simply bolted together.



One of the two columns under construction in BUTTING's Knesebeck facility

www.butting.com

Filters and solutions to minimize process waste

Rosedale Products Inc. manufacturers a wide variety of filters and strainers, including automated duplex models, and low-maintenance centrifugal separators

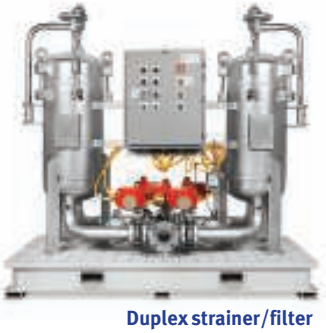
Rosedale Products, Inc. is a leading technology developer of liquid filtration systems and waste minimization products. The company has a vast product line and the flexibility to customize standard products. Knowledgeable sales staff provide customers with the best filtration solutions in the industry. Rosedale's most popular products are bag filters, pleated cartridge filters, and basket strainers.

Centrifugal-action separator

The centrifugal-action separator (photo, above) is used to remove grit, sand, metal chips, fines, and other solids from liquids. It is perfect for use as a pre-filter to extend the life of fine filtration systems. These units require little or no maintenance, as there are no moving parts to fail or wear out, or filter media to clean or replace. The unit only requires a simple purging, eliminating downtime due to cleaning or backwashing. Applications include cooling towers, process water, chemicals, petrochemicals, power plants, mining, heat exchangers, solids recovery, pump protection, and seawater pre-filters.

For trouble-free, continuous operation, Rosedale multi-basket duplex strainers and bag filters (photo, right) offer a wide range of flow capacities and contaminant-holding capabilities (2 to 23 baskets). Continuous operation reduces operating costs with the ability to switch back and forth between two filter vessels, allowing one side to be serviced while the other is in use. All housings can be supplied with an ASME code stamp. Features include:

- multiple housing styles (standard, quick-access, low-profile, hinged);
- housings are opened without tools and without disturbing the piping;
- carbon steel, 304 or 316 stainless steel housings, with special alloys on request, and a choice of four materials for the O-ring seals;
- large-area, 30-in. deep, heavy-duty, 9/64-in. mesh-lined or perforated strainer baskets;
- low pressure drop, and easy to clean;
- rated to 150 psi, with higher pressures on request.



Duplex strainer/filter

Options include steam jackets, inner baskets for two-stage filtration, hydraulic cover lifters, and sanitary fittings.

www.rosedaleproducts.com

The best pollution control system for petrochemicals

Dürr Systems, Inc. is the ideal partner to solve exhaust emission issues in the petrochemical industry

With over 4,000 installations worldwide and 45 years of experience in air abatement, **Dürr**'s capabilities, knowledge, and skills make resolving any pollution control situation simple.

The petrochemical industry has its own unique set of requirements and concerns when it comes to air emissions control. Dürr has three products that are ideal for the industry's specific conditions: the Ecopure RL, Ecopure SCR, and Ecopure VAR.

Taking the standard thermal oxidizer technology one step further, the Ecopure RL is a state-of-the-art rotary regenerative thermal oxidizer with one of the highest thermal efficiencies in the industry. Advantages of this proprietary system are a destruction efficiency of 99%+, low maintenance costs, the opportunity for customization taking into consideration the VOCs present, and short installation and commissioning time thanks to pre-assembly.

The Ecopure VAR is a direct-fired thermal oxidizer designed for destruction of waste gases and liquid hazardous residues with

A choice of thermal oxidation and NO_x removal technologies allows Dürr to tackle any air pollution problem

challenging calorific values. This system has been installed for a wide range of applications, has no restrictions in terms of pollutant type or quantity, is able to incinerate residual organic liquids – even those forming acid gases – and has a number of heat recovery options. With years of proven success, the Ecopure VAR can handle difficult processes with ease.

The Ecopure SCR serves to reduce nitrous oxides (NO_x) from flue gases or process gases when selective catalytic reduction is required to ensure high NO_x conversion rates. This system can be used as a stand-alone application as well as in the flue gas cleaning stage after thermal oxidation. Additionally, it has a destruction/conversion rate of 99%+ all in one complete, turnkey system.

Dürr provides solutions that impress, integrating necessary equipment, including pretreatment and posttreatment components such as dust collection and acid scrubbers, to form a comprehensive air abatement system in one engineered process. Thanks to the company's years of experience, involvement in a broad range of industries, and global reach, Dürr provides the most efficient and effective pollution control systems for the petrochemical industry.

www.durr.com

New valve tray improves performance and flexibility

The FLEXIPRO valve tray from Koch-Glitsch combines the reliability of fixed valves with excellent efficiency and hydraulic characteristics more typical of moving valves

Moving valves offer the advantage of a wide operating range, notes **Koch-Glitsch**, but are more susceptible to fouling than fixed valves and may stick in the open or closed position. They are also prone to erosion or enhanced corrosion of the valve legs, and may "pop" free from their orifices.

Fixed valves have no moving parts and are more rugged and durable than moving valves. In addition, fixed valves have a greater ability to withstand process upsets, especially when combined with FLEXILOCK tray construction (an interlocking tray joint offered by Koch-Glitsch that strengthens joint and uplift tolerance and reduces installation time). Due to their durable construction, the mechanical reliability of fixed valves makes them good choices for towers where uplift rating is required to guard against damage.

Koch-Glitsch introduced the PROVALVE tray in the mid-1990s. The PROVALVE fixed valve has a uniquely shaped tapered cover that is larger than the hole in the deck. This imparts a forward push to liquid flowing across the tray deck, promoting an even and low froth height that suppresses entrainment. The PROVALVE tray has a well-proven track record for fouling resistance in challenging applications.

The new FLEXIPRO valve is an evolution of the PROVALVE fixed valve that features a specially shaped deck orifice to delay weeping. The redesigned valve cover also reduces entrainment. The result is a higher turndown ratio than other fixed valve trays without the disadvantages of moving valves.

The performance of the FLEXIPRO valve tray has been verified by testing in Koch-Glitsch's 5.5 ft (1.7 m) diameter commercial-scale pilot column. These tests confirmed the improvements in entrainment characteristics, increased tray efficiency and reduced weep. The increased jet flood capacity and reduced weeping has resulted in an operating range that allows the FLEXIPRO valve tray to be used where moving valves traditionally are applied, but without any of the reliability shortcomings of moving valves.

The wider operating range of the new

A tapered cover and specially-shaped deck orifice give FLEXIPRO trays the edge

FLEXIPRO valve tray, with enhanced capacity and efficiency, opens new opportunities for both revamps and new towers.

www.koch-glitsch.com

A new, smarter non-contact radar transmitter

The Pulsar Model R86 from Magnetrol provides safe, efficient and cost-effective liquid level measurement

Magnetrol International, Inc. has launched the new Pulsar Model R86 non-contact radar transmitter, an advanced level control solution that offers radar technology with improved performance for a wide range of level measurement applications.

The Pulsar Model R86 is designed to provide outstanding accuracy, reliability and safety for virtually all process industries.

Latest-generation features include improved performance: the 26 GHz radar signal has a smaller wavelength, resulting in smaller antennas and improved (±1 mm) resolution. This is an important distinction for demanding process conditions because the smaller beam angle allows for installation into process connections as small as 1.5 in. As a result, the Pulsar Model R86 assures precise, dependable control for a complete spectrum of level applications.

The user interface experience of the Pulsar Model R86 is driven by advanced diagnostics that transforms the way that radar level measurement is used. Automated echo capture conveys real-time waveform and trend data so users can assess the situation at a glance. In addition, the event history shows up to 20 events including diagnostic and configuration data to pinpoint any issues. Troubleshooting tips are also given to provide practical solutions that can help users reduce downtime.

True versatility is another hallmark of the Pulsar Model R86. The transmitter uses circular polarization, which means there is no need to rotate the antenna to ensure proper orientation. This simplifies installation and delivers proper alignment in virtually every application. High-temperature antennas are designed for use in extremely demanding applications and punishing conditions up to 750°F (400°C). There are also nozzle extensions ranging from 4 in. to 72 in. (100 mm to 1.8 m). That means non-standard nozzle lengths and buried vessel standpipes are not an issue for this advanced solution.

The Pulsar R86 introduction represents the latest radar innovation from Magnetrol, the company that introduced the very first 2-wire, loop-powered guided wave radar transmitter for industrial liquid level applications. It brings a high level of radar performance to applications throughout the process industries.

www.magnetrol.com

Magnetrol's Pulsar R86 (photo) features advanced diagnostics, easy installation, and high accuracy

Leading by example – and by the numbers

Diamond Refractory Services has completed over 100 FCCU turnarounds, with a 90% customer retention rate

For Houston, Texas-based **Diamond Refractory Services**, an EMCOR Industrial Services Company and one of the country's most prominent refractory turnaround providers, the autocratic leadership style that once dominated the American business landscape is purposefully absent.

Instead, Diamond Refractory Services focuses on immersing its API 936-certified project managers and leaders in the day-to-day workings of the organization. This approach saves clients time and money, and has 90% of them returning for new work.

Diamond Refractory Services employs more than 150 certified alloy welders, nozzlemen, safety professionals, forklift drivers, and other skilled professionals. With an average employment tenure of 10 years or more, Diamond Refractory Services supervisors are among the refractory industry's most experienced workers. Long tenure is one of the reasons the company has avoided the drought of skilled workers that other companies have had to deal with.

Diamond Refractory Services' detailed approach to turnarounds extends to safety – the company has been four years without an OSHA recordable incident.

A refractory repair involving Hexmesh, hex cells, and variable tabs

Chase Drake, president and engineering manager, said that much of the company's success with safety can be attributed to employee involvement. "We ask employees for solutions to safety concerns," Drake said. "That ownership becomes part of their lives in and out of the plant. We look to our field personnel for real-world solutions to real-world safety issues. That's one of the reasons we regularly began using rapid arc welding (RAW) in the field. It's safer. RAW eliminates fumes and lowers exposure to hexavalent chromium vapor."

Drake also said that most of Diamond Refractory Services' regular workforce is now RAW trained and certified, which makes them more efficient. He explained that a RAW-certified welder can weld refractory anchors seven times faster than a traditional welder using an electrode. To date, Diamond Refractory Services personnel have installed more than 100,000 anchors – making them one of the most experienced refractory specialists in the Gulf Coast.

For Diamond Refractory Services, completing over 100 FCCU turnarounds with a 90% customer retention rate is the result of hard work, a fierce commitment to safety and training, and a determined willingness to put words into action.

diamondrefractory.com

Operational excellence through innovative technology

CSoft Technologies solves communications problems through software to record shift notes and track safety and quality incidents

CSoft Technologies was established two decades ago to meet a need in plant operations for a central repository containing all the data associated with operator communications for each shift and each position – from field operator to plant manager – with interfaces to plant data historians, lab systems, work orders, and priority alarms.

The result was CNotes, an electronic shift notes and communication system that eliminates paper logbooks and spreadsheets. Web-based and available from any PC or mobile device at the site, CNotes allows every user to see how the entire plant system is performing.

(l–r) Amir Ajani, Amit Banerjee, and Murad Ajani of CSoft Technologies

"Our flagship product CNotes is a unique industry-leading tool for safe and efficient plant operations, as evidenced by its use by some of the premier petrochemical firms," says CSoft Partner Murad Ajani.

Meanwhile the company's plant management dashboard CFlow is an incident investigation solution. It enables end-to-end reporting on all information related to work processes and incidents, and provides a complete audit history. Customer Steve Long, HSE Director with Total Safety, explains: "CFlow is an integral part of our safety management system. On a daily basis, incidents and corrective actions are tracked to closure. It is an excellent tool that allows us to fully capture the critical information associated with safety and quality incidents."

CNotes and CFlow are becoming standards as more companies are looking for solutions that provide best practices in the industry, the company notes. "We develop integrated solutions that present real-time actionable data in a meaningful context across an entire organization for tangible business value," says Executive Director Amit Banerjee.

Another customer, Tony Human, Training Supervisor, Texmark Chemicals, says: "It has been my pleasure to be a client of CSoft Technologies for the past ten years. We are using the CNotes and CFlow enterprise solutions. I am very satisfied with both solutions. Not only are the products economical but the personalized service I receive is outstanding. I recommend this company highly."

"While it is important to deliver high-quality services and products, we never lose sight of the most important aspect: clients and their objectives," says CSoft Founder and CEO Amir Ajani. "Our team of talented professionals engages each client to understand what problems they are trying to solve rather than trying to push the client into a solution that might not address the actual issues."

www.csofttechnologies.com

Process simulation challenge to students

Simulation software company Chemstations invites budding experts to test their skills managing dynamic gas flows in the 2017 Process Simulation Cup

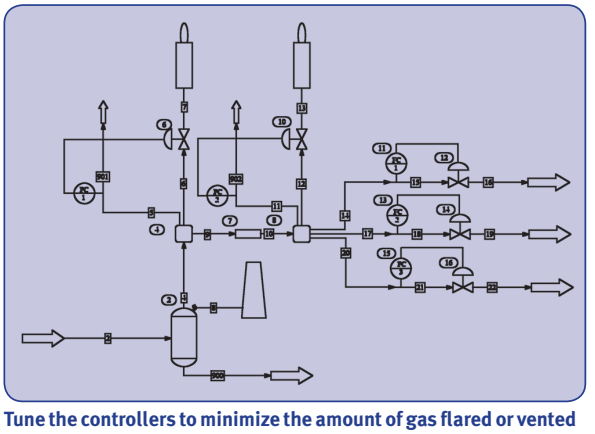
Chemstations is happy to announce the continuation of our Process Simulation Cup competition for 2017 (PSC2017). A worldwide contest open to students eager to show off their process simulation skills, the Cup has an entirely new challenge this year.

PSC2017 problem description: Biogas can be fed to block-type thermal power stations (CHP) to produce heat and electricity required on-site for a fermentation plant. Surplus electricity is exported to the national grid. This local use of the biogas does not require expensive gas cleaning, but has the disadvantage that the storage capacities for both gas and electricity are extremely limited. Hence, a control structure is required to handle surplus production of gas and limits in the intake capacity of the national grid.

Two possible disturbances to steady-state operation of the CHPs are evaluated. Scenario 1 considers a slow but continuous increase in the fermenter's gas production, while in scenario 2 a sudden shutdown of one of the three CHPs is simulated. The goal is to optimize the controller settings so that the amount of gas sent to the flares is minimized (scenario 1) and an opening of the safety valve is avoided or at least kept as short as possible (scenarios 1 and 2).

In the reference case, all controller parameters are left in their default settings (PB = 100% / TI = 1 min / TD = 0 min). This leads to an accumulated loss of gas of 36.2 kg via the flares. The safety valve does not open at any time.

Your objective is to find controller parameters so that even less gas must be burnt in the flares.



Tune the controllers to minimize the amount of gas flared or vented

Interested students can find more details at the website below, including contest rules, FAQs, and detailed instructions for participation. Practitioners are welcome to participate, but will not be included in the student competition. Chemstations invites everyone to challenge themselves and compete for bragging rights to the top simulation skills on the planet. **www.process-simulation-cup.com**

Helping companies resolve heat transfer issues

Effective and reliable heat transfer is crucial to profitability; HTRI has decades of experience helping companies improve the performance of their heat exchangers

HTRI is the leading source of process heat transfer technology, including research, software, training, and services. Incorporated in 1962, HTRI conducts research at its multimillion-dollar facility in Navasota, Tex., USA. HTRI technology has been used by companies worldwide for decades to design, operate, and improve performance of heat transfer equipment.

HTRI products and services provide problem-solving solutions, cost-effective methods, and time-saving results. HTRI employs research engineers who draw on their collective experience and the latest findings from its state-of-the-art test facility to solve problems facing the industry.

Based on years of research results, HTRI software tools are designed so that engineers derive daily operating benefit from them. The acclaimed HTRI ***X****changer Suite* is considered the industry's most advanced thermal process design and simulation software, and offers nine specific modules for different equipment types. A Technical Support team of qualified and experienced personnel backed by the entire research staff helps customers install and use the software, interpret reports, and understand software methods.

HTRI's Proprietary Contracts staff are available to help address diverse heat exchanger problems such as improving exchanger performance or throughput, reducing fouling, or troubleshooting your equipment. They offer outsourcing options for testing, consulting, and custom software solutions.

HTRI trains thousands of end users worldwide through its best-in-class training program. These regional and on-site courses enable attendees to fully utilize HTRI's powerful design software and expand their knowledge of process heat transfer technology.

HTRI conducts proprietary testing at its Research & Technology Center (RTC) located near Houston, Tex.

www.htri.net

Tank gauging solution reduces total cost of ownership

A case study shows how Endress+Hauser's Proservo NMS5 and Promonitor NRF560 are easy to retrofit to existing tanks, combining accuracy, reliability, and low cost of ownership

One of the world's premier plastics, chemicals and refining companies needed a tank gauging solution for a group of spherical tanks holding light hydrocarbon liquids, reports **Endress+Hauser**.

Some of the tanks were still fitted with their original float-and-tape gauges in stilling wells. Most tanks had been upgraded to a newer servo-based float system. A few used free-space radar level measurement, but with unsatisfactory results.

The customer wanted a standardized, reliable, and accurate tank gauging technology requiring little or no modification to the existing tank mountings. The solution was the Proservo NMS5 intelligent tank gauge from Endress+Hauser. This servo-based float system gives high accuracy (±0.7 mm) in custody transfer and inventory control.

Endress+Hauser also supplied Promonitor NRF560 local display units for tank-side monitoring and control. Additional support included project management, fabrication, and commissioning.

The same customer's next group of tanks was a bigger challenge: to integrate new level gauges with an existing digital communication system. Cables were already in place to each of the various spheres, bullet tanks, and floating-roof tanks, but were not in use on those tanks that were not fitted with level transmitters.

Proservo NMS5 atop a storage tank

Endress+Hauser checked the setup and confirmed that the existing communications system had enough spare capacity to handle the new gauges. The company supplied Proservo NMS5 gauges using the BPM protocol, programmed with digital addresses to fit the requirements of the legacy software.

Endress+Hauser was able to commission the new instruments in just two weeks. The new gauges, including RTD temperature data, showed up in the communications system alongside the existing gauges. Endress+Hauser also supplied Promonitor NRF560 units for monitoring and control.

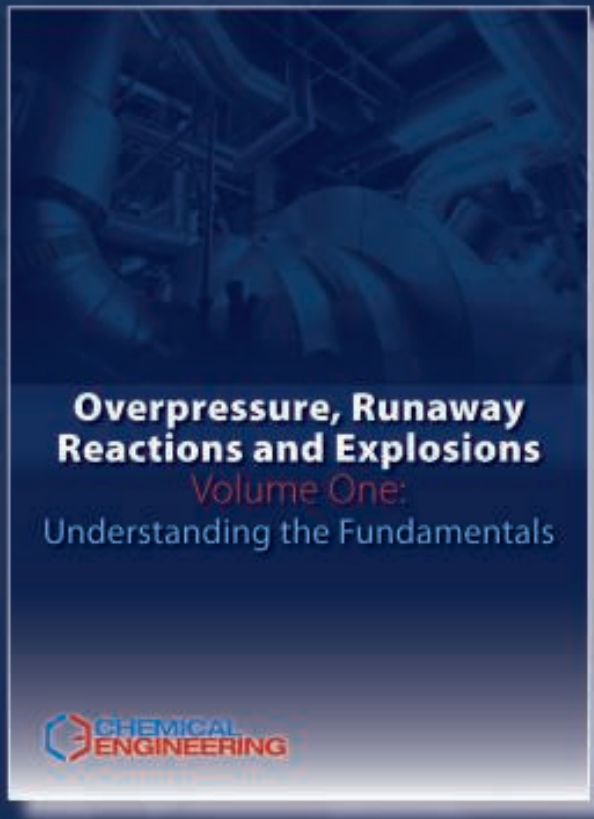
Using existing wiring and software helped to lower the total cost of the project. Another key issue in keeping costs down was the fact that Endress+Hauser provided the customer with all the necessary custom hardware to allow the new gauges to be mounted without modifying the tanks.

www.us.endress.com

Overpressure, Runaway Reactions and Explosions

Volume One:
Understanding the Fundamentals

This Chemical Engineering guidebook contains dozens of practical, how-to engineering articles to better help you do your job. It addresses engineering challenges and solutions related to the prevention of overpressure situations, runaway reactions, plant upsets and potentially explosive operating conditions.



These tutorial-style articles focus on monitoring pressure in the chemical process environment, selecting and operating pressure-relief valves. Also provided are engineering recommendations for safely handling and storing reactive chemicals, and the design and operation of explosion-protection devices and systems.

A classic mixing tool for the petroleum industry

Ross LPD Static Mixers are rugged, reliable devices that combine excellent inline mixing with minimal pressure loss

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

Shown are removable LPD mixing elements supplied with retainer ring and flanged housing

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

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

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

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

www.staticmixers.com

Automatic repeatable sampling solution

The Sentry ISOLOK automatic sampling system provides a repeatable sample at user–programmable times and intervals, without requiring regular human interaction

The ISOLOK automatic sampling system from **Sentry Equipment Corp.** is available for sampling liquids, slurries and bulk solids, and is especially suited to specialty batch chemical processes. The sampler can be controlled remotely by a Sentry controller or a distributed control system (DCS). Controllers and remote operating modules are available in a variety of configurations. Users can change the programming, sample time and other parameters if the sampler is used for multiple products within the same reactor, for example.

The ISOLOK system minimizes waste, as the volume of the sample can be controlled precisely. It can be customized to provide a sample directly to an analyzer, and to allow real-time dosing of dilution agents to minimize safety risks from the need to handle hazardous samples.

The ability to get a sample whenever desired, in the volume desired, in the same manner every time is a huge aid to achieving consistent process performance. Automated sampling removes any doubt about how or when a sample was taken. The ISOLOK captures fixed sample volumes at fixed time intervals, for uniformity and consistency. This virtually eliminates operator error. Sampling events can be triggered by control parameters such as reactor temperature or concentration. This eliminates overdosing of chemicals and may allow reaction times to be optimized.

This ISOLOK SAL-B sampler integrates an ISOVALVE ball valve into the body to ease inspection and maintenance

Designed for harsh environments, ISOLOK samplers feature rugged stainless steel construction. Specialized alloys and sealing materials are available. Options include port closures, various container types, sampler enclosures (with or without heaters), sample heating, and refrigeration.

ISOLOK samplers are designed with practicality in mind. For example, the ISOVALVE ball valve built into the sampler body on the model SAL-B provides added safety and convenience during inspection or maintenance. When off-line inspection or maintenance is needed, the ISOVALVE can be closed and the entire sampler removed while the process line remains in pressurized service. For safety, telltale ports on the isolation valve allow verification that pressure has been relieved before the sampler is detached.

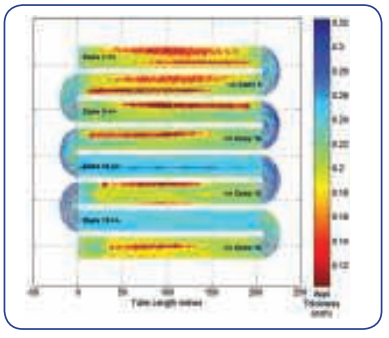
www.sentry-equip.com

Optimizing critical fired heaters is now easier than ever

Quest Integrity provides industry expertise and engineering optimization planning and management to increase the life cycle value of fired heater assets

Unexpected asset failures present a number of complications to a facility, including costly repair and production interruptions. Historically, asset reliability and management methodologies have been reactive – only adjusting practices once a costly failure has already occurred. However, today's modern technologies allow operators to proactively manage their assets, mitigating many of the risks associated with premature asset failure. Significant improvements in technology innovation and reliability practices provide operators with life extension opportunities that were not available just a decade ago.

Quest Integrity understands that unique assets require unique solutions. Due to specific operator and individual asset requirements, a general model for asset integrity optimization is not an effective long-term solution. A powerful optimization management strategy should be specifically designed to address the current and future condition of the asset, achieving a higher level of performance and reliability, while decreasing the risk of unplanned shutdowns. Customized for the life-cycle of each individual fired heater asset, Quest Integrity's Fired Heater Optimization program consists of a multi-disciplinary inspection and engineering approach that includes tube creep and corrosion damage measurement and assessment, infrared thermometry (IR) data management, ultrasonic in-line inspection and remote digital visual inspection (RDVI). A variety of engineering assessments, including fitness-for-service, remaining life, risk assessment and failure analysis are utilized to significantly extend asset life, effectively managing cost and preventing catastrophic failures.



Ultrasonic inspection data indicating areas of severe wall thinning in fired heater tubing

Depending on the condition of an asset, Quest Integrity's team of dedicated technical experts assist operators in determining the appropriate strategic action plan to ensure optimal performance and reliability of fired heaters.

Quest Integrity is a global leader in the development and delivery of asset integrity and reliability management services and solutions. The company's solutions consist of technology-enabled, advanced inspection and engineering assessment services and products that help organizations improve operational planning, increase profitability, and reduce operational and safety risks.

www.questintegrity.com

What you need to know about blast protection

The most dangerous time at a refinery isn't when it's operational, it's when it's in transition, notes blast safety specialist RedGuard

Some of the deadliest refinery explosions have occurred during turnarounds and when maintenance was being performed, not when the facility was operating routinely. During a turnaround, tens of thousands of separate procedures are performed, including moving volatile contents into position to take equipment offline or online. There are additional workers in place, many performing non-routine tasks. It is during these exercises that most blast events occur.

Blast overpressure, which happens instantaneously after an explosion, is a key component of the damage that results from a blast event. The bigger the blast event, the more damaging the blast overpressure, which causes most primary injuries. These deaths and injuries are generally a result of building collapse.

RedGuard has been manufacturing blast-resistant buildings, designed to protect the lives of those working in hazardous areas, since 1998. While there is no official set of regulations that guides the use of blast-resistant buildings, the company suggests adhering to the recommended practices set out by the American Petroleum Industry (API RP 752/753). These cover the use of blast-rated buildings (BRBs), both permanent and portable, to protect occupants against potential hazards.

Not all blast-rated buildings are created equal, RedGuard points out

A building's blast pressure rating is far from the only important factor when looking for a BRB. While blast pressure is a key component of the BRB design formula, the duration of the blast and a building's overall response level rating are what tell the real story of how a BRB will hold up to a blast. A blast pressure rating is meaningless if the BRB cannot sustain its rating throughout the blast event. A 5- or 8-psi rating may sound good, but if the building has a high response level rating, that means that during a blast event the building could suffer a high level of damage and those inside will have a high risk of casualties. A BRB from RedGuard will have a low- or medium-response level rating, along with the close, sturdy wall stud spacing that protects lives. Interior components, such as cabinetry, lighting, electrical/plumbing design and furniture are all designed and chosen specifically to handle a blast event.

Today, BRBs run the gamut from basic rental units like RedGuard's LeaseFleet, to understated comfort or top-of-the-line luxury, available in the company's SafetySuites. Virtually all the amenities found in a traditional building can be combined with the safest blast resistance in the industry.

redguard.com

Water analysis made easy

Myron L Co. supplies a wide range of portable instruments for water professionals

Myron L Co.'s new ULTRAPEN PT5 dissolved oxygen (DO) and temperature test pen (photo) is accurate, fast, and simple to use. Advanced features include automatic correction for changes in membrane temperature; DO saturation adjustment for altitude and sample salinity; real-time readings; and three calibration methods (air, water, and o ppm DO). Its accuracy of ±0.01 ppm DO concentration and ±0.1% DO saturation, combined with waterproof, rugged construction, make it ideal for any DO application.

The ULTRAPEN PT5 is just one of a large number of instruments Myron L Co. has developed over the course of more than 50 years in business. Originally founded in 1957 as a research and development company, Myron L Co. is privately owned and based in Carlsbad, Calif. Today it is a leading manufacturer of high-quality and simple-to-operate conductivity and pH instrumentation.

Applications for Myron L Co. instruments include drinking water, wastewater treatment, environmental monitoring, pools and spas, deionized water, metal finishing, electronics manufacture, textiles, horticulture, and medical dialysis.

Companion products to the ULTRAPEN PT5 are the PT1 (conductivity/TDS/salinity), the PT2 (pH), PT3 (ORP), and PT4 (free chlorine equivalent); all pens also measure temperature. Their compact format belies their quality: housed in durable aluminum, they are tough, accurate and stable, with extensive calibration options not found in other instruments of this class.

Other portable instruments include the powerful ULTRAMETER III 9P with its accompanying titration kit for measuring conductivity, resistivity, TDS, pH, ORP, free chlorine, alkalinity, hardness, Langelier saturation index, and temperature.

The company also manufactures a range of controllers for the continuous control of conductivity/ORP, resistivity, and pH/ORP. Applications include reverse osmosis systems, desalination, power plants, wastewater treatment, metal plating, electronics, pharmaceutical manufacturing, and general laboratory use.

The DS series of portable meters are analog instruments that provide accurate readings of conductivity/TDS at the push of a button. The pDS version adds pH measurement. They cover ranges from 0–50 µM/µS to 0–10,000 µM/µS, or 0–25 ppm to 0–10,000 ppm TDS. Rugged, compact and accurate, they have evolved over 40 years.

To complement its instruments, Myron L Co. offers a wide selection of pH buffers and standard solutions for conductivity/TDS. All are traceable to NIST standards. **www.myronl.com**

The ULTRAPEN PT5 measures dissolved oxygen accurately, in a package that is both rugged and ultra-portable

A choice of solutions for pressure regulation

Cashco has launched three new devices for the control of gas pressure

The new ULR-1 ("Un-Loading Regulator") valve from **Cashco** is more than an enhanced product. It also brings clarification and new information, says Clint Rogers, General Manager of Cashco's Valve Division.

The ULR-1 was originally marketed as the U1 by Kaye MacDonald, which Cashco bought in 1999. Unfortunately, the only documentation for the U1 and similar products was the original schematics, which showed how the tubing and fittings were to be installed, Rogers says.

"Previously, a customer would have had to locate the technical bulletin, work their way through its product coder and then a separate product coder for the correct bill of materials for the hookup," Rogers explains. "Not any more. With these new products, all of the information is in the technical bulletin and the operating manual."

As Rogers explains, the ULR-1 is a DA4 regulator with a Cashco CA1 back-pressure valve mounted onto it. Using the inlet pressure from the valve, the CA1 is set to control the outlet pressure of the main valve. Because the outlet of the CA1 constantly exhausts into the atmosphere, the media through the valve must be environmentally safe gas such as oxygen or nitrogen.

For even more choice in pressure regulation, Cashco has also introduced the SLR-1 and SLR-2 Self-Loading Regulators. The SLR-1 is a high-performance, pressure-loaded, pressure-reducing regulator with a self-contained regulator mounted onto it. Inlet pressure from the main valve is diverted to the pilot, which, in turn, reduces the loading pressure to the cover dome in order to maintain the set point of the main valve. The pressure inside the dome is static, so gas is only released to atmosphere when the outlet pressure setting is reduced or the system is shut down.

Cashco SLR-1 (left) and SLR-2 (right)

The new SLR-2 self-loading regulator is similar to the SLR-1, but its loading valve is not self-relieving. Instead, the cover dome bleeds through a filter and check valve back into the outlet of the main valve. This feature allows the SLR-2 to be marketed for hydrogen gas, natural gas and sour gas (NACE) applications.

www.cashco.com

A strategic approach to wastewater treatment

OXIGEST from Smith & Loveless is a compact and flexible wastewater treatment system that combines performance and reliability with affordable capital and operating costs

Concentric tanks help to minimize the footprint of the OXIGEST system

Recurring issues in wastewater treatment system design include achieving regulatory compliance, minimizing land and facility space, and keeping capital and long-term operational costs in check. CPI facility designers and consulting engineers need proven technology solutions that minimize project costs while achieving the environmental goals of their clients. **Smith & Loveless** is one of the leading companies that design-build firms rely upon because of its proven technology expertise, complete project support, and engineered system solutions like the OXIGEST integrated wastewater treatment system.

Proven in hundreds of installations, OXIGEST is a custom-designed, high-performance aerobic treatment system that meets the stringent demands of today's CPI water needs. Its design parameters include flow capacities of 0.1–5 MGD (380–18,925 m^3/day) in a single tank, with waste strengths of up to 20,000 lb. BOD per day. It can treat for stream or sewer discharge, polish anaerobic reactor effluent, or integrate with a water re-use and recycle scheme.

OXIGEST uses a compact arrangement of concentric tanks to provide aeration, clarification and advanced treatment while allowing these unit processes to be individually controlled. Compared to conventional multi-tank or in-ground systems, OXIGEST reduces concrete use, total plot area, construction time, and external yard piping and pumping. Design, operational complexity and energy requirements are minimized.

Wastewater enters the OXIGEST system in one of three ways: directly into an aeration zone, or via "equalization" or "selector" zones. The equalization zone, which is moderately aerated, stabilizes flow and organic loading. The selector zone stops the growth of undesirable bacteria by briefly mixing the influent with returned activated sludge (RAS) solids in an anoxic environment. Multiple aeration zones are employed for specific activated sludge processes or desired treatment levels, and to facilitate continuous operation.

Following the aeration phase, treated water enters the integral clarifier. Blower air-driven stainless steel pumps handle the RAS/WAS functions, reducing maintenance hassles associated with mechanical pumps, and providing automation and sampling capabilities for remote control.

OXIGEST can include process variations such as nitrification/denitrification and sludge storage. Automated thickening and decanting maximizes solids concentration while minimizing sludge disposal volumes.

www.smithandloveless.com

Single-source provider cuts costs and boosts uptime

Team Industrial Services offers a wide range of specialized services, with a single point of contact for improved efficiencies and maximum cost savings

Subcontracting vital parts of a project to multiple sources can lead to longer turnaround times, lessened quality and increased costs. Forming a strategic relationship with a well-vetted supplier is proven to create shared savings and improved operational efficiency.

The key is in the selection process. Business objectives of both organizations must be in line with one another for a long-standing agreement to take place. Are the companies' core values compatible? Can the service provider perform the work within the cost parameters? Does the contracted company have relevant experience and people with the right skills located near the company's work sites?

As a single-source provider, **Team Industrial Services** offers critical inspection, maintenance, repair and integrity management services to its customers. The company provides an integrated approach to turnaround, maintenance and capital projects, meeting every requirement from planning, scheduling, cost tracking and complete staff execution. Strong relationships are built and maintained. This encourages best practice sharing, resulting in constant examination of how work can be done better, safer, and in a more cost-effective manner.

Team offers critical inspection, maintenance, repair and integrity management services to customers worldwide

Team's extensive service offerings combined with its global presence enables prompt response with a comprehensive solution in any situation. The span of its worldwide reach facilitates an unprecedented knowledge of all local safety, quality and compliance requirements.

Additionally, each service is backed by the company's world-class engineering and manufacturing teams. Clients receive components that are designed specifically for the intended job, installed by trained Team technicians.

Having one company to deal with instead of many lends itself to effective time and administrative management. Organizations striving to standardize their safety programs will also find more success with fewer, more-involved suppliers. Efficiency is recognized when the best aspects of both the operator's and the contractor's programs are combined.

Ultimately, each company must know one another's business and establish trust and camaraderie among key players to view the relationship as a win-win strategy. Team recognizes that its global success is ultimately measured by its customers' trust and confidence, which can only be earned through continual outstanding service 24/7/365.

teaminc.com

Over six decades of experience in exhaust gas cleaning

CR Clean Air specializes in wet scrubbing systems, offering a wide range of designs and chemical reagents to suit equally diverse applications

CR Clean Air has been providing wet scrubbing systems to the chemical process industries for almost 70 years. From the initial venturi fume scrubbers developed in the 1950s to the fully skidded packages it offers today, CR Clean Air has always been driven by the need to engineer the best possible solution for each plant's emission control needs. Experienced in a wide range of applications, from handling acid gases such as HCl and SO_2 to the removal of fine and submicron particulates from contaminated vapor streams, CR Clean Air's depth and breadth of experience is unmatched. As a leader in clean air technology, the company has been at the forefront of dealing with many complex chemistries and challenging pollutants, from ethylene oxide mitigation to NOx emissions.

CR Clean Air's offerings include jet venturi fume scrubbers with integral separator tanks for bulk removal of pollutants and larger particles; high-energy jet venturis with cyclonic separators for sub-micron particles; and packed tower designs for the many situations in which higher removal efficiencies are required to meet ever more stringent emissions limits.

CR Clean Air has the experience to engineer a system that will work the first time, while its commitment to quality ensures that the equipment will continue to work for decades to come – be it a standby scrubber to handle an emergency release of toxic vapor, or an odor control unit that needs to run 24/7. From small manually controlled units to large fully automated systems with complex instrumentation and built-in redundancy, CR Clean Air's team of electrical, chemical and mechanical engineers can assist in developing customized solutions. Additionally, their offerings are available in a wide range of materials, both metal and non-metal, including carbon steel, stainless steel, corrosion-resistant alloys, FRP, polypropylene, PVDF and dual laminates.

CR Clean Air has systems installed across a wide range of industries: aerospace, chemicals, fibers, food, pharmaceuticals, pulp and paper, and semiconductor, just to name a few. The range of pollutants is just as varied, including HF, HBR, NH_3, silicates, dust, and VOCs. CR Clean Air has a range of approaches in its arsenal, including straightforward once-through water systems to chemically scrubbed systems with recirculated caustic or other reagent to neutralize contaminants.

From arsenic to zirconium tetrachloride, CR Clean Air scrubs gases that other systems won't touch.

www.crcleanair.com

A combined venturi/tower is one of the many types of wet scrubbers offered by CR Clean Air

Plastic control valves handle corrosive chemicals

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

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

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

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

Plastic valves and actuators from Collins

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

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

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

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

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

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Economic Indicators

2015 2016 2017

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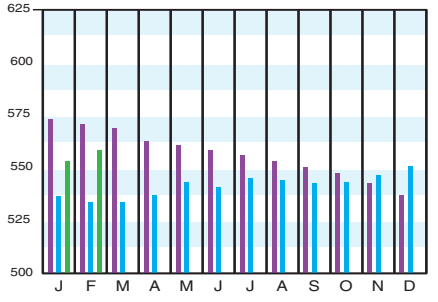
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Feb. '17 Prelim.	Jan. '17 Final	Feb. '16 Final
CE Index	558.5	553.1	533.9
Equipment	672.0	664.2	637.0
Heat exchangers & tanks	587.4	578.3	546.2
Process machinery	670.3	669.5	648.6
Pipe, valves & fittings	852.0	835.2	791.2
Process instruments	403.2	398.4	378.9
Pumps & compressors	973.1	971.3	972.2
Electrical equipment	512.1	512.6	506.7
Structural supports & misc	729.7	722.4	700.0
Construction labor	323.8	324.3	319.5
Buildings	552.3	550.2	536.9
Engineering & supervision	316.0	313.5	315.8

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

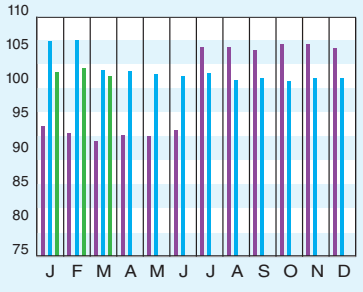
Annual Index:
2009 = 521.9
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7



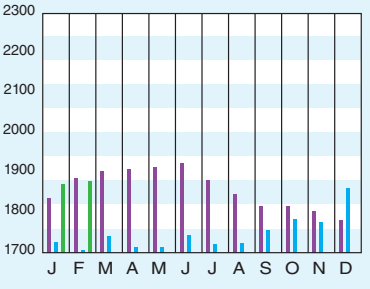
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS	YEAR AGO
CPI output index (2012 = 100)	Mar. '17 = 101.3	Feb. '17 = 101.3	Jan. '17 = 100.6	Mar. '16 = 100.9
CPI value of output, $ billions	Feb. '17 = 1,879.6	Jan. '17 = 1,874.8	Dec. '16 = 1,861.8	Feb. '16 = 1,667.8
CPI operating rate, %	Mar. '17 = 76.2	Feb. '17 = 76.2	Jan. '17 = 75.7	Mar. '16 = 76.4
Producer prices, industrial chemicals (1982 = 100)	Mar. '17 = 251.8	Feb. '17 = 244.3	Jan. '17 = 241.9	Mar. '16 = 221.4
Industrial Production in Manufacturing (2012=100)*	Mar. '17 = 102.9	Feb. '17 = 103.3	Jan. '17 = 103.0	Mar. '16 = 102.1
Hourly earnings index, chemical & allied products (1992 = 100)	Mar. '17 = 172.8	Feb. '17 = 170.9	Jan. '17 = 170.1	Mar. '16 = 160.1
Productivity index, chemicals & allied products (1992 = 100)	Mar. '17 = 103.2	Feb. '17 = 102.7	Jan. '17 = 103.3	Mar. '16 = 103.1

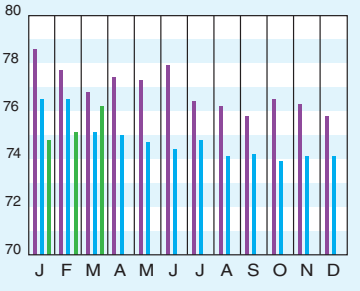
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



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

CURRENT TRENDS

The preliminary value for the February *CE* Plant Cost Index (CEPCI; top; the most recent available) represents a gain from the previous month's value. Significant increases in the Equipment and Engineering & Supervision subindices offset a small decrease in the Construction Labor subindex to push the overall PCI value higher. The Buildings subindex was slightly higher also. The preliminary monthly CEPCI number for February 2017 stands at 4.6% higher than the corresponding value from February 2016. Meanwhile, the latest Current Business Indicators (CBI; middle) for March 2017 saw the CPI Output Index and the CPI Operating Rate both stay flat compared to the previous month, while the Productivity Index increased slightly.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