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November 2008

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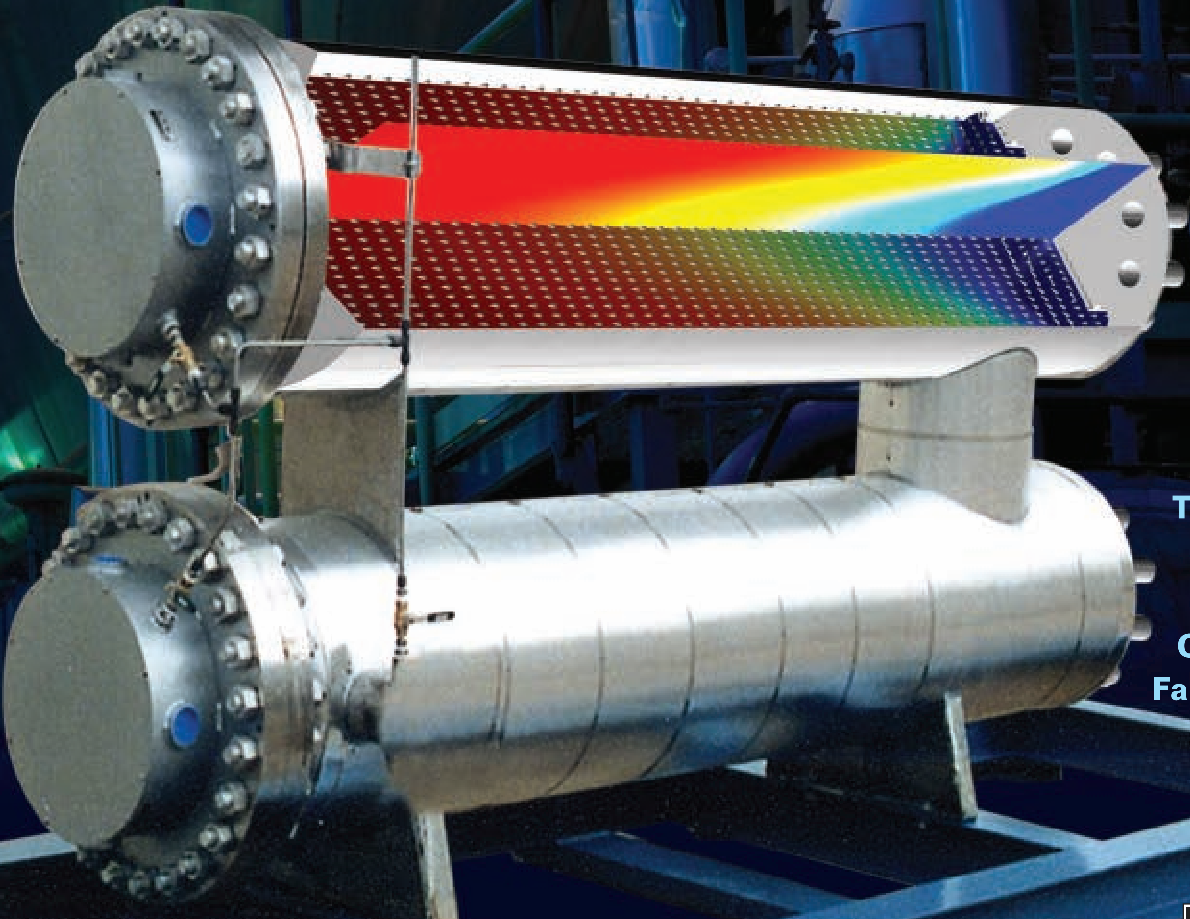

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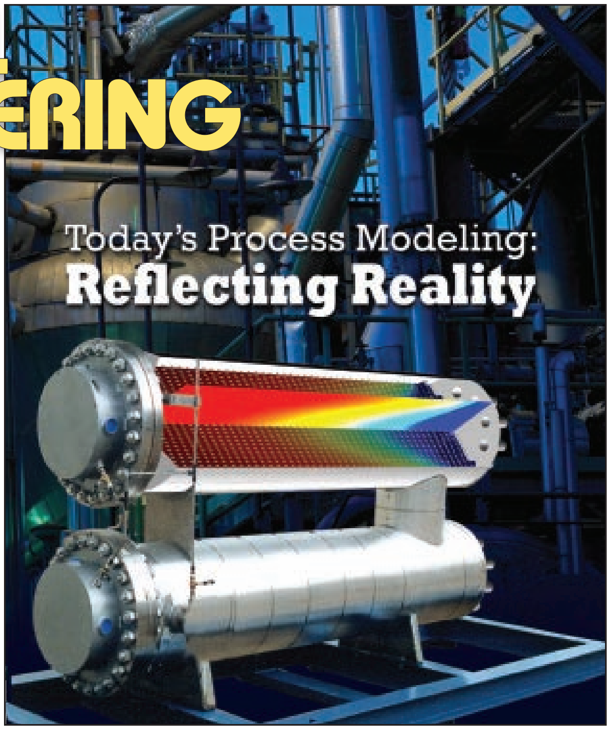


Cover images courtesy of: COMSOL, Inc.; Emerson Process Management; Gaumer Process Heaters

Editor's Page

Falling petrochemical demand

The world of petrochemicals is approaching a critical time in its history. A cyclical downturn, caused by a build up of new supply in the Middle East and Asia, is occurring at the same time as energy and feedstock prices — while highly volatile — appear to have moved to sustained higher levels. Add into this picture a major credit crisis, a recession in the U.S. and elsewhere, and it is clear that this business cycle could be very different from those of the past. Meanwhile, there are more challenges: consumer environmentalism is taking root in some regions, and legislation to control carbon emissions seems all but certain to become law in Europe and the U.S. in the next few years. For the first time in a long time, the petrochemical industry needs to ask whether it is temporarily facing slower growth in demand or the start of limited demand destruction. The trick will be distinguishing between the two in a fickle and fluid business environment.

Some early warning signs are already visible. Year-on-year consumption of the major plastics resins in the U.S. has fallen over the past two years. At the same time, consumption growth for major petrochemicals has turned negative in North America and Europe.

Most attention in the petroleum-refining and petrochemical industries is on low cost production. Little focus is on consumer behavior. More should be. In a new environmental age, consumers may start to pass over products derived from fossil fuels. There is some evidence that it is happening already:

- When gasoline prices were at $4/gallon, U.S. consumers cut their miles driven. Smaller vehicles became more fashionable as did mass transit. With gas prices down around $2.80/gallon at the time of publication, this effect may be reversible, but it could also be a sign of a permanent erosion in per capita demand
- Cloth and paper bags are challenging the dominance of plastic for packing groceries, and beverage packaging may be shifting from PET bottles
- Smaller but more-functional cell phones are becoming an alternative, not an addition, to land lines, potentially reducing plastics demand

Any demand destruction will be highest in the developed countries. In emerging economies, rising populations and a growing middle class should foster per-capita consumption growth. But demand destruction in one place is likely to impact the market as a whole.

Meanwhile, environmental legislation is looming in North America and Europe. If adopted, carbon pricing schemes will amount to a tax on industrial production, influencing competitiveness, product pricing and consumption levels in the effected regions. An EU emissions-trading scheme set to come into force for chemicals in 2013 is seen by industry commentators as the equivalent of a 10–35% tax on production. The result could be a shift in where certain petrochemicals are made, and even give some a bad image among the public as contributors to global warming. Regulations like REACH (Registration, Evaluation and Authorization of Chemicals) in Europe are meant to merely identify substances of concern, but they are likley to also create pressure for the replacement of some chemicals.

Due to the unique properties and usefulness of petrochemicals, there is no prospect that the world will completely turn its back on petrochemicals, but there is a real risk that consumer-driven effects will destroy some existing consumption and moderate future growth. The degree to which this happens will depend on the price of energy, the depth of a global economic slowdown over the next 12 months or so, and the direction of environmental legislation in the developed world. To head off demand destruction, the petrochemical industry will have to go on the offensive now, touting its environmental stewardship and the practicality of its products. ■

John Pearson, Divisional President

Dreyfus Foundation establishes $250,000 prize for chemical science

The Camille and Henry Dreyfus Foundation announces the establishment of the Dreyfus Prize in the chemical sciences to recognize an individual for exceptional and original research in a selected area of chemistry that has advanced the field in a major way. The biennial prize of $250,000 is one of the largest awards dedicated to the chemical sciences in the U.S. The first prize is scheduled to be announced in April 2009.

The first Dreyfus Prize will be presented in the field of materials chemistry, honoring the accomplishments of the Dreyfus brothers, Camille and Henry. Born and educated in Switzerland in the nineteenth century, the Dreyfus brothers were pioneers in both science and industry. Their development of the first commercially successful system for the production of cellulose acetate fiber contributed significantly to the evolution of the modern textile industry.

"A key feature of the Dreyfus Prize is that the area of focus will change each cycle. This underscores the rich diversity of chemistry and will ensure the contemporary nature of the Dreyfus Prize," says Dorothy Dinsmoor, president of the Camille and Henry Dreyfus Foundation. Further information is available at www.dreyfus.org.

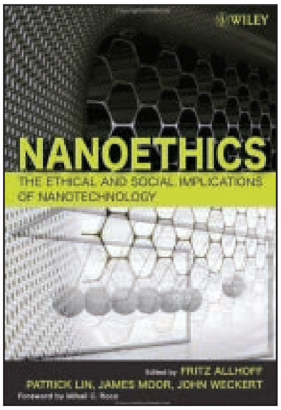
Call for papers: 2009 AIChE Spring National Meeting

The Call for Papers for the 2009 AIChE Spring National Meeting in Tampa, Fla., April 26–30, is now open. Professionals working in all areas of chemical engineering and related disciplines are invited to submit proposals. Submissions in the following areas and topical conferences are particularly welcome:

- Engineering Sciences and Fundamentals
- Separations Division (also see Topical T8)
- Management Division
- North American Mixing Forum
- Energy and Transport Processes (also see Topical T5)
- Environmental Division
- Process Development Division
- Nuclear Engineering Division
- Fuels and Petrochemicals Division
- Liaison Functions
- Topical 4: The 21st Ethylene Producers' Conference
- Topical 5: Emerging Energy Frontiers in Research
- Topical 6: 9th Topical Conference on Gas Utilization
- Topical 7: 12th Topical on Refinery Processing
- Topical 8: Distillation Topical
- Topical 9: Sustainability: Lessons, Actions and Outlook
- Topical A: Applications of Microreactor Engineering

To submit a proposal, please visit www.aiche.org/spring and click on the Call for Papers link. Deadline for all Preliminary Submissions is December 1, 2008.

Bookshelf



.NanoEthics: The Ethical and Social Implications of Nanotechnology. Edited by Fritz Allhoff, Patrick Lin, James Moor, John Weckert. John Wiley and Sons, Inc. 111 River St., Hoboken, NJ 07030. 2007. 385 pages, $39.95, paperback.

Reviewed by Christopher M. Kelty, Department of History of Science, Harvard University, Cambridge, Mass.

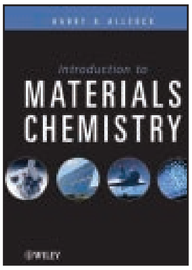
This book is a collection of essays covering a very wide range of issues related to the nanosciences and nanotechnology, some of which are previously published, some of which are new. The quality of the essays is highly variable with a handful of well-written, thought-provoking pieces and a large collection of cursory, speculative or otherwise vague articles. Because of this, there is a lot of repetition. At least a third of the articles give 1–2 pages defining what nanotechnology is, though not always consistently. Whether the discipline of nanoethics exists, or should exist, is an issue the editors take up in the introduction, without necessarily answering.

Clearly, many of the questions asked in this volume are questions that should be asked across the domain of science and engineering in society, such as the question of the moral obligation to developing countries, the ethics of life-extension or the privacy concerns over ever-proliferating surveillance devices. Other contributions narrow the concern to nanotechnology more specifically, such as the issue of regulating nanomaterials differently than bulk materials or carefully studying the environmental and health risks of new nanomaterials. Those essays that are focused on specific questions related to ongoing research or regulatory problems are the richest ones. Some of the best discussions takes place in the articles focused on the precautionary principle (Part III) and its implications and those on democracy and policy (Part V), especially the issue of civic engagement in science. Other sections cover health and environment (Part IV), broad social impacts (Part VI) and the distant future (Part VII).

Overall, the issues raised here are issues that do deserve more attention from scientists and engineers, from government and from citizens, even if they are not necessarily nano-specific. However, there are also a range of concerns that might not deserve to take up our valuable attention: the dangers of artificial intelligence, self-replicating robots out of control or the ethics of colonizing other planets. Such issues are the stuff of science fiction ethics, and they have to date commanded the lion's share of media and public attention on nanotechnology for exactly this reason. Nanoethics caters to this popular attention by re-printing the *Wired* article, Why the future doesn't need us, by Bill Joy, and Ray-

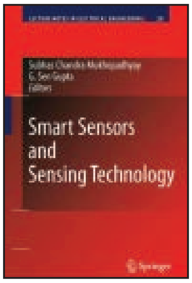
Bookshelf

mond Kurzweil's testimony concerning the societal implications of nanotechnology, both of which bypass the realities of scientific and engineering research and its day-to-day challenges in favor of long-term prediction based on scant evidence and little more than common sense as a methodology. While the book contains a good many reflections on hard problems, perhaps the first ethical hurdle will be refusing the temptation to let science fiction ethics stand in for a concerted, research-oriented ethical deliberation.

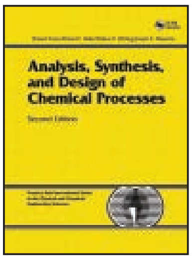


Introduction to Materials Chemistry. By Harry R. Allcock. John Wiley & Sons, Inc. 111 River St., Hoboken, NJ 07030-5774. Web: wiley.com. 2008. 432 pages. $99.95.

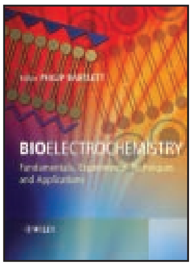
Control Valve Primer: A User's Guide. Fourth edition. By Hans D. Baumann. ISA, 67 Alexander Drive, Research Triangle Park, NC 27709. Web: isa.org/books. 2008. 161 pages. Nonmember: $109.00, member: $99.00.



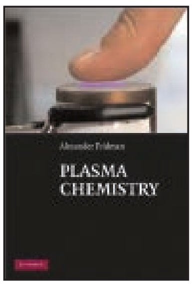
Smart Sensors and Sensing Technology. By S. C. Mukhopadhyay and G. S. Gupta. Springer, 233 Spring St., New York, NY 10013. Web: springer.com. 2008. 447 pages. $129.00.



Analysis, Synthesis and Design of Chemical Processes. Third edition. By R. Turton, R. C. Bailie, W. B. Whiting and J. A. Shaeiwitz. Pearson Higher Education, 1 Lake St., Upper Saddle River, NJ 07458. Web: pearsonhighered.com. 2009. 1,040 pages. $130.00.



Bioelectrochemistry: Fundamentals, Experimental Techniques and Applications. By P. N. Bartlett. John Wiley & Sons, Inc. 111 River St., Hoboken, NJ 07030-5774. Web: wiley.com. 2008. 494 pages. $240.00.



Plasma Chemistry. By Alexander Fridman. Cambridge University Press, 32 Ave. of the Americas, New York, NY 10013-2473. Web: cambridge.org. 2008. 1,024 pages. $170.00.

Chemical and Energy Process Engineering. Edited by Sigurd Skogestad. CRC Press, 6000 Broken Sound Parkway, NW, Suite 300, Boca Raton, FL 33487. Web: crcpress.com. 2008. 440 pages. $89.95. ■

Kate Torzewski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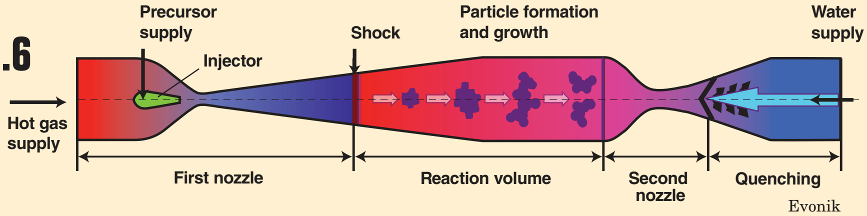
Chemementator

Edited by Gerald Ondrey November 2008

Making nanoparticles at Mach 2.6



Evonik

A new pilot reactor — claimed to be the world's first, complete two-step supersonic reactor — for producing nanoparticles has started operation at the Technology Service Center of the Wolfgang Industrial Park (IPW) GmbH, a subsidiary of Evonik Industries AG (Essen, Germany; www.evonik.com). Designed by Evonik's Process Technology & Engineering Service Unit, in collaboration with seven universities and the German Aerospace Center (DLR; Cologne, Germany), the reactor uses supersonic flow to generate particles in the gas phase. Its advantages over conventional reactors are its high heating and cooling rates as well as its homogeneous temperature and velocity profile, which enable the production of particles with a controlled diameter and narrow size distribution, says Dr. Dannehl, senior engineer in the Particle Technology unit of Evonik Technology & Engineering Service Unit of Evonik. The supersonic reactor has thus far been used for making SiO_2 nanoparticles with yields of up to several kilograms per hour.

In the reactor (diagram), a pressurized mixture of air and methane is fed to a porous burner in which the combustion of the gases ensures a homogeneous temperature profile. Before the burner narrows in the first nozzle, a precursor (for example, tetraethylorthosilicate for making SiO_2) is injected. At the narrowest point of the nozzle (6 mm X 15 mm area) the mixture reaches the speed of sound (Mach 1), and ultimately reaches up to Mach 2.6 through isentropic expansion. Downstream, a shock wave is created causing the translational energy to be converted to internal energy, and the temperature rises to about 1,200K as the precursor and hot-gas mixture ignites homogeneously. As the hot material travels through the reaction volume, nuclei grow, aggregate and fuse — under plug-flow conditions — to form spherical SiO_2 particles. The product stream is then "frozen" as it enters the second nozzle, where the gas phase again speeds up in the narrow channel, thereby stopping the reaction. A diffuser is used to stop the flow, and a water quench prevents the products from heating up. The particle size can be made smaller or larger by varying the reaction length.

Solid-catalyst, ionic-liquid combination shown to depolymerize cellulose

Researchers at the Max-Planck-Institut für Kohlenforschung (Mülheim, Germany; www.mpi-muelheim.mpg.de/kofo) have demonstrated that solid acids are powerful catalysts for the hydrolysis of cellulose dissolved in an ionic liquid. Even the cellulose fraction of wood, which is predominantly lignocellulose, can be hydrolyzed by the technique, says Ferdi Schüth, leader of the institute's heterogeneous catalyst group. The cellulose undergoes selective depolymerization into cellulose oligomers, which can be readily precipitated by adding water, he says.

Hydrolyzing cellulose into fermentable sugars is a crucial step in the production of biofuels or chemicals from biomass; however, the β-glycosidic linkages that bind the sugars together are protected by the tight packing of cellulose chains in microfibrils, explains Schüth. As a result, severe conditions, such as dilute sulfuric acid at high temperatures, have been required for hydrolysis, which also leads to undesirable side products and requires additional steps to neutralize and dispose of spent acid.

Schüth's group has found that cellulose dissolved in the ionic liquid BMIMCl (1-butyl-3-methylimidazolium chloride) in the presence of macroreticulated styrene-divinylbenzene resins functionalized with sulfonic groups [Amberlyst 15DRY, a product of Rohm and Haas (Philadelphia, Pa.)] produces reducing sugars after about one hour at 100°C. Schüth believes the reaction is the most selective process to date, forming predominantly oligomers in the first stage, which subsequently break down into sugars. If the process is terminated at the right time, cellulose fragments ideally suited for further processing in biorefineries can easily be isolated, he says. Schüth described the research, published in a recent issue of *Angewandte Chemie*, at a press event last month at BASF SE (Ludwigshafen, Germany).

Heavy crude

UOP LLC (Des Plaines, Ill.; www.uop.com) plans to do further development of its Catalytic Crude Upgrading (CCU) technology through an agreement with Brazil's Petrobras (Rio de Janeiro) and Albemarle Corp. (Baton Rouge, La.). CCU is a process for upgrading heavy oil in the field so that it may be pumped through a pipeline.

Based on UOP's fluid catalytic cracking (FCC) technology, CCU upgrades a portion of the heavy raw crude to create cutter stock to dilute the remainder of the crude. Under the agreement, Albemarle will provide an improved FCC catalyst and Petrobras, which has piloted the process, will do further testing.

Foam reactor

A porous foam reactor that is ten times more energy efficient than conventional packed-bed reactors is being developed at the Laboratory of Chemical Reactor Engineering, Eindhoven University of Technology (Netherlands, www.tue.nl). The reactor features a solid foam made of aluminum and carbon, which serves as a gas-liquid contactor as well as a catalyst support. Because the foam consists of up to 97% open space, the pressure drop over the foam was demonstrated, experimentally, to be ten times lower than that of a packed bed at the same gas and liquid velocities, says researcher Charl Stemmet. In a follow-up project, the solid foam is coated with palladium using standard wash-coating techniques, and an oxidation reaction will be studied. The project's industrial partners, BASF Nederland,

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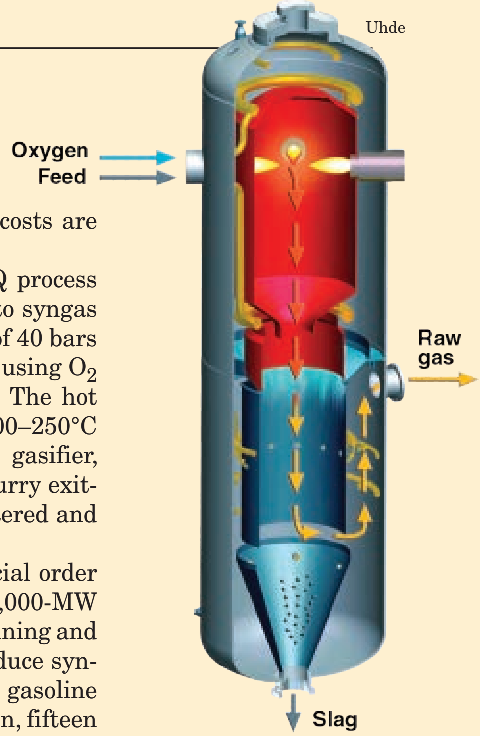
Note: For more information, circle the 3-digit number on p.66, or use the website designation.



A new gasifier slated for its commercial debut

Uhde GmbH (Dortmund, Germany; www.uhde.biz) has commercialized a new gasifier design, the Prenflo (pressurized entrained-flow) with Direct Quench (PDQ) process, which is an optimized design of its Prenflo PSG gasification process for applications requiring hydrogen-rich syngas generation (ammonia, methanol, H_2, liquid fuels and IGCC power plants with carbon capture and storage). PDQ combines the dry feed system, multiburners and membrane wall of the Prenflo PSG process with a proprietary water-quench system that saturates the raw syngas with water for subsequent gas treatment to generate syngas-based products, such as H_2, liquid fuels or chemicals. Because the quench occurs in the same reactor vessel with water (instead of gas), capital-intensive systems, such as a waste-heat boiler, a dry fly-ash removal system and a quench-gas compressor are no longer required, says Karsten Radtke, head of gas technologies at Uhde. Investment costs are thus reduced by 30%, he says.

As in the PSG process, the PDQ process (diagram) converts coal powder into syngas (mainly H_2 and CO) at a pressure of 40 bars and a temperature of over 1,500°C using O_2 and steam as the gasifying agent. The hot gas is then quenched to about 200–250°C by a cascade of water within the gasifier, then cleaned in a scrubber. Coal-slurry exiting the bottom of the gasifier is filtered and most of the filter cake recycled.

Uhde received the first commercial order for the PDQ process in June — two 1,000-MW (thermal) gasifiers for a U.S. coal mining and operating company, which will produce syngas for making methanol-derived gasoline when it starts up in 2012. Since then, fifteen 1,000-MW_{th} units have been selected from five different customers that will build coal-to-liquids or synthetic natural gas facilities based on Prenflo PDQ, says Radtke.

A less-expensive catalyst to make EG from cellulose

Researchers at the Dalian Institute of Chemical Physics (China; www.english.dicp.ac.cn) and the University of Delaware (Newark; www.che.udel.edu) are developing a tungsten-carbide/nickel catalyst that degrades cellulose into polyols at 245°C and 60 atm. The catalyst is believed to facilitate hydrolysis and hydrogenation reactions. Laboratory results show that the use of WC, instead of traditional platinum and ruthenium catalysts, leads to a higher yield of ethylene glycol (EG) relative to other polyols, an outcome that is enhanced by promoting the WC with a small amount of Ni. The synergistic effect of WC and Ni boosts the EG yield to 61% — the highest reported yield of EG from cellulose conversion, say the researchers.

The new catalyst is expected to be more cost-effective for cellulose degradation than catalysts based on expensive platinum group metals. Also, because of the increasing demand for EG as an intermediate in the manufacture of various products, such as polyester fibers, resins and antifreeze, the production of polyols from renewable resources is an attractive alternative to those based on ethylene oxide.

A trash-to-syngas process earns a patent

PHREG Technologies, Inc., a startup company in Yorba Linda, Calif., has received a patent on a pyrolysis process that converts municipal waste and other bio-organic materials into a synthetic gas of 350–600 Btu/scf quality, depending on the nature of the waste. So far the company has only modeled the process, but Peter Nick, president, says the technology is designed to use proven, reliable components. "It's basically a small blast furnace," he says, noting that gasification and slag separation take place in a single reactor.

In the PHREG concept, shredded trash is fed to the top of a vertical reactor and pyrolized by hot, upflowing driver gases. Syngas product exits the top of the vessel, and slag (about 2 vol.% of the feed) is recovered from the bottom. The reactive driver gases are made by substoichiometric combustion of recycled product gas at 3,000–3,200°F. After cleanup, the syngas can power a turbine-generator or be processed to obtain hydrogen, methanol, or ammonia.

Nick estimates that a 2,500-ton/d plant (representing trash from about a million people), generating 60–100 MW of electricity, would cost about $210 million. The payback time would be 2.5–4 yr, depending on offsetting landfill tipping fees (ranging from $30 to 100/ton in the U.S.) and applicable "green" power charge rates ($70–160/MWh).

(Continued from p. 13)

DSM Research, Ecocerамics, Lummus Technology and Shell Global Solutions, will scrutinize the data for making the decision on whether to implement this technology.

Smart hoppers

Last month at Powtech (Nuremberg, Germany; September 30–October 2), the K-Tron Process Group (Niederlenz, Switzerland; www.ktron.com) unveiled a new alternative to other forms of mechanical hopper agitation. The non-contacting ActiFlow device prevents bridging and rat-holing of cohesive bulk materials in stainless-steel hoppers using a patent-pending drive system with an intelligent control system. ActiFlow eliminates mechanical agitators with secondary motors and gearboxes, and eliminates the need for flexible side-wall agitation devices or aeration pads.

Used in loss-in-weight feeding applications, ActiFlow is bolted to the outside of the extension hopper, above the feed screws. A patent-pending self-tuning algorithm used in the control unit monitors the system, and continuously adjusts the amplitude and frequency

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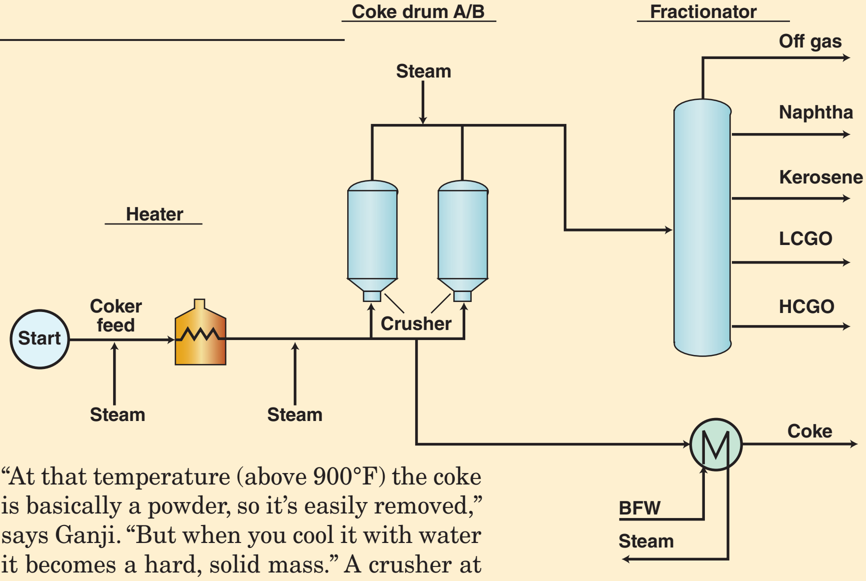
This process improvement speeds up delayed coking



Decoking in a delayed coker operation is a laborious process that can take up to 18 h. A new method that reduces the time to 6 h has been developed by US Cokertech, LLC (Norman, Okla.). This effectively triples capacity for the same drum size, says Kazem Ganji, president.

In a conventional delayed coker, residual or heavy oil in a petroleum refinery is pumped through a tube furnace at 900–940°F into one of two parallel coke drums. Vapors pass to a fractionator, and coke accumulates in the drum. When the drum is full it is taken offline for decoking, and the feed is redirected to the second drum. In decoking, the drum is purged with steam to remove volatile material, filled with water to cool the coke, then the drum is drained and the solid coke is removed by a hydraulic cutter.

Cokertech's Improved Delayed Coker Unit (IDCU) cuts the decoking time and reduces operating costs by eliminating the cooling and hydraulic cutting steps. Instead, steam is injected into the top of the drum to maintain the drum pressure at 50 psig, a valve is opened at the bottom of the drum, and the coke is pushed out by the steam (diagram). "At that temperature (above 900°F) the coke is basically a powder, so it's easily removed," says Ganji. "But when you cool it with water it becomes a hard, solid mass." A crusher at the drum exit maintains a maximum particle size of about 1 in. to avoid clogging a downstream heat exchanger, where the coke is cooled to raise steam.

Ganji says a new IDCU unit costs $2,500–3,500 per bbl/d, versus $5,000–6,000 for a conventional coker drum, while an existing coker can be modified for $750–1,000 per bbl/d. The coke-making cycle of the process can be reduced to match the decoking time by installing a larger furnace, which costs much less than a drum, he says. Cokertech has piloted the process, and Ganji says he has a letter of intent for the installation of 12,500-bbl/d IDCUs in 12 minirefineries.

Bringing the corrosion resistance of tantalum to off-the-shelf stainless-steel parts

Tantaline (Lyngby, Demnark; www.tanteline.com) has developed a process that creates a surface alloy of tantalum on a metal substrate (typically stainless steel). As a result, the surface acquires the corrosion resistance of tantalum — the most corrosion resistant metal commercially available — without having to fabricate complicated parts from the expensive metal. Unlike alternative coating methods that are sprayed or dipped, Tantaline's Alloy Bonding Surface Technology causes Ta atoms to grow into the substrate, creating an alloy at the interface. As a result, the surface alloy cannot chip or spall, resists pressure variations, and has a wear-resistance similar to or better than stainless steel, says Søren Eriksen, Tantaline's R&D manager.

Parts to be treated are first placed into a vacuum chamber where a mixture of tantalum pentachloride and hydrogen reacts at 700–900°C and 15–50 mbar to form a dense film of Ta metal on the surface by chemical vapor deposition (CVD). Because the feed gases are distributed by convection and diffusion, the CVD process is nearly independent of the part's geometry, enabling even complex parts to be treated. The tantalum layer is then alloyed with the core metal by a patented alloy bonding technology, and then a layer of pure tantalum is grown on the surface alloy, giving the final surface all the characteristics of pure tantalum. A Ta thickness of 50 µm is sufficient for most applications, but can be as large as 200 µm if needed, says Eriksen.

For the past 15 years, the company has been researching, developing and producing a variety of valves, fittings, instrumentation and other components for customers who deal with corrosive processing environments (such as sulfuric and hydrochloric acid). Early next year, Tantaline will start up a new facility, which will increase its capacity by ten times. Treated parts are expected to be directly competitive with those made of special metals, such as titanium, zirconium and nickel alloys, says Eriksen.

(Continued from p. 14)

of the material activation inside the hopper to maintain an accurate weighing signal. Advanced filtering algorithms are used to screen out extraneous vibrations, even when the device is running.

Supercon heater

Researchers at Sintef (Trondheim, Norway; www.sintef.no) have replaced the copper conductors in the induction coils of an induction heater with super conductors. In so doing, the energy efficiency is increased to 80–90%, as demonstrated in laboratory trials. Induction heaters are commonly used by the aluminum industry to preheat Al billets to 500°C before extruding the billet into profiles. However, "only 50% of the energy supplied is used to heat the billet," explains researcher Magne Runde. The remaining half is wasted energy. The induction coils, which are 1.5 m in dia., use a magnesium diboride superconductor enclosed by a nickel matrix.

Biotech milestone

The Percivia PER.C6 Development Center (Cambridge, Mass.) — a joint venture between DSM Biologics (Parsippany, N.J.; www.dsm.com) and Crucell N.V. (Leiden, Netherlands; www.crucell.com) — has been scaled up to 250 L by DSM Biologics scientists at its GMP facility in Groningen, Netherlands. The researchers

(Continues on p. 18)

WO_3 photo-catalyst active under visible light for VOCs decomposition

Researchers at the National Institute of Advanced Industrial Science and Technology (AIST; Tsukuba, Japan; www.aist.go.jp), and the University of Tokyo have developed new photocatalysts that are more efficient at decomposing volatile organic compounds (VOCs) than the commonly used titanium dioxide. The catalysts — tungsten trioxide promoted with palladium or copper — decompose VOCs, such as formaldehyde, acetaldehyde, formic and acetic acids, and toluene, into water and CO_2 when irradiated with visible light. This feature makes the catalyst promising for preventing sick housing and building syndrome and reducing malodorous substances in rooms, hospitals and cars.

The researchers succeeded in enhancing the catalytic activity of WO_3 by adding promoting catalysts, such as Pd and Cu compounds they developed. The catalyst system is made by simply mixing powdered WO_3 with fine powders of the promoter. Compared to TiO_2, the Pd-WO_3 system showed seven times higher catalytic activity for decomposing formaldehyde, and the less-expensive Cu-WO_3 catalyst three times higher activity under visible light illumination. A Pt-WO_3 system also showed catalytic activity, but has not been pursued further due to the high cost of Pt.

Both the Pd and Cu-promoted WO_3 are active under sunlight, room lighting and inside cars, where the ultraviolet fraction of sunlight is filtered out by glass. Because the catalyst components are more expensive than TiO_2, the researchers are working to reduce costs by increasing the efficiencies. Plans are underway to apply Pd-WO_3 for high-performance air-cleaning filters for painting factories, and for combining the Cu-WO_3 with antibacterial properties for hospital floor tiling and household use in wall coverings and window shade blinds.

(*Continued from p. 16*)

achieved 8 g/L for an immunoglobulin (IgG) expressed by PER.C6 cells using chemically defined cell culture medium. Crucell's PER.C6 technology has been developed for the large-scale manufacturing of biopharmaceutical products, such as recombinant proteins.

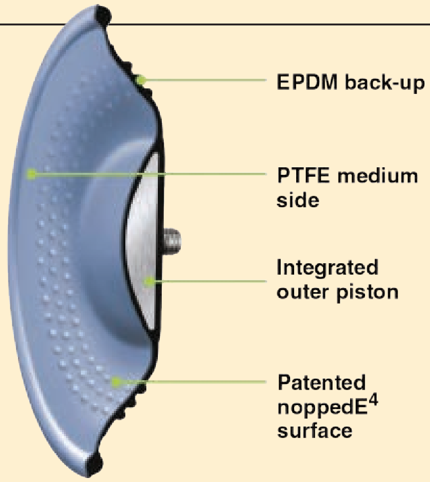
Selective As adsorber

Lanxess AG (Leverkusen, Germany; www.lanxess.com) has developed a hybrid adsorber for removing arsenic from drinking water. Lewatit FO36 is a combination of a polymeric anion exchange resin and an iron-oxide with a goethite (iron oxyhydroxide) structure. A proprietary process is used to distribute the iron oxide in the pores of the resin as a thin layer a few nanometers thick, thereby increasing the As selectivity.

This diaphragm adds life to air-powered pumps

Crane ChemPharma Flow Solutions (Düsseldorf, Germany; www.cranechempharma.com) has developed a new compound diaphragm, the DEPA E^4, which is said to increase life span, improve safety and increase efficiency of air-operated diaphragm pumps. The laminated design of the DEPA E^4 ensures that the diaphragm surface is impermeable, thus providing an ultraclean working mechanism that prevents leaks and deposits while greatly limiting areas for bacteria buildup, says the manufacturer.

The diaphragm (photo) is constructed as a single unit from a combination of PTFE [poly(tetrafluoroethylene)] and EPDM (ethylene propylene diene M-class rubber). The outer piston — usually a separate component in standard pumps — is entirely encapsulated. A patented "noppedE^4" surface, consisting of a uniform sequence of small mounds radiating in a band within the diaphragm, imparts superior flexibility to the DEPA E^4, even when compared to standard rubber diaphragms, says the firm.



The diaphragm is available in four sizes between 1/2 to 2 in., and offers high chemical resistance over the pH range of 0 to 14. Because EPDM is electrically conductive, the diaphragm is suitable for use in ATEX-conforming pumps, and it is approved for use in Zone 0 when used with pumps made with a stainless-steel casing. ■

Bubbler alternative

In the activated sludge process for treating wastewater, oxygen is commonly introduced by diffusing fine air bubbles. This method not only requires energy intensive blowers, but also suffers from poor efficiency at high solids loading because the bubbles coalesce, thereby reducing the residence time and the surface area for O_2 transfer from the bubble. These problems are reduced by a falling droplet method being developed by a team from the Dept. of Chemical Engineering at the University of Newcastle (Australia; www.newcastle.edu.au).

In the new method, liquid is pumped to a height where it is turned into droplets, which then fall into a catchment tub. Experiments have shown that the greater the fall height, the greater the mass-transfer, with the greatest mass-transfer rate occurring during the early stages of the fall. It is also found that greater O_2 transfer per volume occurs with smaller droplet sizes.

A device with 17 L/min flowrate was used in the study, which involved drops with 3–7 mm falling from a height of 200–800 mm. An O_2 transfer rate of about 1.35 kg/kWh was measured. Trials with brewery waste indicate that the system is able to produce smaller droplets with feeds of 10,000 mg/L suspended solids than with fresh water. ❑

2008 SALARY REPORT

Ch.E.s wonder when the CPI will feel the hit of the changing economy

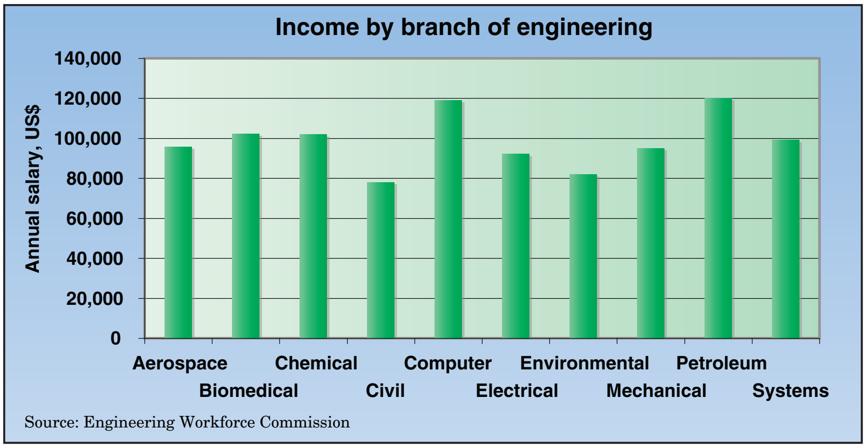


FIGURE 1. With a median salary of $102,000, Ch.E.s are still near the top of the list

The past decade has been a volatile period for chemical engineers in the workforce. The late 1990s was a booming time in the chemical process industries (CPI), with salary increases greater than ever and an unprecedented demand for Ch.E. expertise. This prosperity quickly gave way to harder times in the early 2000s, when engineers struggled to keep their salary increases on par with inflation. Luck had turned around again in recent years with steadily increasing pay, but in light of the recent economic crisis, Ch.E.s wonder — when will the CPI feel the hit of the changing economy?

Recent salary trends

This year, most Ch.E.s enjoyed a greater annual salary boost than has been found in nearly a decade. In its 2008 salary survey, the Engineering Income and Salary Survey and the National Society of Professional Engineers (NSPE; Alexandria, Va.; www.nspe.org) report a median income of $102,000, an impressive 11.1% increase since 2007. Gulshan Dua, vice-president of process engineering and gas processing of SNC-Lavalin's chemical and petroleum business unit, has seen a high level of job satisfaction with sustained growth. "The trend in the last two years in particular has been significant increases in salaries and overall packages, as much as 40 to 60% increases."

As expected, education, licensure and experience pay off greatly for Ch.E.s. According to the NSPE survey, having earned a masters degree boosts the median salary to $104,600, a 7.5% edge over Ch.E.s with a bachelors degree, up from 4.9% in 2007.

Meanwhile, attaining Professional Engineer (P.E.) licensure proves to give a significant boost to Ch.E. salaries. With a median income of $114,000, P.E.s earn a 37.3% higher salary than unlicensed Ch.E.s, a number that may also reflect the fact that many licensed engineers have completed a higher level of education and have more years of experience than most other Ch.E.s.

An annual survey report released by the Engineering Workforce Commission, a division of the American Association of Engineering Societies, Inc. (EWC; Washington D.C.; www.aaes.org/ewc) provides engineering salary data at every level of experience, proving that experience pays off, with steadily increasing salaries with increasing years of experience. Table 2 and Figure 2 show Ch.E. salary data for 2008, which illustrate this trend, with new graduates starting around the $60,000 mark and the most seasoned Ch.E.s commanding a median salary of $110,000.

In Figure 3, we compare EWC data from its five most-recent annual salary surveys. The graph shows the median salary of working Ch.E.s as a function of years since a bachelors degree was earned. Data for 2004 through 2008 is shown, with data for years up to 2007 adjusted for inflation to 2008 equivalency. From this data, we see that pay generally increased with experience, with the exception of 2004 and 2007 data, where the salary of engineers approaching retirement reduced. Also, when comparing years, we see that survey participants did not see salary increases that kept up with the rise of inflation from 2005 to 2006, though data has remained somewhat consistent since then.

TABLE 1: INCOME BY BRANCH OF ENGINEERING

Aerospace	$95,800
Biomedical	$102,375
Chemical	$102,000
Civil	$78,000
Computer	$119,178
Electrical	$92,240
Environmental	$82,000
Mechanical	$95,000
Petroleum	$120,000
Systems	$99,200

Source: Engineering Workforce Commission

When compared to engineers of other disciplines, Ch.E.s still boast one of the highest median salaries, as shown in Figure 1. EWC's latest report, which found a median Ch.E. salary of $102,000, is beat out by computer engineers, and only slightly by biomedical engineers, as seen from the data in Table 1. Petroleum engineering proves to be the most profitable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WELL ENOUGH ALONE.

area of Ch.E. practice, with a median salary of $120,000, the highest of any engineering discipline.

Overall, according to the National Association of Colleges and Employers (NACE; Bethlehem, Pa., www.naceweb.org), the chemical industries boasted the second brightest outlook of any category of employer, being exceeded only by computer-software-development companies. Andrea Koncz, employment information manager of NACE, reports that companies in the CPI plan to hire 19.2% more new graduates than they did last year.

Though employers are seeking to hire a record number of Ch.E.s, an October 2007 NACE report that studied data from the Bureau of Labor Statistics shows that engineering enrollments are decreasing at a rate of 2.2% per year. With a slowly dwindling supply of Ch.E. professionals, the demand for this expertise is higher than ever. Usha Singareddy, director of compensation for Dow Chemical Company (Midland, Mich.; www.dow.com), has seen a decreasing availability of new Ch.E.s, noting that "numbers have gone down tremendously," though the quality of Ch.E. graduates remains high. One factor that she sees as causing this is a dropping ratio of students enrolling in Ch.E. programs to other engineering programs. Despite the profitability of working in the CPI, Singareddy sees many students moving toward other engineering disciplines, including computer and electronic engineering.

TABLE 2: CHEMICAL ENGINEERS — SMOOTHED MEDIAN SALARY

Years since baccalaureate degree							
	3	4	5	6	7	8	9.5
2004	—	—	—	—	—	—	87,833
2005	—	—	—	—	—	—	83,021
2006	60,577	65,231	66,495	68,289	71,849	76,789	78,848
2007	64,701	73,190	76,708	78,768	78,344	79,976	80,134
2008	59,964	64,386	65,802	67,733	71,601	77,797	79,104

*2004–2007 data adjusted to 2008 dollars

The outlook for Ch.E.s in the U.K. and Ireland has brightened as well, as determined by IChemE's 2008 salary survey (Rugby, U.K.; www.icheme.org). Like Ch.E.s in the U.S., IChemE survey participants were lucky if they didn't see a decrease in salary earlier in this decade — from 2002 to 2004, the reported median salary did not change. Since 2004, however, salaries have steadily increased. The median salary in the 2008 report was £47,000, up 8.8% from 2006.

In the U.K., professional engineers are given the designation of "Chartered Engineers." As in the U.S., Chartered Engineers participating in the IChemE survey earned a much higher salary than non-chartered participants, with a median chartered salary of £57,500 over £36,000, a 59.7% advantage.

Looking toward the future

Ch.E.s may have enjoyed steadily increasing salaries over the past couple of years, but the changing economy may dictate a slowdown in the CPI and Ch.E. employment. Andrea Koncz says that this is a difficult issue to predict. "With the downward trend in the economy, perhaps all areas will be affected." However, she notes, "there is a definite demand for chemical engineers, and with gas prices rising and [engineering enrollments declining], I would like to think they will not be affected."

Kevin Swift, managing director of economics and statistics for the American Chemistry Council (ACC; Arlington, Va.; www.americanchemistry.com), explains that the outlook may not be as positive as we hope. "If you look at industries that Ch.E.s are usually employed in, they usually peak at this point in the cycle." He points out that the housing market has gone down 60% in the past year, while vehicle sales have dropped 30%, two major markets that will directly affect the CPI. While the demand for domestic sales in the chemical industries has dropped, until recently, increasing international exports had somewhat offset these losses. Now that foreign markets are entering the same economic turmoil as the U.S., Swift is seeing a drop in exports as well. All of this points to potentially rocky waters for Ch.E.s. "It will be a tough environment for a year or so," Swift says. Despite recent trends in the increasing demand for Ch.E.s, "industry might cut back production levels, and therefore, employment could drop."

Though the outlook may be grim, or uncertain at best, some sectors of the CPI may weather this economic storm better than others. John Pearson, president and CEO of Access Intelligence's chemical business media division,* expects that the companies involved in the green revolution may bode well over the upcoming year. On the U.S. West Coast, he has noticed that start-up alternative-fuel companies have been doing quite well during this time, citing companies such as LS9 (South San Francisco, Calif.; www.ls9.com), which focuses on the area of biofuel production.

Though SNC-Lavalin's Dua does not expect to see salaries increasing at the same rate as they have been recently, she still has a positive outlook, predicting 8–12% increases in 2009. She also agrees that the energy industry does indeed have a brighter

*Chemical Engineering is published by Access Intelligence

CURVES VERSUS YEARS OF EXPERIENCE*

11.5	14.5	18.5	23	28	33	38
89,977	94,287	96,588	109,844	118,355	123,263	119,106
86,960	93,818	98,606	109,577	114,670	121,787	125,623
81,020	84,971	91,068	99,648	104,657	108,463	108,822
83,348	85,796	91,067	99,504	101,630	100,875	92,796
81,970	84,531	90,667	96,366	101,463	105,326	106,749

Source: Engineering Workforce Commission

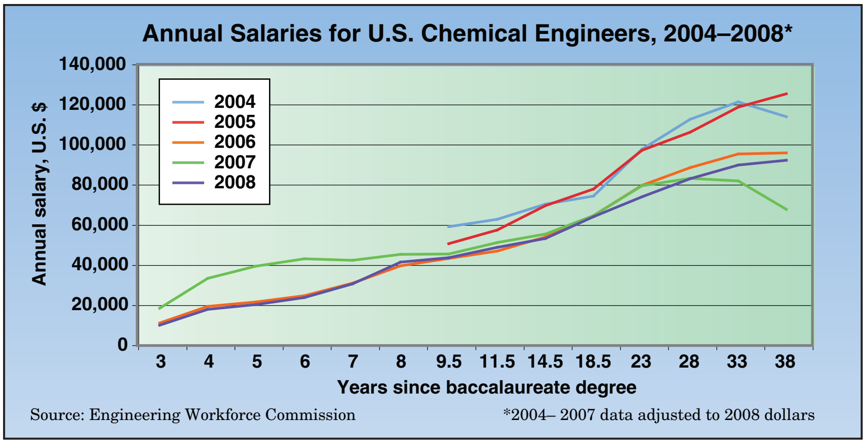


FIGURE 2. **At times earlier this decade, Ch.E.s struggled to keep their salaries up with inflation. Now, salaries are much more consistent**

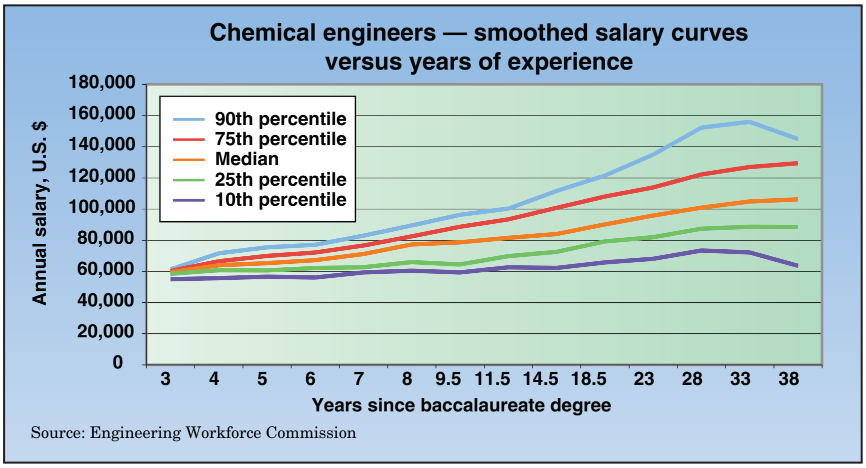


FIGURE 3. **In 2008, new graduates saw starting salaries around the $60,000 mark, while the most seasoned Ch.E.s commanded a median salary of $110,000**

future. "A significant economic growth is expected in the coming 10 to 20 years in the energy sector. This will be complemented by stricter compliance with environmental regulations, in particular, related to carbon capture and sequestration, fuel efficiency improvements, use of alternative (to fossil fuels) fuels, and minimizing the use of the scarce water resources, and so on, which will all be adding to development of newer projects." Dua points out that these new projects will require a high level of innovation, research and development, making the energy sector an area where Ch.E.s with masters and Ph.D. degrees would be in greatest demand.

Increasingly global workforce

As engineering enrollment continues to decline yet Ch.E. demand increases, U.S. CPI executives are becoming increasingly concerned about the global position of the U.S. CPI.

In a Bayer survey of Fortune 1000 science and technology company CEOs, concerns about the science technology, engineering and mathematics (STEM) workforce showed up strongly. At 95%, nearly all of the executives are concerned that the U.S. is in danger of losing its global leadership position in science and technology due to a shortage of STEM talent,

TABLE 3: CHEMICAL ENGINEERS — SMOOTHED MEDIAN SALARY CURVES VERSUS YEARS OF EXPERIENCE													
Years since baccalaureate degree													
	3	4	5	6	7	8	9.5	11.5	14.5	18.5	23	28	33	38
90th percentile	61,800	72,166	75,981	77,627	83,463	90,135	96,912	100,827	112,183	121,975	135,474	152,879	156,522	145,526
75th percentile	60,762	67,058	70,382	72,665	77,172	82,969	89,133	93,885	101,227	108,494	114,401	122,724	127,525	129,976
Median	59,964	64,386	65,802	67,733	71,601	77,797	79,104	81,970	84,531	90,667	96,366	101,463	105,326	106,749
25th percentile	59,015	61,272	61,204	62,676	63,244	66,466	64,893	70,291	72,985	79,729	82,445	87,899	89,123	89,042
10th percentile	55,474	56,175	57,130	56,567	59,884	61,030	59,847	63,159	62,835	66,349	68,591	73,976	72,764	64,105
Source: Engineering Workforce Commission														

with more than half reporting that their companies are already experiencing such a shortage. When it comes to rising international competition, 68% are concerned that other countries' increasing access to STEM talent is giving rival companies based in these countries a competitive advantage over those in the U.S., with 20% of respondents saying they are "very concerned." Dow's Singareddy notices this trend as well, explaining that she is seeing a significant drop in American students, while the international student population continues to grow.

In the past few years, the CPI has seen an interesting change in the Ch.E. workforce worldwide. Andreas Beckers, head of corporate communications at Uhde GmbH (Dortmund, Germany; www.thyssenkrupp.com) points toward the increasing workforce in Asia. Just a few years ago, engineering firms could attract Ch.E.s in Asia for relatively low salary. "Now," Beckers notes, "the engineering workforce is growing across India and China." Their demand is growing at the same time, and U.S. and European firms can no longer secure these professionals as easily. "Salaries must now be much higher in order to hold on to these engineers," Beckers explains. SNC-Lavalin's Dua, too, sees this change in the global Ch.E. workforce affecting the U.S, saying that the situation has changed drastically in the last 2–3 years with respect to the availability of good process engineers from China and especially India. "The demand for them has increased tremendously, and hence, their expectations [have too]," she says. Furthermore, she warns that "the downturn in the industrialized world will be made by growth in the developing world, namely India, China and South America."

Despite a high demand and increasing salaries for engineers in Asia, there appears to be a surplus of Ch.E.s in Nigeria. Using her own country as an example, one reader explains that "there are up to 30,000 chemical engineers in Nigeria without a job, despite [all of] the petroleum companies in the country." With the focus of the rising global Ch.E. workforce in Asia, the CPI may be overlooking an untapped resource in African countries and other areas of the world.

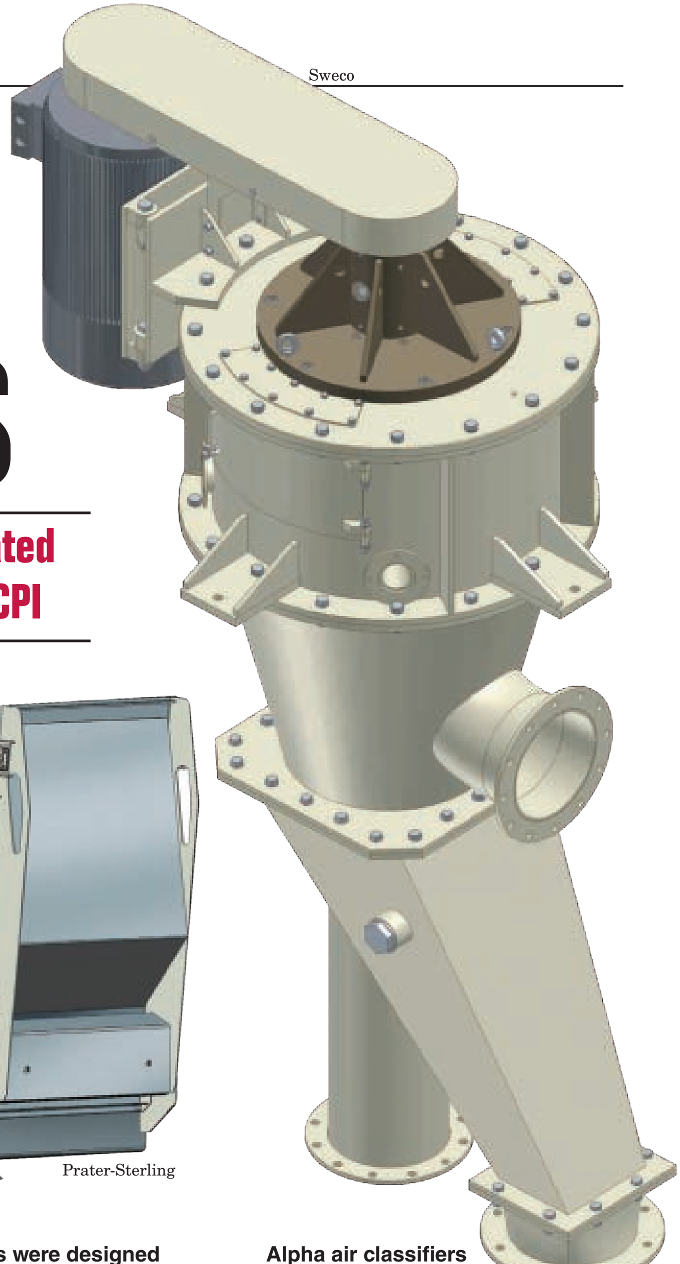
SNC-Lavalin's Dua provides insight into the negligence of the U.S. to explore talent in such areas. "I have dealt with a few chemical engineers from some untapped resources and have mixed opinions — not all have the right skill set and experience to fit directly into the North American markets — some need extensive on-the-job training." ■

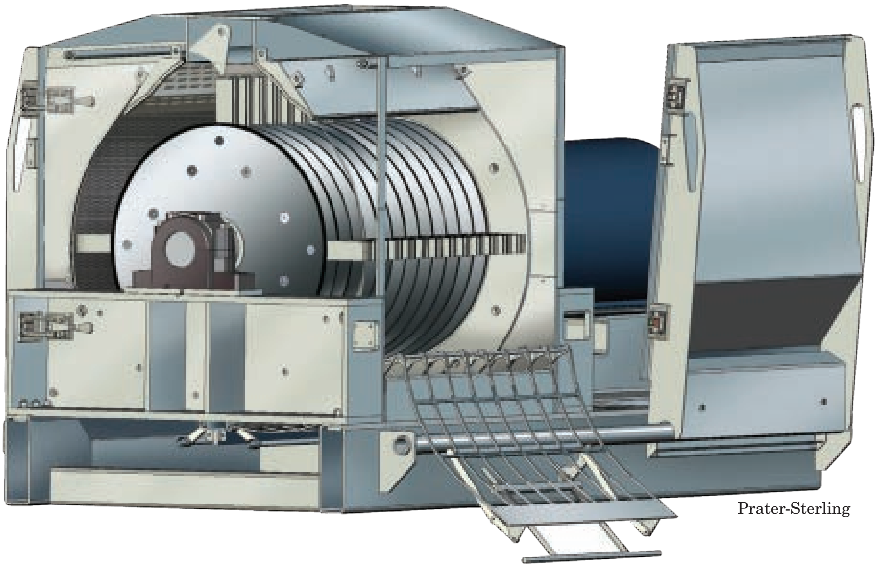
Kate Torzewski

Newsfront

WHEN SIZE MATTERS

Particle sizing equipment gets updated to meet the changing needs of the CPI


Sweco


Prater-Sterling

Evolution Hammermills were designed for cellulosic and grain ethanol applications. Besides pulverizing any grain, there are models designed to grind cobs or wood chips for cellulosic ethanol, all while requiring up to 20% less energy

Alpha air classifiers were developed for the production of fine products below 40 µm. As a centrifugal classifier, this model can achieve high yields at very low, specific energy consumption

As chemical processors continue to feel the pinch of the worsening economy, particle sizing is becoming an increasingly important issue because it can impact reaction rates and productivity. With the needs of chemical-process-industries (CPI) customers in mind, manufacturers of a variety of particle sizing equipment — from classifiers to hammer mills to grinders — are enabling their products to create smaller and smaller particle sizes, increase quality, reduce waste and boost throughput.

A finer grind

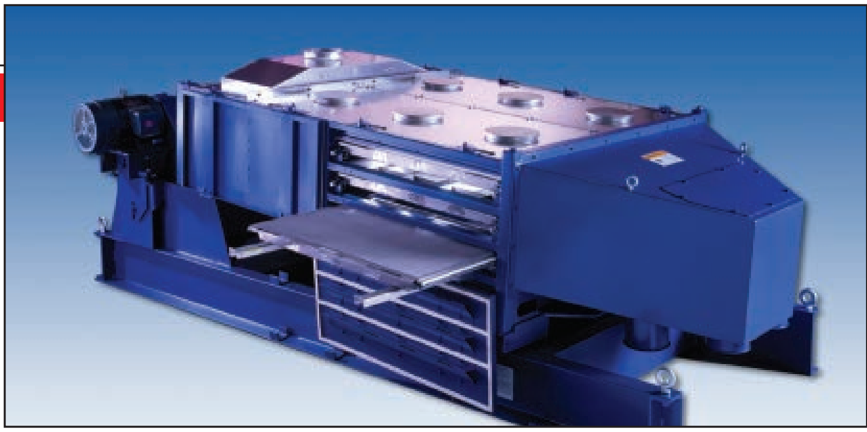
According to almost every particle-sizing equipment manufacturer, there is a definite trend toward finer particle sizes because, as the particle becomes smaller, more surface area is exposed, which can result in higher reaction rates, more potent product or higher productivity. However, as equipment makers upgrade machines to help their CPI customers achieve smaller particle sizes, they are also making operational improvements, such as increased energy efficiency or improved roll positioning systems, allowing processors to get more bang for their purchase buck.

For example, Modern Process Equipment (Chicago, Ill.) has updated its Gran-U-Lizer line, which has traditionally featured pairs of corrugated rollers through which material passes, to accommodate finer particle sizes via the use of a variety of roll surfaces. In addition, abrasion-resistant roll materials are being developed to reduce the amount of wear on the rolls.

Brian Thomas, vice president, says tolerances and positioning are also being improved. "As our roll positioning system becomes more precise, we can control the gap between the grinding rolls to one-half of one-thousandth of an inch, which is one-eighth the thickness of a hair," says Thomas. "In some cases rolls can be run so they are actually touching the product as it goes through."

Bill Brown, division manager, chemical/minerals at Hosokawa Micron Powder Systems (Summit, N.J.), says his firm also hears customers asking for finer particle sizes, as well as energy efficiency, and is responding by modifying existing equipment offerings. One example of Hosokawa's response can be seen in the remake of the Mikro ACM air classifying mill, which is a high-speed impact mill that offers grinding and classifying in a single machine. "We've made so many adjustments to this machine that it looks different, so we've named the updated model the eCM," notes Brown. "Via the updates we've been able to reduce the energy requirement or make a finer particle-size distribution at the same energy requirement or utilization in certain applications using the eCM."

Rotex



The APEX dry separation screener is made for efficient performance, quick and easy maintenance and cleaning and increased process uptime within a production line

Enhancing quality

Oliver Schmitt, business line manager, process systems, with Malvern Instruments Ltd. (Malvern, England), agrees that there is a general trend towards the production of finer particles with narrower particle-size distributions, but adds that many products also now have very well-defined upper or lower specifications. "These specifications deliver enhanced functionality, allowing the manufacturer to access new markets or improve the quality of an existing product," he says.

He explains that the best way to achieve this tight particle size is to install online particle sizing equipment that delivers realtime analysis, such as Malvern's Insitec range of at-, on- and inline-particle-size analyzers. They provide particle size measurement in the size range of 0.1 to 1,000 microns for both wet and dry streams. Malvern also supplies the Parsum range of instruments, which use the technique of special filter velocimetry to provide inline measurement for particles up to 6,000 microns.

Another means of achieving improved quality is to install sizing equipment such as a variable-speed air classifier that is able to recover or extract more "good" product per ton. "This means the equipment needs to be more efficient at taking good product from the material that is presented to it, while having the ability to reject undesirable, oversized prod-

NANOSIZE ME

While many chemical processors are looking to grind to smaller and finer particle sizes, some are taking it a step further and attempting to achieve nanoscale-sized particles. "Our customers are starting to see the benefits of nanosize particles, whether it's reducing to nanoparticle size using wet media milling or downstream processing of nanoparticles such as coating nanoscale-sized carbon particles, so we are introducing products that focus on nanoparticle technology to meet those needs," says Bill Brown, division manager, chemical/minerals with Hosokawa Micron Powder Systems (Summit, N.J.).

The Hosokawa Nano Particle Technology Center (Summit, N.J.), headed by C.C. Huang, is dedicated to developing, manufacturing and commercializing nanoparticles and composite materials. The center works in conjunction with Hosokawa's Nano Technology Centers in Japan to bring American customers the same technologies, including Mechano Chemical Bonding (MCB) Technology. MCB addresses the cost and processing issues of nanoparticle applications. It is a technique by which materials can be chemically bonded together by using mechanical energy without any binders. Various nanocomposites and engineered particles can be created with superior functional performance.

In addition to this technology, the U.S. Center also offers a variety of nanoparticle processing equipment, including the Alpine AHM, a universal wet mill. It features an enclosed horizontal agitated ball mill for both closed-circuit and single-pass submicron to nanometer milling applications, as well as steep particle-size distributions and an easily exchangeable screen.

For downstream processes, the Center offers the Nobilta, which is designed for particle surface modification and sphericalization, micro to precision macro mixing and production of engineered composites. It is equipped with a water-cooled jacket for even operating temperature control and has options for hard-facing and ceramic line components. It is suitable for applications that produce heat-sensitive, sticky and abrasive materials.

However, Hosokawa is not alone in its pursuit of the nanoparticle size. Brookhaven Instruments Corp. (Holtsville, N.Y.), which specializes in light-scattering, particle-sizing equipment, is also moving into this territory with its NanoDLS, a particle size analyzer for flow and batch mode applications.

Jeffrey Bodycomb, products manager, says the NanoDLS is the gateway to absolute nanoparticle sizing, including proteins and their aggregates, polymers, dendrimers, micelles and other colloidal materials. Based on the principles of dynamic light scattering, the analyzer uses an automatic, variable-power laser at 638 nm, maximum 35 mW power, an optical cell design, a single-mode fiber, a self-protecting avalanche photodiode and a 25ns/522-channel digital autocorrelator. The optical cell design allows the unit to measure samples from extremely low to high concentrations, which, in turn, permits small volumes and vertical flow patterns. ❑

uct," says Joseph Muscolino, sales manager with Sturtevant (Hanover, Mass.). "This permits processors to get more useable product from the same amount of material and increases the quality of the finished product because it has less contamination from the oversized particles."

Sturtevant's Side Draft classifier fits this bill, according to Muscolino. The energy-efficient classifier is suitable for consistent separation of particles in the 100 to 400 mesh range. Its working principle is simple: Material enters through the feed spout, is evenly conveyed across the top of the distribution plate and drops into the separating zone, creating a uniformly dispersed curtain of material. Forces generated by the rejector cage and process air subject the curtain of material to particle size classification. High separation efficiencies and precision of classification are obtained by controlled air flow and rejector cage speed. The multi-pin, variable-speed rejector cage allows only the selected fines to pass into the fines chamber and exhaust into the system collector. The coarse particles, after passing through the separating zone, fall into the coarse outlet.

Muscolino says this model is finding increased use in coal-to-chemical facilities that need to use a sizing device to upgrade the particle size of the coal-fired fly ash so it can be used as a filler in cement. The air classifier rejects undesirable oversized carbon particles that contaminate fly ash. Oversized particles are also problematic in silica flour applications where the powder needs to remain very white and pure, and air classifiers with wear-resistant alumina liners are a proven solution.

Similarly, Henry Sachura, regional sales manager with Sweco (Florence, Ky.) says his customers are seeking the same type of quality efficiency. “Our CPI customers have been asking for a true cut where there are no fines in the overs and no overs in the fines,” he notes. “So they are looking at adding ultrasonics, air classification or more exotic screen meshes to their screening processes.”

As a result, Sweco now offers Ecutec Alpha air classifiers, which have been developed to consume very little energy during the production of fine products below 40 µm, to be used in conjunction with grinding mills.

The Alpha classifier can be fed either by gravity from the top or in the main airstream from below. For separations below 20 µm, the product is introduced from the bottom for optimum dispersion of the feed. Where coarser separations are required, it is possible to introduce feed from the top of the classifier, and this configuration helps minimize the energy consumption by reducing the pressure drop.

The unit can be supplied with a ceramic classifier wheel, and the body itself can be lined with ceramics or polyurethane for wear protection or to prevent contamination. The rotor and the body can also be constructed in stainless steel.

Waste reduction

With the rise in commodity pricing comes a rise in the cost of waste. For many chemical processors, this means there is now value in creating finer particle sizes without producing a lot of dust or leaving much residue in the machine. Seeing their customers’ desire to make classifications of finer particles, but not wanting excess waste, Hosokawa Micron Powder Systems retuned its Acucut High Energy air classifier. With the updates, the unit uses dual-stage operating controls to ensure sharp cuts and narrow-band,

PARTICLE SIZING EQUIPMENT AND SERVICE PROVIDERS

Company	Website
Allgaier Werke	www.allgaier.de
Atlantic Coast Crushers	www.gocrushers.com
Brookhaven Instruments	www.bic.com
Carrier Vibrating Equipment	www.carriervibrating.com
Eriez Magnetics	www.eriez.com
Franklin Miller	www.franklinmiller.com
Hosokawa Micron Powder Systems	www.hmicronpowder.com
Hosokawa Nano Particle Technology Center	www.hosokawanano.com
IPEC	www.rotormill.com
Kemutec Group	www.kemutec.com
Malvern Instruments Ltd.	www.Malvern.com
Minox/Elcan Industries	www.minox-elcan.com
Modern Process Equipment	www.mpechicago.com
Netzsch	www.netzschusa.com
Prater Sterling	www.prater-sterling.com
Rotex	www.rotex.com
Schutte Buffalo Hammermill	www.hammermill.com
Sturtevant	www.sturtevantinc.com
Sweco	www.sweco.com

particle-size distributions typically below the 10 micron range. Options are available for control of product contamination, protection against corrosion and classifying adhesive powders. An extremely high dispersive energy applied to the process material ensures high yields, even with sticky and difficult to disperse products.

Boosting capacity & throughput

The trend toward getting more material out of the same process also applies to particle-sizing operations. However, in many cases facilities can't make room for equipment with larger capacities and a larger footprint. "In retrofit applications, there's usually limited floor space, so we have to squeeze more into an existing package in order to improve throughput efficiency," says Dan Ferris, applications engineering manager with Rotex Global LLC (Cincinnati, Ohio).

To assist with this need, Rotex offers the APEX dry separation screener. "We've been able to take the existing models and increase the screen area by going taller with a stacked design," explains Ferris. "This allows us to add capacity via stacked screen areas without increasing the footprint."

The APEX is available with screen areas from 9 to 110 ft^2 and offers gyratory reciprocating motion that rapidly distributes, stratifies and separates particles as they move across the screens to the discharge end. In addition to the larger screen area, the machine was designed for simplified maintenance and cleaning with screens weighing less than 7 lb and easy access to outlets for reduced downtime.

And for cellulosic- and grain-ethanol applications that are in need of a capacity boost, the Evolution hammermill, introduced by Prater-Sterling (Bolingbrook, Ill.), can provide a 15 to 25% increase in throughput while giving a substantial amount of horsepower savings.

Besides pulverizing grain, there are models designed to fine grind whole cobs, large wood chips and cellulosic fibers for cellulosic ethanol in one pass. Because of the way the Evolution is designed, raw materials are pre-ground so the screen never sees the whole product, which helps get the product ground and out of the mill faster, using less horsepower. ■

Joy LePree

Circle 25 on p. 66 or go to adlinks.che.com/7378-25

Circle 26 on p. 66 or go to adlinks.che.com/7378-26

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b. Legitimate Paid and/or Requested Distributions		
(1) Outside County Paid/Requested Mail Subscriptions	55,909	55,657
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PS Form 3526-R, September 2007

Automation
Products Group

FOCUS ON

Temperature and Pressure Measurement

Control Company


Fluke

Ashcroft

Calibrate high-quality thermometers with this instrument

The 4180 Series Precision Infrared Calibrators (photo) includes two new models, 4180 and 4181, which according to the manufacturer are easy enough to use in the field and accurate enough to use in the laboratory. The 4180 calibrator has a temperature range of –15°C to 120°C, with radiometric (non-contact infrared) display accuracy of ± 0.40°C; and the 4181 calibrator measures from 35 to 500°C, with radiometric display accuracy of ±0.35°C. The 4180 Series calibrators have features that allow users to address quality issues commonly not covered by other calibrators in the same class, including emissivity and size of source effect. Additional features including target stability, target uniformity, 6-in. target diameter, traceable radiometric calibration, and compensation for the emissivity settings of the radiation thermometer being tested overcome some of the other most common limitations. — *Hart Scientific, a division of Fluke, American Fork, Utah*
www.hartscientific.com

A pressure transducer for hazardous applications is introduced

The PT-400 Amplified Output Pressure Transducers (photo) provide a minimum of 10-million operating cycles with high accuracy of ±0.25% F.S. , in operating temperatures from –40 to 180°F. Additionally, these sensors cover pressures ranging from 0 up to 20,000 psi, along with high-burst pressure to 3X full scale (limited by the process connection) and overpressure to 2X full scale for in-process reliability. The PT-400 is designed for demanding applications in oil drilling, water and wastewater industries as well as for general use in other industries. Weighing in at just 10 oz, the PT-400 transducers offer standard 4–20-mA, 0–5-Vd.c. and 0–10-Vd.c. outputs. Their integrated electronics are fully enclosed inside an all-welded stainless-steel housing. Their rugged construction and performance attributes make them well suited for static and dynamic pressure measurement where an amplified output signal is desired. A number of options, including extended temperature compensation, higher accuracy ratings and alternate process fittings, among others, are available. — *Automation Products Group, Inc. (APG), Logan, Utah*
www.apgsensors.com

Ultra-compact pressure transmitters offer an economical alternative

The new GC51 and GC52 gauge and differential pressure transmitters (photo) offer an economical alternative to network process transmitters when a digital protocol is not required. The innovative design features an ultra-compact NEMA 4X/IP65 enclosure measuring only 2.65-in. dia. Stainless-steel wetted parts accommodate either wet or dry media. The GC51 is available in ranges up to 0–7,500 psig and the GC52 offers D/P ranges up to 400 in. of water. A built-in LED display and a 4–20-mA output provide both local indication and remote signaling. These transmitters are ideal for measuring fluid levels in tanks, water towers and across differential pressure membranes in water purification systems, says the manufacturer. In addition, media isolators can be added for sludge or caustic media installations. — *Ashcroft Inc., Stratford, Conn.*
www.ashcroft.com

This infrared thermometer includes a handy wristband

This company's Traceable Infrared Thermometer (photo) with a handy wristband operates simply: turn on; point at sample; and take a reading in less than a second. The unit reads both in Farenheit and Celsius temperature scales with a temperature range of –67 to 482°F and –55 to 250°C. The instrument can be used on any surface — solids, semi-solids and liquids. Non-invasive, no-touch, measurements
(Continues on p. 57)

Note: For more information, circle the 3-digit number on p. 66, or use the website designation.

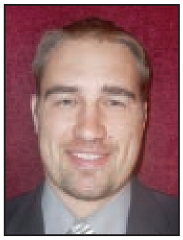
WHO'S WHO

Bollinger

Sonnenberg

Erskine

Perkins



Sawall

ChemLogix (Blue Bell, Pa.) appoints *Francis Ezeuzoh* director of finance and accounting.

Harioff Kottmann is named CEO of **Clariant International Ltd.** (Muttenz, Switzerland).

Clayton Reed joins **Omnitrol Networks** (Mountain View, Calif.) as vice-president of sales.

Steven A. Sonnenberg becomes executive vice-president of **Emerson** (Austin, Tex.) and president of Emerson Process Management, while *John Berra* is named chairman of Emerson Process Management.

Mettler-Toledo Product Inspection (Ithaca, N.Y.) elects *Rick Bollinger* strategic accounts manager — pharmaceutical.

Michael Santangelo is named customer service supervisor by **Midland Manufacturing** (Skokie, Ill.).

Racine Federated Inc. (Racine, Wis.) names *John Erskine Jr.* chairman of the board. He is succeeded as president by *Dave Perkins*.

James Stoppert is elected president and CEO of **Segetis, Inc.** (Minneapolis, Minn.).

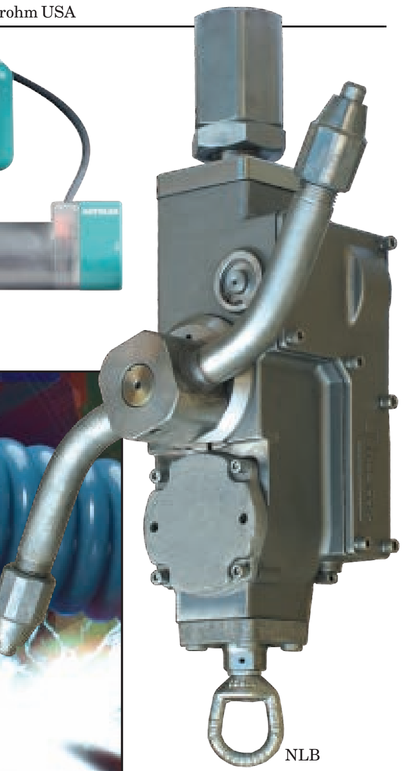
Wika (Lawrenceville, Ga.) appoints *Steve McCullough* CFO.

Richard Sawall becomes vice-president of the **Wisconsin Biodiesel Association** (Milwaukee, Wis.). ■

Kate Torzewski

New Products

Metrohm USA



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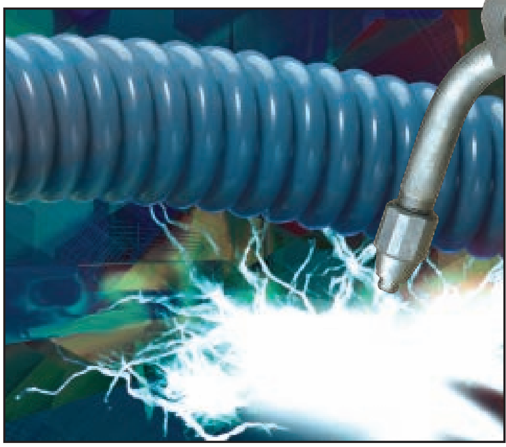


Parker TexLoc

Non-sparking, non-magnetic safety tools for hazardous locations

Manufactured from special aluminum-bronze or copper-beryllium alloys, these non-sparking, non-magnetic hand tools (photo) meet ATEX regulations for safe use in areas where hazardous, flammable or combustible vapors, liquids, dusts or residues may be present. This line of safety tools consists of hammers, flange wedges, striking wrenches, impact sockets, screwdrivers, shovels and other hand tools. They comply with the ATEX Directive stating that no tools that can cause sparks are permissible in Ex Zones 0, 1 and 2 (flammable gas, mists or vapors); Zones 20, 21 and 22 (combustible dusts) and M1 and M2 for mining. Each tool is laser engraved for the proper Ex Zone classifications indicating the zones for which it can be used. — *CS Unitec, Norwalk, Conn.*
www.csunitec.com

Conductive tubing eliminates static discharge and prevents buildup

A full range of conductive fluoroplastic tubing is now offered in a variety of sizes and configurations to eliminate and prevent the build-up of static charges. PTFE Conductive Tubing (photo) is available with a conductive I.D. that conforms to AMS-H-27267 — having a minimum conductance of 10–20 micro-amps with 1,000 V-d.c. applied over a 14-in. length. Designed to eliminate static charges affecting combustible fluid transfer and to prevent the build-up of static charges that might damage sensitive electronic devices, it can be supplied a wide variety of configurations. Available in sizes from 1/8- to 4-in. I.D., Conductive Tubing can be supplied as smoothbore tubing, liners, and in convoluted and wire-wrapped convoluted styles. It provides anti-static properties to eliminate dust and other particulates, and offers increased wear- and UV-resistance. — *Parker TexLoc, Fort Worth, Tex.*
www.parker.com

For electrochemical analysis, use this rotating disk

The Eco Chemie Autolab Rotating Disk Electrode (RDE; photo) is designed for electrochemical analysis. Featuring a sleek motor design and sealed, low-noise contacts, the RDE substantially minimizes the noise interference that is often associated with rotating disk studies. Autolab RDE maintains speeds from 100 to 10,000 rpm, and it can be controlled manually or from a remote analog system. To address a wide range of applications, electrode tips are available with both 3- and 5-mm diameter disks in Pt, Ag, Au and glassy carbon. A 5-mm blank tip is also available for personal material studies. Autolab RDE is backed by expert application and service support through this firm. — *Metrohm USA, Inc., Riverview, Fla.*
www.metrohmusa.com

These tank-cleaning heads improve uptime

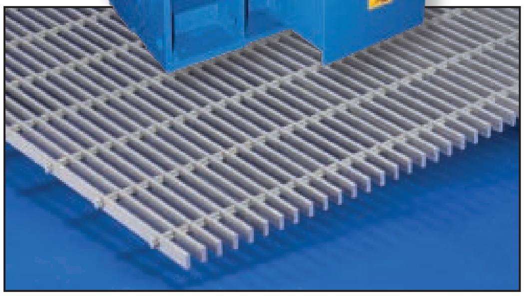
Two new NLB 3750 3D tank cleaning heads (photo) feature a redesigned hub assembly that triples the seal life of previous models and greatly simplifies seal replacement, according to the firm. Both deliver the 3D cleaning action made popular by previous NLB models, with rotating high-pressure water jet nozzles mounted on a revolving head to maximize interior coverage in tanks and reactors. The NLB3750-85 operates at pressures from 4,000 to 13,000 psi with a flow rate of 80 gal/min. The NLB3750-110 operates at from 4,000 to 8,000 psi and 110 gal/min. Both have stainless-steel bodies for durability and ease of cleaning. High-pressure water jets remove chemical and resin build-up from tanks and reactors faster and more thoroughly than manual methods, while eliminating the need for anyone to enter a confined space. — *NLB Corp., Wixom, Mich.*
www.nlbusa.com

Note: For more information, circle the 3-digit number on p. 66, or use the website designation.

New Products

Omega Engineering

WEG Electric Motors



Strongwell

Precision handheld pumps for pressure and vacuum calibration

The HPP series precision calibration pumps (photo) are available in four models. The HPP-100 and HPP-VAC are economical pumps designed for 0 to 6.9 bar (0 to 100 psi) and 0 to –.95 bar (0 to 028 in. Hg) vacuum, respectively. Both models feature dual O-rings on all pistons for smooth operation with zero leakage. The HPP-600 is a pneumatic pump that can generate both vacuum and pressure. It covers a range from –.95 bar (28 in. Hg) vacuum to 41 bar (600 psi) pressure. The HPP-10K hydraulic pump can generate pressure from 0 to 690 bar (0 to 10,000 psi). It is compatible with most hydraulic fluids, oils and water. All pumps are designed to provide long-term reliability in harsh environments, making it ideal for use in automotive, chemical and petroleum industries. — *Omega Engineering, Inc., Stamford, Conn.*

www.omega.com

Fiberglass grating can replace steel in many applications

Duragrid 1-in. R-7300 fiberglass grating is specially designed to replace 1-in. steel grating in corrosive environments, such as offshore drilling and production platforms, refineries and chemical plants. It is extremely strong and impact resistant, able to span 36 in. with a load of 100 lb/ft^2 and a deflection of less than ¼ in. Virtually maintenance-free, it will not rust and corrode like steel grating, thus reducing maintenance costs. With a rectangular-bar design, it is well-suited for applications exposed to wave uplifts, or when all surfaces of the bars need to be kept clean. At half the weight of 1-in. steel grating, Duragrid is easily handled in installation, and cost less to ship than steel grating. Also, a non-skid surface on fiberglass grating is safe for workers, while having low electrical and thermal conductivity. — *Strongwell, Bristol, Va.*

www.strongwell.com

New communication interfaces improve the versatility of flowmeters

This firm has introduced new communication options for its Micro Motion 2400S transmitter. These compact devices, which mount integrally onto Micro Motion Elite Coriolis meters, are now available with DeviceNet or Profibus DP communication protocols in addition to the traditional interfaces such as 4–20 mA, frequency and HART. The new communication options make the Micro Motion 2400S transmitter ideal for OEMs operating in global markets, where different communications standards are often employed. The transmitter provides a simple and fast interface with an existing PLC architecture together with the added benefits of direct digital communications. — *Emerson Process Management, Boulder, Colo.*

www.emerson.com

These two motors designs comply with API requirements

Two new PetroDuty motor designs are being offered by this firm — the 4th edition API-541 and 1st edition API-547.

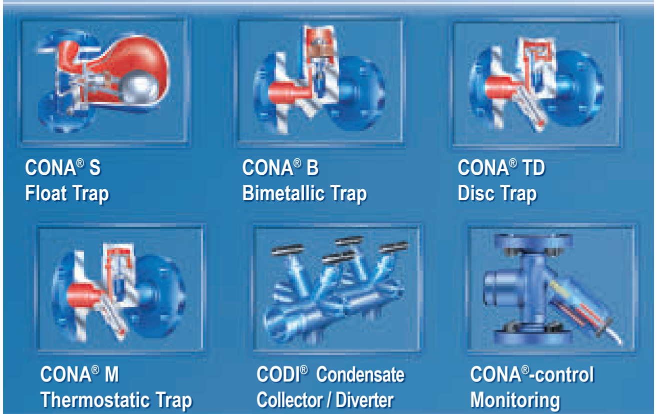
These new motor designs have been specifically developed to satisfy or exceed the strict requirements set forth by the American Petroleum Institute (API). The newest PetroDuty-541 is rated 500 h.p. and above, as set forth by the API, for use in critical applications in the petroleum industry. With a voltage capacity of 2,300–13,200 V, it also offers dual voltage at 2,300 and 4,000 V. The PetroDuty-547 is suitable for use in general purpose petroleum or chemical applications, as well as in other industrial severe-duty environments. Rated for 250–3,000 h.p, it has a voltage capacity of 2,300–3,200 V. Both motor designs operate on 50 and 60 Hz frequencies. — *WEG Electric Motors Corp., Atlanta, Ga.*
www.weg.net/us

Plast-O-Matic Valves

These spigot ends are compatible with all major piping manufacturers
Factory-installed spigot connections are now available for this firm's thermoplastic valve and piping products line. Constructed of ultra-pure, corrosion resistant polypropylene or Kynar PVDF, the Series ZSP True Blue spigot ends (photo) minimize deadleg, and are designed for BCF (bead and crevice-free) and infrared butt-fusion and socket-fusion piping. Spigot sizing is dimensionally compatible with all major piping manufacturers. An optional Class 100 cleanroom and double-bagging procedure is available for ultra-pure applications. — *Plast-O-Matic Valves, Inc., Cedar Grove, N.J.*
www.plastomatic.com

Boker's,

This firm now offers 22,800 washer sizes in a variety of materials
This manufacturer of washers has added 800 sizes to their product offering. With this addition, non-standard washers and spacers are now available (photo) without tooling charge in more than 22,800 sizes, and offered in a choice of more than 2,000 commonly specified and hard-to-find materials, including low carbon sheet steel, five types of spring steel, stainless steel, aluminum, brass, copper and nickel silver, as well as non-metallics such as Delrin, Teflon, Mylar and nylon. This



New Products


Lyon Workplace Products

broad variety of sizes encompasses miniature washers as small as 0.080-in. O.D., to large washers with O.D.s up to 5.140-in. Customers can simply select a size and specify a material and quantity at this firm's website. — *Boker's, Inc., Minneapolis, Minn.*
www.bokers.com

This workstation keeps computers safe on the plant floor

A new computer workstation (photo) is designed for shop floor use in manufacturing plants, maintenance facilities and warehouses — anywhere computer security and protection against dust, dirt and other airborne contaminants are important. The new workstation easily handles a 21-in. monitor, keyboard, CPU, printer and supplies. Features include: an ergonomic, sliding keyboard shelf; keyed alike built-in locks secure to the doors; a Lexan upper-door insert for easy screen viewing; a power surge suppressor strip; and vibration resistant 5-in. Performa rubber casters. The overall cabinet is 30-in. width by 28 ¼-in. depth by 59 ¼-in. height. The workstation is available with forklift base (ships assembled) or mobile base (casters not installed). — *Lyon Workplace Products, Aurora, Ill.*
www.lyonworkplace.com

This anti-surge compressor controller has an built-in HMI

This firm has introduced its first stand-alone compressor anti-surge controller with a built-in color HMI (human machine interface) display. The Em-400 HMI displays a live compressor surge map for easy viewing of compressor performance. In addition to the live compressor map, the Em-400 HMI also provides all of the information and control capability found in more expensive HMI systems. This compact display, which is built into the front panel of the Em 400 controller, does not require any additional panel space. Other features of the Em-400 include control of up to three compressor bodies, capacity control, performance monitoring, load sharing, recycle transfer control, user-directed pressure override control and standard ethernet communications. — *Petrotech, Inc., New Orleans, La.*
www.petrotechinc.com ■

Kate Torzewski

NOVEMBER

New Products


WIKA Alexander Wiegand


K-Tron

Loos Deutschland


Malvern Instruments

An inline seal with a clamp connection

In addition to both threaded-pipe and flanged connections, sterile, standard-compliant connections for instruments are now also possible in the form of a clamp connection (DIN 11 864-3). The standard material for wetted parts is 1.4435 stainless steel, and special materials, such as 1.4539 stainless steel or Hastelloy, are also available. The 981.51 diaphragm seal (photo) is especially suitable for applications in the pharmaceutical and food industries, as well as for painting lines. The patented inline seal is notable for its cylindrical construction, enabling it to be mounted directly into pipelines and making it self-draining. — *WIKA Alexander Wiegand GmbH & Co. KG, Klingenberg, Germany*
www.wika.de

Characterize foreign particulate matter on filters, automatically

New capabilities have been added to the Morphologi G3 automated particle-characterization system, enabling the fully automated detection, enumeration and size classification of foreign particulate matter (FPM) collected on a filter (photo). In the pharmaceutical industry, this is especially important in controlling particulate contamination of materials for injection or inhalation. Analysis of FPM on filters has traditionally been performed by manual light microscopy; now, the Morphologi G3 brings fully automated image analysis to accelerate characterization and remove operator subjectivity. — *Malvern Instruments Ltd., Malvern, U.K.*
www.malvern.com

Three new receivers for dense-phase and vacuum conveying

The P-Series vacuum sequencing receivers have been redesigned to the same finish standards as this firm's line of weigh feeders. As part of the redesign, the modularity of the P-Series receivers was improved through the introduction of extension modules to increase receiving volume. The new sealing and grounding designs make cleaning and disassembly more operator friendly. Premium Pneumatics offers dense-phase vacuum conveying for short distances, in addition to dilute-phase vacuum conveying capabilities. The vacuum receivers feature sanitary design and meet the 3-A sanitary standard for pneumatic conveyors. Three models include: the P10, conveying up to 600 kg/h; the P30 (photo), conveying up to 1,800 kg/h; and the P100, for up to 4,000 kg/h. — *K-Tron (Switzerland) Ltd., Niederlenz, Switzerland*
www.ktron.com

Save fuel and water with this boiler condensate module

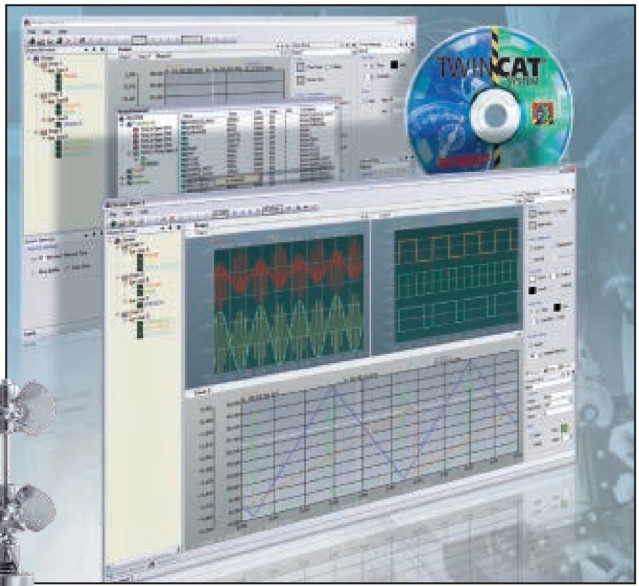
The planning, production and installation of high-pressure condensate systems used to be very complicated, but this firm has developed a compact module. The CSM-CC high-pressure condensate service module (photo) should be considered for a high-pressure condensate level of 50% and higher. The module is individually dimensioned for each order, and consists of a heat-insulated pressurized tank with sensors wired on a terminal strip, actuators, fittings, pump modules and a control cabinet. The condensate tank base contains a heating nozzle pipe in which the condensate temperature and pressure are maintained. Depend-

Note: For more information, circle the 3-digit number on p. 66, or use the website designation.

New Products


UWT


Pfeiffer Vacuum

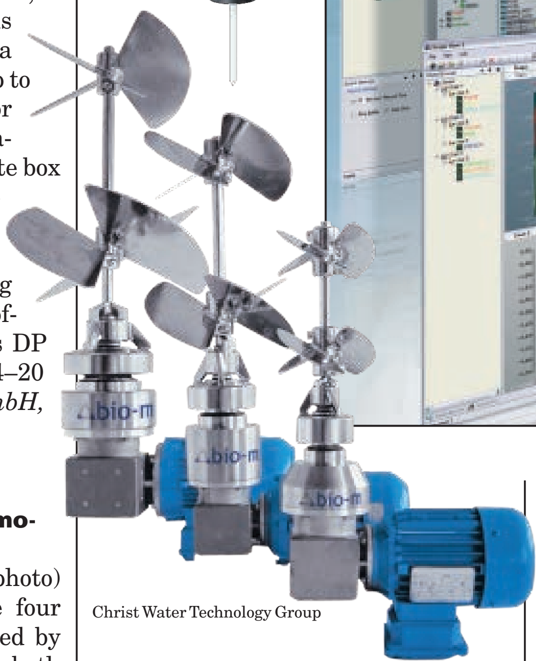

Beckhoff Automation

ing on fuel costs, condensate parameters and operating times of the boiler systems, the system can pay for itself in as little as a year, says the manufacturer. — *Loos Deutschland GmbH, Gunzenhausen, Germany*
www.loos.de

This level-measurement device gets a redesign
The completely redesigned plumb bob electrochemical level-measurement system, Nivobob (photo), offers the following enhancements: increased durability, via a brushless motor; a new rope system, which extends the time between services; and a larger measurement distance (up to 40 m with the tape version). For smaller plants without visualization systems, an additional remote box is available that allows up to 15 instruments to be remotely controlled. Measurement data can easily bne integrated into existing control systems, as the Nivobob offers both ModBus and Profubus DP communication, alongside the 4–20 mA output signal. — *UWT GmbH, Betzigau, Germany*
www.uwt.de

Four new sizes of this turbomolecular pump
The line of HiPace turbopumps (photo) has been broadened to include four new sizes. They are characterized by their high pumping speeds for both light (H_2, He) and heavy (Ar, CH_4) gases, achieving high throughputs for even heavy gases. In addition to photovoltaics and semiconductor technology, the pumps range of applications includes coating architectural glass and eyeglass lenses, as well as industrial applications such as furnace engineering. Protection Class IP 54 and SEMI S2 assure their suitability for industrial applications. — *Pfeiffer Vacuum GmbH, Asslar, Germany*
www.pfeiffer-vacuum.net

Avoid contamination with these magnetic mixers
The magnetic agitators of the BMR Series (photo) meet all requirements that exist today for GMP-compliant production. The open design of the magnetic impeller permits cleaning in place (CIP), as demonstrated by independent studies carried out by the Swiss University in Wädenswil, in accordance with the three methods European Hygienic Engineering and Design Group, total organic carbon (TOC), and riboflavin. The generous dimensions and material combination (silicon carbide on zirconium oxide) of the ceramic sleeve bearing offer the longest operating lifetime, says the manugfacturer. Thanks to hydrodynamic properties of the agitator blade and the patented “lift-off” lubrication channels, wear and the release of unwanted particles are almost negligible. — *Zeta Holding, a member of the Christ Water Technology Group, Tobelbad, Austria*
www.zeta.com


Christ Water Technology Group

A new tool for scientific automation
A graphic display of curves is essential for optimizing controllers and setting drive axes. The new TwinCAT Scope (photo) features a separate Logger and Viewer, and has been redesigned for scientific automation. The Logger, which can be installed in a Windows CE control system, records the data from different channels with time stamps and saves them intermediately. The data can come from different PCs and software devices, including PLC and Motion Control. The viewer fetches data from the Logger and displays it. — *Beckhoff Automation GmbH, Verl, Germany*
www.beckhoff.com

Pick the WFI system that meets your needs
The Polaris range of water-for-injection (WFI) products is designed in accordance with GAMP, cGMP, ISPE and FDA guidelines to meet the product quality specifications of USP, Ph Eur and other international pharma-

New Products

Veolia Water Solutions and Technologies

copoeia standards. Polaris MED multiple effect stills use a falling film technology to produce up to 10,000 L/h (with 3 bars industrial steam) of WFI from a purified warter feed, with options for simultaneous or alternate clean steam and WFI production. For higher flowrates, or where purified water is not available as a feed, Polaris VCD vapor compression stills are capable of producing up to 25,000 L/h of WFI from a softened mains water feed. They can ber heated by steam or an electric immersion heater, and an electrically powered vapor compressor provides the additional energy necessary to produce distilled water at a temperature between 25 and 90°C. Polaris CSG (photo) produces 5,000 kg/h of clean steam from a purified water feed, and incorporates a stripping device using clean steam to remove incondensable gases to improve product quality. — *Veolia Water Solutions and Technologies, Saint Maurice, France*
www.veoliawaterst.com

Lee Products

A manifold for precise injection of small amounts of fluid

This injection manifold mount system (photo) enables the precise injection of a fluid into a flow stream. Any ported VHS (very-high-speed) micro-dispense solenoid valve can be mounted so that the outlet port is in close proximity to the flow stream. This ensures the dual benefit of minimal captive capillary volume and increased injected volume repeatability. The new mount system is suitable for laboratory, biomedical and chemistry applications, and especially for flow-injection analyzers. Key features include a captive capillary volume of 0.5 µL and pressures up to 120 psi. — *Lee Products Ltd., Gerrards Cross, U.K.*
www.leeproducts.co.uk

GEA Tuchenhagen

Up to six valves can be mounted on this distribution ring

The valve ring distribution system on Vesta sterile valves (photo) allow complex processing using different operating, cleaning and sterilization media. Compared with conventional systems with single valves or complex and expensive valve blocks, the single-seat valves in the Vesta Multiport distribution system are located pocket-free in a ring with an appropriate annular passage section. A maximum of six isolation valves can be located in both the inlet and return circuits, and it is possible to have different valve sizes in one ring. The Multiport also allows different flow directions for the inlet and return pipework, with fixed grid spacings. — *GEA Tuchenhagen GmbH, Büchen, Germany*
www.tuchenhagen.com

Frewitt

This sieve mill keeps getting better

The ConiWitt sieve mill (photo) offers a number of improvements over its predecessors. For example, the milling distance can be precisely adjusted to less than I mm, even without the sieve support ring that was required in the past. The sieve surface is 25% larger, and therefore the flowrate is higher than conventional models. With Triclamp connection, the milling head can be easily and quickly detached from the shaft, which makes the ConiWitt suitable for lighter-duty laboratory work. — *Frewitt S.A., Granges-Paccot, Switzerland*
www.frewitt.com

Lots of wireless devices are now ready for action

Last month, this firm began shipping open interoperable *Wireless*HART standard products from its Smart Wireless range of pressure, flow, level, temperature, pH and discrete transmitters and gateways; AMS Suite predictive maintenance and Wireless Snap-On software; 375 Field Communicator, and with native wireless


POMPETRAVAINI DESIGN:
PRECISELY TAILORED
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interface DeltaV and Ovation digital systems. The continuous stream of future new products will also use the standard, introducing the soon-to-be-released valve position transmitter, the Smart Wireless THUM Adapter that will unleash standard diagnostics in legacy devices. — *Emerson Process Management, Baar, Switzerland*
www.emersonprocess.com

A new class for this belt scale

Intercont Opus is designed for legal-for-trade belt scales that have been used for evaluating electronics in Germany and other countries for many years. Compared to its predecessor, the Intercont Opus offers state-of-the art technology, based on the ARM9-based processor platform. Approval for the new product includes previous 1 and 2 accuracy classes, but also the most demanding class 0.5 in accordance with EC Directive 2004/22/EC, which means that it is recognized by all EU Member States. Intercont Opus is available as a panel-mounting unit or as a stainless-steel device for onsite installation. Modbus, Profibus DPV0, DeviceNet or Ethernet are available for connection to the automation system. — *Schenck Process GmbH, Darmstadt, Germany*
www.schenckprocess.com

Transmit temperature readings wirelessly with this device

JUMO

The Wtrans series now contains a new transmitter with M12 connection for adaption to existing Pt 1000 resistance thermometers (photo). Additional receiver designs are also available, which have two analog inputs instead of four, and also have two relays for a variety of monitoring tasks. The transmitters are located in a probe handle and are protected by a watertight housing. The radio frequencies used are largely insensitive to external influences, permitting transfer even in tough industrial environments. The probe is available with an installation length of 50

Circle 43 on p. 66 or go to adlinks.che.com/7378-43


Kaeser Kompressoren

GoatThroat Pumps

to 1,000 mm. The transmitter covers the temperature range of –30 to 260°C (with a fixed protective tube), or –100 to 500°C (with M12 connector and remote probe). — *JUMO GmbH & Co. KG, Fulda, Germany*
www.jumo.net

Save energy and time with these new rotary blowers
Unveiled at Powtech 2008, the DB 166 C and DB 236 C (photo) are this firm's latest generation of rotary blowers. System operators not only benefit from the significant energy and operational savings that these blowers offer, but are also able to take advantage of considerable savings for installation, planning, commissioning and certification, says the manufacturer. Covering air deliveries from 10 to 25 m^3/min for pressures up to 1,000 mbarg (500 mbar vacuum), the new DB blowers also provide "exceptional" reliability and availability. As with all other Compact Series blowers, these new models are fitted with an energy saving EU-eff1 rated drive motor as standard, and feature Omega Profile rotors with a specially designed block casing to ensure low energy consumption. Integration of the Omega Control Basic with the firm's advanced controller enables the units to precisely match blower performance to meet demand. — *Kaeser Kompressoren GmbH, Coburg, Germany*
www.kaeser.com

These filtration membranes outperform their predecessors
Tetratex Extreme ePTFE membrane filter elements display a significantly higher permeability compared to previous Tetratex membranes, and deliver increased dust-collector airflow characteristics and excellent particle-capture rates, says the manufacturer. The complex structure of the membrane ensures particulate emissions can be maintained at near-zero levels for the operational life of the media. The new membranes are used for in-

Michell Instruments

dustrial filtration applications, and are designed to maximize filtration efficiency, airflow and operational durability. — *Donaldson Filtration Components Ltd., Newton-Le-Willows, U.K.*
www.donaldson.com

Standard milling machines and classifiers get downsized
Introduced last month at Powtech 2008 (Nuremberg, Germany; September 30–October 2), the Picojet opposed jet mill is one of the manufacturer's minimachines that have been downscaled from the well-known standard machine range that will gradually be added to the Picoline series. The Picojet fluidized-bed opposed mill, with integrated classifier, features a 20-mm classifying wheel that runs at speeds up to 60,000 rpm, simultaneously maintaining the rinsing gap geometry with tolerances of just a few micrometers. Reinstalling the classifying wheel after cleaning can be carried out so precisely with no need for elaborate adjustment that all operation critical tolerances are reproducible. The classifier from the Picojet can be used as an independent module on the Picozirk classifier mill, or can be used on its own as the Picosplit classifier. For dry powder processing, the range is completed by the Picolex fine impact mill and the Piconizer spiral jet mill. — *Hosokawa Alpine AG, Augsburg, Germany*
www.alpine.hosokawa.com

New software version enables faster, more complex modeling
Ansys POLYFLOW 3.12 is the latest version of software for the analysis of plastic and rubber processing, glass forming and food processing. The new Version is faster, more efficient and can handle larger problems than previous releases, since it includes several new solvers and modeling features tailored for specific applications, says the firm. Newly built in is the ability to provide data to structural analysis software from the company, which improves the accuracy of virtual prototyping predictions. — *Ansys, Inc., Southpointe, Pa.*
www.ansys.com

This long-lasting pumps deliver most liquids from drums
Made from high-performance polypropylene, these liquid-transfer pumps (photo, p. 32I-7) will safely deliver most solvents, acids, caustics and oils from 5–55-gal drums at a rate of 4 gal/min, depending on the viscosity. Typically, owners will need to change O-rings once or twice during the pump's 8–10-year lifetime. The pumps are offered with Viton, Santoprene, EPDM or Nitrile sealing, depending on the fluid. — *Goat-Throat Pumps, Milford, Conn.*
www.goatthroat.com

Keep turbines ice-free with this hygrometer
Protection against icing is vital to prolonging the life and efficiency of gas turbines. Applying the cooled-mirror measurement principle, the Optidew hygrometer (photo) delivers a repeatable, drift-free dew point or relative humidity measurement. The robust design of the Optidew for anti-icing systems is capable of withstanding the moist demanding conditions. When compared with traditional polymer RH probe, the Optidew Anti-icing version offers far better accuracy and stability, says the firm. The unit has a dynamic measuring range from –50 to 90°C dew point over a temperature range of –10 to 90°C, and provides two 4–20-mA output signals. — *Michell Instruments, Ely, Cambridgeshire, U.K.*
www.michell.com ■

Gerald Ondrey

Cover Story

Process Modeling Moves Center-Stage

A model solution for the CPI: reducing risk while increasing profit

Mark Matzopoulos
Process Systems Enterprise Ltd.

Process modeling has progressed from the "molecule accounting" of steady-state flowsheeting packages to become a central platform for capturing and deploying chemical process industries' (CPI) intellectual property (IP). Systematic modeling has moved center stage to help companies differentiate themselves from their competitors while also providing a set of tools with which it is possible to adapt rapidly to changing market conditions.

The traditional approach

Until recently, process modeling usually meant "process simulation", and simulation typically meant either performing flowsheeting studies using a commercial program, running an in-house Fortran model of a reactor, or performing a computational fluid dynamics (CFD) analysis of the fluid flows inside a stirred tank.

Each of these activities still has a valid place in the panoply of techniques deployed within the CPI to generate information for design and operational decisions. Indeed, each has unique advantages: process flowsheeting tools are easy to use and generate heat and material balances and basic equipment-design information quickly; in-house programmed models embody valuable corporate knowledge collected over many years; CFD tools can model individual units to a very high level of mechanical detail for detailed equipment design.

However, besides the fact that each of the approaches outlined above is usually pursued largely independently with little overlap between either the software or the groups of people doing the work, each has its own limitations. Flowsheeting is effectively a "molecule accounting" exercise that uses standard off-the-shelf (and "black-box") models that are not able to reflect the complexity of many common processes, particularly in industries other than the traditional oil-and-gas and petroleum-refining base. In-house programmed models are often inflexible and difficult to maintain, and have the added disadvantage that the knowledge of the code and the assumptions inherent in the model typically reside in one or two individuals; they also tend to be limited to single units and cannot deal with the surrounding flowsheet. CFD models generate high accuracy information on fluid flow and mixing, but are not ideally suited to handling complex chemical phenomena such as crystallization and polymerization occurring within the fluids — information that is of critical importance to the process designer or reaction engineer.

In addition, none of these traditional approaches deals effectively with process dynamics, meaning that it is not possible to design for transient conditions. This is the chemical engineering equivalent of architects being restricted to designing in two dimensions, and it limits or eliminates application in the whole area of batch processing.

Notwithstanding the drawbacks of the traditional approaches, in recent years modeling as a whole has

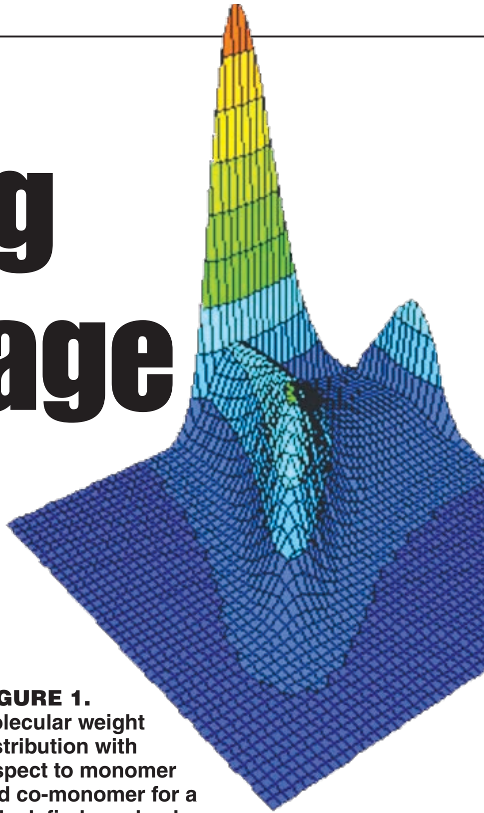

FIGURE 1. Molecular weight distribution with respect to monomer and co-monomer for a polyolefin-based polymer: The model was used for recipe design for production of a new grade of polymer

taken on a much-more-elevated and central role within the CPI, from the mainstream chemical manufacturers in Japan and Korea to catalytic technologies providers such as Süd-Chemie, fuel cell companies such as UTC Power and Toyota and food manufacturers such as Friesland Foods.

What has brought about this change? Well, for a start, modeling tools and methodologies have matured significantly. Concerted research, investment in software implementation and successful application to large-scale systems have gone a long way to overcome the limitations described above. The net effect is that it is now possible to model complex chemical processes to a high degree of predictive accuracy, to the point where models provide reliable quantification for support of many key design and operating decisions and — crucially — for management of the IP and the risk associated with innovation.

Secondly, new methodologies have been devised, refined and proven. Current tools allow the incorporation of experimental data — laboratory, pilot and plant — into models in order to ensure that they reflect observed reality. If performed correctly, this can provide models with a predictive capability that is virtually scale invariant.

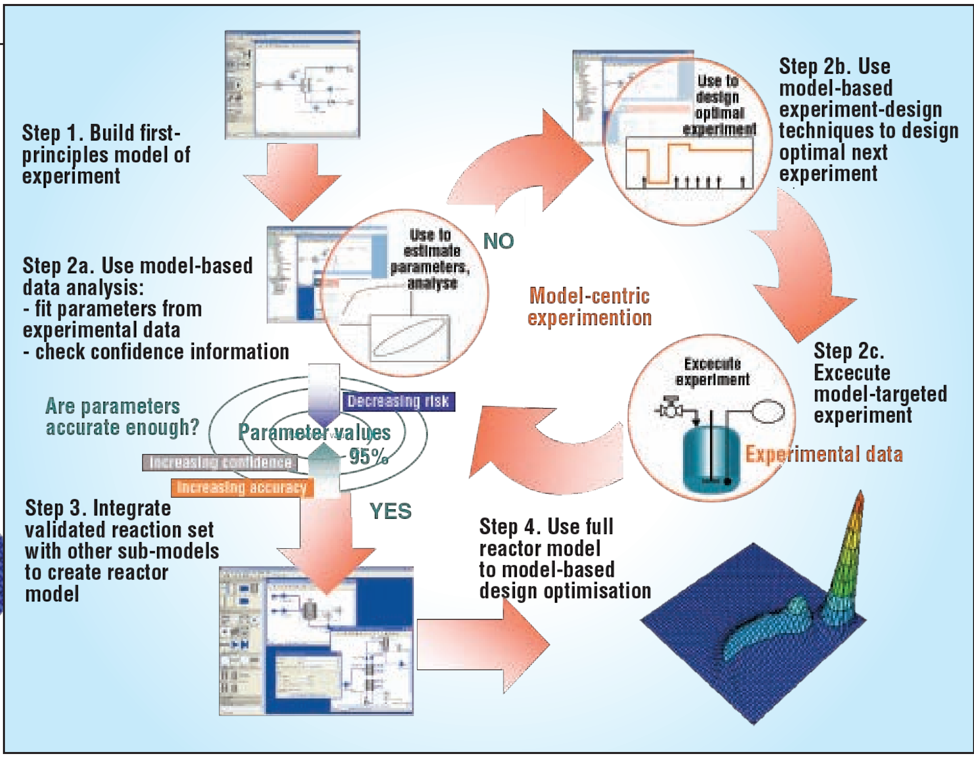

FIGURE 2. **Shown here are the key steps in constructing a validated first-principles model with a good predictive capability over a range of scales**

Similarly, the ability to couple CFD hydrodynamic models with models of chemical phenomena, now well established, means that complex mixing effects and chemical reactions can be considered simultaneously. The combination of these factors means that activities such as crystallizer scaleup or the design of multitubular reactors, once black arts, are now routine applications of modeling.

Models can now provide accurate quantification in support of most areas of design or operation within a single framework — from highly detailed models of individual equipment to plant-wide flowsheets; from startup to shutdown as well as the steady-state operation in between; across the "process lifecycle" from experimentation by research chemists to day-to-day operation by plant operators, and across all sectors of the CPI.

Modeling has, in fact, reached the stage where models have enough predictive accuracy to replace physical testing in many cases. Model-based innovation technologies apply high-accuracy models to rapidly explore the design space for new reactors, fuel cell design or new catalyst formulations, with only the most promising candidates going to physical testing.

Perhaps as important as the technological advances is a change in perception by management. "Modeling-aware" managers increasingly realize the potential of modeling to capture IP, and use this not only to accelerate innovation and develop unique commercial advantages, but to drive down development costs and make their organizations more efficient. Equally important, there is an increasing body of qualified people schooled in process systems engineering, many who used state-of-the-art modeling tools for their Ph.D. research, and there is an increasing body of "off-the-shelf" models discussed in literature and available commercially.

All of this means that the companies deploying such techniques are gaining a rapid innovation advantage over their slower peers. This will be particularly true in the future for IP-based organizations, such as process technology companies and process licensors.

Capturing IP

So how does a company go about capturing its IP in a model?

The model. First it is worth defining what a process model is. Whether written in Fortran or a modern modeling language, a model is essentially a collection of physics, chemistry, engineering and operating knowledge in equation form, coupled in some way with empirically determined data. When executed for a given set of inputs (for example feed flowrates and conditions and fixed unit parameters), it will calculate outputs (for example, product flowrates and other values). It should by definition have a predictive capability so that, given a new set of feed or reactor operating conditions, it calculates accurate revised rates for the product streams. At its best, a model is capable of predicting actual behavior with accuracy over a wide range of conditions, making it possible to explore the design or operational space comprehensively and be confident in the results.

Past practice has combined models — the relationships describing a process — with their mathematical solutions, often with data thrown into the mix in the form of hard-coded values or empirical functions with limited ranges of applicability. The resulting models — often black-box models, where users were unable to modify or even see the underlying relationships — were limited in scope, inflexible, difficult to maintain and often lacked robustness. The coarse assumptions in the generic models gave them limited predictive capability.

Modern "equation-based" techniques separate the engineering aspects from the mathematical solution using fourth-generation languages or graphical representations. They also separate model and data. This means that a complex unit can be now described in tens of lines of physical and chemical relationships rather than thousands of lines of code, with significant implications for development time, quality assurance, ease of understanding and maintenance, and of course, lifecycle cost. This fact alone has removed a significant hurdle from the development and application of models.

Modeling across the corporation and process lifecycle. Perhaps the main advantage is that equation-based systems provide the ability to customize models to include valuable corporate knowledge and reflect exact process configurations. This significantly improves their ability to be used for innovation and generation of competitive advantages.

Modern modeling environments provide this capability in the most natural and accessible way. In equation-based, "open model" systems the model is essentially an executable document — in effect, a blueprint for the process — that captures the fundamental structures of the physics and chemistry without requiring the authors to concern themselves with the details of the mathematical solution.

Once such a blueprint is available, it becomes a place where different groups within the organization can deposit their corporate knowledge in a way that can readily be utilized by other groups. For example, reaction specialists can work with R&D chemists to create a reaction set, which is then used by reaction systems engineers to design a reactor, which is deployed within a flowsheet by chemical engineers, and so on. Once seen as a management dream, this type of workflow is becoming more commonplace in companies adopting a systematic modeling approach.

Combining first principles models and data. Models are typically a combination of the theoretical and the empirical. Current best practice is to fix everything that can reliably be known from theory. There is no point in attempting to infer a mass balance by analyzing data when the equation can simply be written down. This drives models toward "first-principles," which are usually the chemical engineer's definition of first principles — multicomponent diffusion, reaction kinetics, and so on — rather than a more rigorous definition involving molecular or quantum physics.

When all the "known knowns" (to paraphrase Donald Rumsfeld) are listed — typically heat- and material-balance relationships, reaction kinetics, hydraulic relationships, geometry, and so on — it is time to address the "known unknowns". These are typically the parameters — well known to engineers and chemists — within these equations: heat transfer coefficients and reaction kinetic constants, for example. Generic values for these can often be found in the literature or in corporate knowledge for the process, which sometimes is sufficient. However as can be seen below, there is often significant advantage to be gained in determining more accurate or appropriate values from real data — experimental, pilot or operating data.

This approach brings the best of both worlds, combining as it does well known theory with actual observed values. But how does it work in practice?

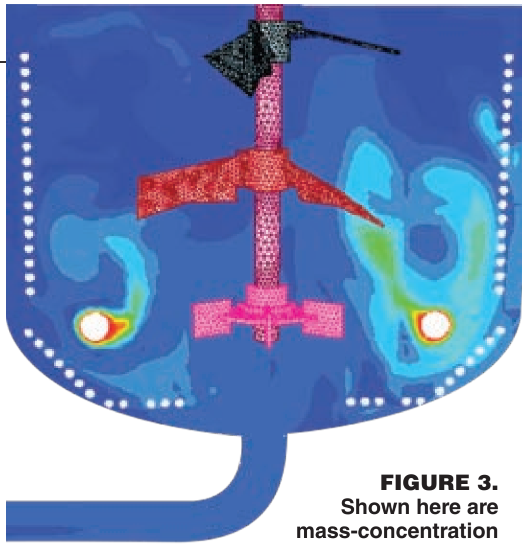

FIGURE 3. Shown here are mass-concentration contours for propylene oxide in a semi-batch polyol reactor

A 'how to' summary

The key steps in constructing a validated first-principles model with a good predictive capability over a range of scales are as follows:

Step 1. Construct the first-principles model. This is probably perceived as the most daunting step by people not familiar with the art. However, it need not be as onerous as it sounds. If starting from scratch, many of the relationships you would implement have been known for generations: conservation of mass, conservation of momentum, conservation of energy and pressure-flow relationships are standard tools of the trade for chemical engineers. Thermophysical properties are widely available in the form of physical properties packages, either commercially or in-house. The challenge lies mostly in selecting the appropriate level of fidelity for your requirements and availability of data.

However, most people don't start from scratch. There is an increasing body of first-principles models of many types of processes available from university research, in equation form in the literature, or as commercially supplied libraries. In fact, as models increasingly become constructed from faithful representations of fundamental phenomena, such as multicomponent mass transfer and reaction kinetics, they become more universally applicable to diverse processes.

Step 2. Estimate the model parameters from data. Having constructed the first principles model of a unit or a process, it will often — and almost always when dealing with reaction, for example — be necessary to estimate some parameters from data. This can be simpler or more challenging than it sounds, depending on the quality of data available. Usually initial values are taken from literature or corporate information sources. Then, in order to ensure a high degree of predictive ability across the design or operational space these values are adjusted by applying mathematical optimization-based, parameter-estimation (PE) techniques to the experimental (laboratory or pilot plant) or operating data using the information contained in the model. Thus the model parameters are "tuned" to reflect the observed behavior as closely as possible.

If performed correctly, with data gathered under suitably defined and controlled conditions, parameter estimation can generate scale-invariant sets of parameters, which has enormous implications for predictive modeling. It means that, for instance, the reaction kinetic parameters determined from an experimental apparatus at a scale of cubic centimeters can accurately predict performance in a reactor several orders of magnitude larger.

Modern parameter-estimation techniques are capable of estimating multiple parameters in complex models involving tens or hundreds of thousands of nonlinear equations using data from dozens of experiments. In addition, the ability to use dynamic as well as steady-state experiments means that it is now possible to design experiments that generate far greater information content than previously possible.

Step 3. Analyze the experimental data. Parameter estimation has an important additional benefit: model-based data analysis. The estimation process produces quantitative mea-

UTC Power Corporation

FIGURE 4. UTC Power systematically applies modeling to reduce the cost of physical testing during fuel cell development

sures of the degree of confidence associated with each estimated parameter value, as well as estimates of the error behavior of the measurement instruments.

Often this analysis exposes inadequacies in the data — for example certain reaction-kinetic constants in which there is a poor degree of confidence, or which are closely correlated with other parameters. It is usually easy to identify the parameters of most concern and devise additional experiments that will significantly enhance the accuracy of, and confidence in, subsequent designs.

Step 4. Design additional experiments, if necessary. Frequently this is done in an intuitive way, for example, by designing an experiment that maximizes production of an impurity rather than the main product, in order to better characterize the kinetics of the side reaction. For more complex situations, model-based techniques for the design of experiments — a major recent development — make it possible to design experiments that maximize the information generated, thereby minimizing the uncertainty, for the target parameters.

Optimal experiment design is achieved by determining the optimal values for key aspects of experimental procedure, such as the temperature profile to be followed over the duration of the experiment, the initial charges and temperature, and the times at which measurements (for example, samples for analysis) should be taken. In addition to maximizing parameter accuracy, the approach typically results in significantly reduced experimentation time and cost.

Step 5. Repeat Steps 2 to 4 until parameter values are within acceptable accuracy. Determining acceptable accuracy in this context means evaluating the effects of possible values of parameters on key design criteria (for example, the conversion of a key component in a reactor), as part of a formal or informal risk assessment. This can be done using the model itself.

It is the combination of the first-principles model and suitably refined data that provides the uniquely predictive capability of such so-called advanced process models over a wide range of conditions.

Once suitable model accuracy has been achieved, the model can be used to optimize many different aspects of design and operation. It is possible to determine optimal size and configuration of reactors; to minimize process energy costs; to optimize recipes and operating policy in order to reduce batch times and maximize product quality; to scale up crystallizers with confidence that they will actually produce crystals of the right size and shape; to determine the likely temperature gradients in a fuel cell on load change; to rank catalyst alternatives and select the optimal catalyst type; to determine catalyst loading regimes; to determine optimal operating conditions for given plant constraints; to determine optimal operating policies for changes in feedstock or other upsets or events; to troubleshoot poor operation; to generate linearized models for model-predictive control within the automation framework; and so on.

The benefits to this approach

The procedures outlined above are all readily achievable and are being applied in many different areas of the CPI.

For companies designing new processes or catalyst formulations, for example, models of sufficient accuracy reduce the need for physical (for example, pilot plant) testing by restricting this to the one or two examples identified by a comprehensive preliminary exploration of the design space.

What this means in broad terms for the process corporation is that it is now possible to do the following:

- Design process, equipment and operations to an unprecedented level of accuracy, and apply formal optimization techniques to determine key parameters rather than rely on trial-and-error simulation. This alone can bring about percentage improvements in "already optimized" processes, translating to significant profits for products in competitive markets
- Represent very complex processes — for example, crystallization and polymerization, or the complex physics, chemistry and electrochemistry of fuel cells — in a way that was simply not possible in the past. This facilitates and accelerates the design of new processes, enables reliable scaleup, and provides a quantitative basis for managing the risk inherent in any innovation.
- Integrate R&D experimentation and engineering, as well as use models as a medium of transfer for the activities of various departments within those divisions.

The ability to create models that can be used in a number of contexts within the organization means that it is possible to recover any investment in developing models many times over. For example, models are increasingly embedded in customized interfaces and supplied to end users such as operations or purchasing personnel, who benefit from the use of the model's power in providing advice for complex decisions without having to know anything about modeling.

What is in the pipeline?

There are still well-known cases where different tools perform different jobs better. For example, fluid dynamics is better handled by CFD packages than by the advanced process-modeling approach described above, which is better for dealing with complex chemical phenomena. Increasingly it is possible to combine the two approaches to get the best of both worlds. For example, it is now possible to reduce the modeling of a full-3D fuel-cell stack from a CFD model that would involve many millions of calculations to a hybrid model that contains only a few hundred thousand. Similar considerations apply to multitubular reactors, which may contain as many as 20,000 catalyst-filled tubes — all with different temperature profiles — within a liquid-filled shell. The computation is still challenging, but results can be achieved in hours rather than days or weeks and without any significant compromise on accuracy.

More exciting developments are on the way. Advances in the related fields of global sensitivity analysis (GSA) and global optimization will have significant implications for process design in the future. Global sensitivity analysis can be used to map the uncertainty — in the form of probability distributions — in various process parameters onto the probability distribution for various plant key-performance indicators (KPIs). Thus, the uncertainty in a particular reaction-kinetic constant can be translated into the likelihood of making a product that represents less-than-optimal profit — or indeed zero profit. The resulting analysis can be used to direct research dollars into the study of the parameters that have the greatest effect on, say, profitability, raising the possibility of quantitatively justified R&D spending.

Similarly, global optimization coupled with robust numerical-solution techniques will make it possible to search much-wider design spaces than are currently possible. New developments in modeling of thermophysical properties such as the SAFT (statistical associating fluid theory) equation of state — an advanced thermodynamics platform that is revolutionizing physical property calculation for complex or "difficult" materials such as associating fluids, polymers and electrolytes — make it possible to predict accurate, pure component and mixture properties from a minimum of data. In the near future it will be possible to model, for example, the power station CO_2 post-combustion clean-up and include the design of the solvent as an optimization variable.

Jack be nimble, Jack be quick

This may well be the motto of the CPI in the future (or indeed at present) as supply and demand positions change daily, with significant financial consequences.

Innovation by its nature always involves a degree of risk arising from uncertainties and gaps in available knowledge. To make rational — and in many cases rapid — decisions on complex matters requires accurate quantification of the options available.

The availability of powerful general-purpose models means that this is now possible. The companies that adopt such techniques wisely will benefit in competitive advantage in the future. ■

Edited by Gerald Ondrey

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CHEMICAL ENGINEERING
FACTS AT YOUR FINGERTIPS
Department Editor: Kate Torzewski

Biodiesel Production

Biodiesel can be produced from vegetable oils by three types of reactions: base catalyzed transesterification of the oil; direct acid-catalyzed transesterification of the oil; and conversion of the oil to its fatty acids, and then to biodiesel.

Biodiesel is typically produced by a base-catalyzed reaction (Figure 2). This method of production has several advantages, including the following: low temperature (150°F) and pressure (20 psi) reaction that requires only standard materials of construction; direct conversion to biodiesel with no intermediate compounds; and high conversion (98%) with minimal side reactions and a low reaction time.

In the chemical reaction for base-catalyzed biodiesel production, vegetable oil is reacted with a short chain alcohol (signified by ROH) in the presence of a catalyst to produce glycerin and biodiesel. The fatty acid chains associated with the oil, which are mostly palmitic, stearic, oleic, and linoleic acids for naturally occurring oils, are represented by R', R'' and R''' (Figure 1).

PRODUCTION STEPS

Mixing of alcohol and catalyst. The catalyst is typically sodium hydroxide (caustic soda) or potassium hydroxide (potash). It is dissolved in the alcohol using a standard agitator or mixer. Methanol or ethanol is commonly used as the alcohol.

Reaction. The mixture of alcohol and catalyst is charged into a closed reaction vessel, and the oil is added. The reaction mix is kept just above the boiling point of the alcohol, 160°F, to speed up the reaction, although it is sometimes recommend to run the reaction at room temperature. The reaction time can vary from 1–8 h. Excess alcohol is used to ensure total conversion of the oil to its esters.

The amount of water and free fatty acids in the incoming oil must be monitored, because if either level is too high, it can inhibit soap formation and the separation of glycerin downstream.

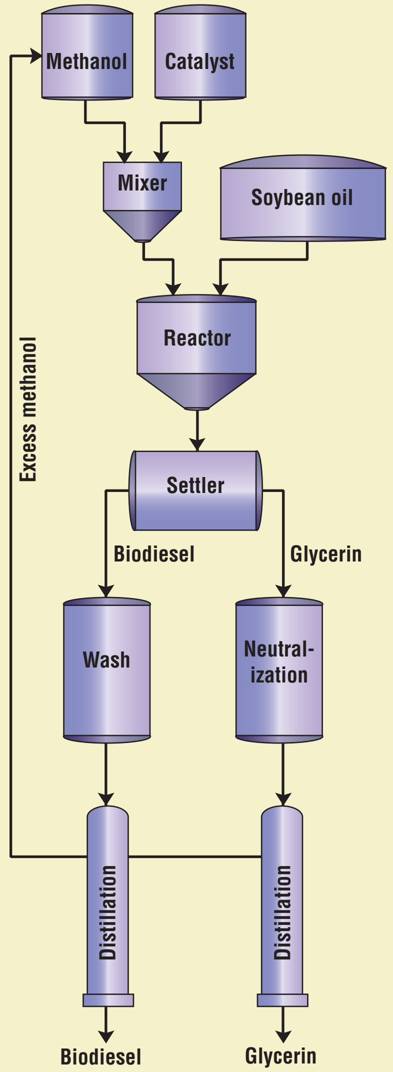
Separation. Glycerin and biodiesel are the two main products of reaction, with each containing an amount of unreacted alcohol. Since the glycerin phase is much more dense than biodiesel phase, the two phases can be separated by gravity in a settling vessel, with glycerin simply drawn off the bottom of the settling vessel. Alternatively, a centrifuge can be used to separate the two materials more quickly.

Glycerin neutralization. The separated glycerin contains unused catalyst and soaps, which are neutralized with an acid. Water and alcohol are removed to produce glycerin at 80–88% purity to sell as crude glycerin. Alternatively, glycerin can distilled to 99% purity or higher for selling to the cosmetic and pharmaceutical industries.

Methyl ester wash. After the biodiesel is separated from glycerin, residual catalyst or soaps can be removed with a gentle warm water wash.

Alcohol removal. Unreacted alcohol in both the glycerin and biodiesel phases is removed by flash evaporation or distillation. The recovered alcohol is then reused for mixing with the catalyst. Alcohol removal can occur after the wash and neutralization, as shown in Figure 2 to the right, but it can occur before these steps as well.

Product quality and registration. Prior to use as a commercial fuel in the U.S., the finished biodiesel must be analyzed to ensure it meets ASTM specifications. Additionally, all biodiesel produced must be registered with the U.S. Environmental Protection Agency (Washington, D.C) under 40 CFR Part 79.



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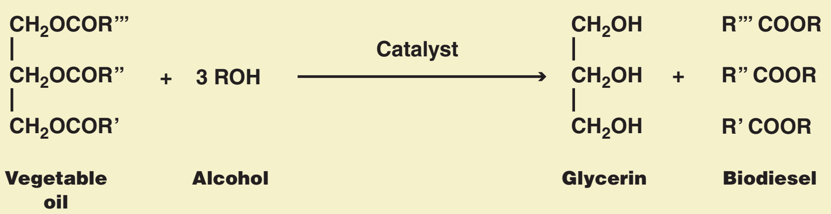

Pressure-Relief System Design

Unexpected high-pressure situations can be relieved with a proper relief-system design

Siddhartha Mukherjee
Lurgi India Company Ltd.

Pressure relief systems are vital in the chemical process industries (CPI) for handling a wide variety of situations. They are used to prevent pressurization above a system's design pressure; for venting during an unusual or emergency situation; and for normal depressurization during a shutdown, as examples. In some cases, such as when noncombustible gases including steam, air and nitrogen are used, venting into the atmosphere may be an option. In other cases, such as those typically encountered in the hydrocarbon sector, elaborate systems for the disposal of vented gases may be required.

This article describes some of the causes of overpressurization, the types of valves and rupture disks that are available and some of the components needed for a pressure relief system. Example calculations are given, as well as a list of installation considerations.

Causes of overpressurization

An overpressurization may result from a single cause or a combination of events. Typically, not all causes will occur simultaneously. In case of an external fire in vessels that predominantly handle vapors, such as knockout drums, there may be a rapid temperature rise in the metal accompanied with a rise in pressure due to expansion. In case of external fire in vessels that contain liquids, there will be a rise in pressure as the liquid vaporizes. Pressure may also rise abruptly due to thermal expansion when a blocked-in pipeline or other equipment containing a liquid is heated. Relieving pressure under these situations is essential to prevent failure. It is also required in systems where a continuous flow of vapor or liquid is suddenly stopped by a downstream blockage.

While a full description of the various causes of overpressurization is beyond the scope of this article, details are provided by API [*1*]. The following is a partial list:

- Blocked outlet
- Failure of control valve
- Cooling water failure
- Power failure
- Instrument air failure
- Heat-exchanger-tube failure
- External fire

Safety relief valves

There are several types of safety relief valves available on the market, including the following.

Conventional: Conventional pressure-relief valves are susceptible to back pressure. Such valves are not recommended when the total back pressure exceeds 10% of the set pressure. For systems operating at pressures close to atmospheric or at low pressures, the limit of 10% is rarely achieved. Therefore, these valves find application mainly in high-pressure systems, or in systems that relieve to the atmosphere (for example, steam and air).

Balanced bellows: Balanced pressure-relief valves are used when conventional pressure-relief valves cannot be used because of the reasons mentioned above. Such valves are not susceptible to back pressures as high as 50% of set pressure. The valve opening is independent of the back pressure. At higher back pressures, these valves will still relieve at the set point, but with a reduction in capacity. Therefore, it is recommended that if balanced pressure-relief valves are to perform as rated, the back pressure should be limited to about 50% of the set pressure.

Pilot operated: In such valves, the main pressure-relief valve opens through a pilot valve. Pilot operated valves are used in the following circumstances: 1) The pressure-relief-valve set pressure is lower than 110% of the operating pressure and 2) when high back pressures are applicable. The opening of the valve is independent of back pressure.

Rupture disks

A rupture disk is a pressure relieving device that is used for the same purpose as a relief valve, but a disk is a non-reclosing device — or in other words, once it is open it will not close. This means that whatever is in the system will continue to vent until stopped by some form of intervention. The following are the applications of rupture disks [*3*]:

For quick action: Rupture disks are very fast acting. Therefore, they are used in cases where relief valves may not be fast enough to prevent a catastrophic failure. Some engineers prefer to use rupture disks to prevent heat-exchanger-tube ruptures because they are concerned that pressure relief valves would be too slow to prevent pressure build-up scenarios.

To prevent plugging of relief valves: In certain processes, the process fluid contains solid particles that may cause blockage within a relief valve, rendering it useless. In such cases, a rupture disk is normally used upstream of the relief valve. Purified terephthallic acid plants (PTA) is a typical application example.

Handling highly viscous liquids: In systems handling highly viscous liquids, such as polymers, depressurization through a relief valve may be too slow for a given situation. A rup-

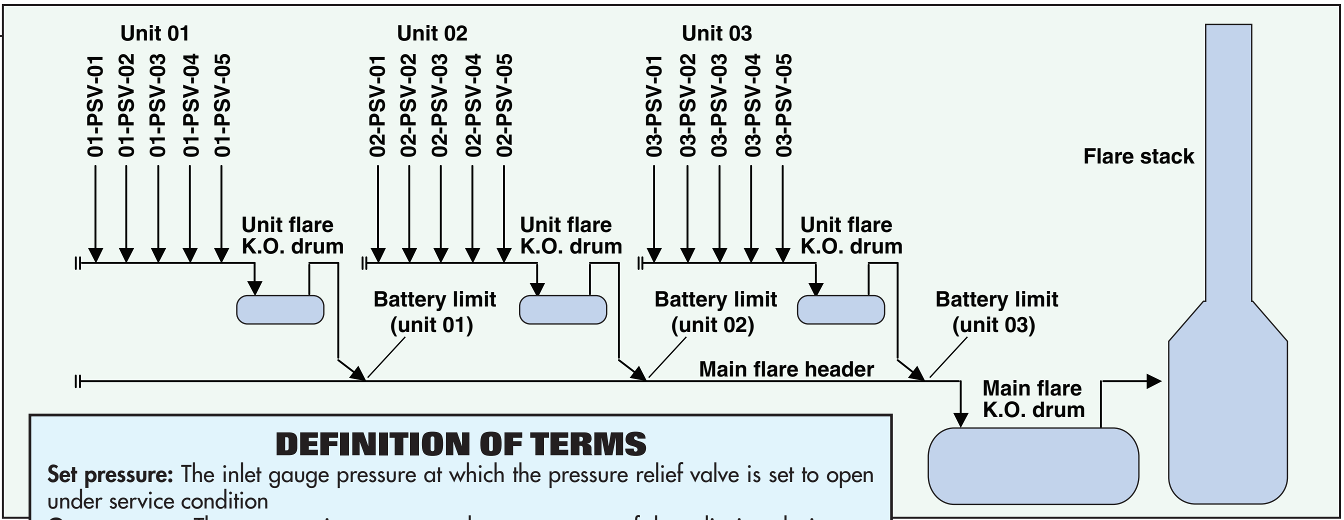

FIGURE 1. A network of flare headers may be used in a complex process

DEFINITION OF TERMS

Set pressure: The inlet gauge pressure at which the pressure relief valve is set to open under service condition
Overpressure: The pressure increase over the set pressure of the relieving device expressed as a percentage
Relieving pressure: The sum of the valve set pressure and the overpressure
Superimposed back pressure: The static pressure that exists at the outlet of a pressure relief device at the time the device is required to operate. It is the result of the pressure in the discharge system coming from other sources and may be constant or variable
Built-up back pressure: The increase in pressure in the discharge header that develops as a result of flow after the pressure relief device opens
Back pressure: The pressure that develops at the outlet of a pressure relief device after the pressure relief device opens. It is the sum of the superimposed and the built-up back pressures

Abbreviations

P_1	Pressure at pipe inlet, kg/cm^{2}a	M_w	Gas molecular weight, kg/kmol
P_2	Pressure at pipe outlet, kg/cm^{2}a	f	Moody's friction factor
W	Gas flowrate, kg/h	k	Ratio of specific heats, C_p/C_v
Z	Gas compressibility factor	a	Absolute pressure, as in kg/cm^{2}a
T	Gas temperature, K	g	Gauge pressure, as in kg/cm^{2}g

ture disk is the preferred choice.

Loss prevention: In systems handling low-molecular-weight hydrocarbons, there is always a chance that some material will pass through the pressure relief valve into the flare system — leading to material loss. In such cases, a rupture disk is normally used upstream of the relief valve.

For economic reasons: Many process industries use exotic materials, such as titanium and Hastelloy C. In these cases, rather than having a pressure relief valve made of Hastelloy C, it may be cheaper to have a rupture disk made of Hastelloy C followed by a stainless-steel pressure-relief valve.

PRESSURE RELIEF SYSTEMS

Open and closed systems

In cases where non-hazardous fluids are used, such as steam, water and air, a typical pressure-relief system consists of several pressure relief valves that discharge through short tail pipes to the atmosphere. These systems are termed *open disposal systems*.

When hazardous fluids, such as hydrocarbons are in use, the tail pipes are connected to a common flare header, which is ultimately routed to a flare stack where the hydrocarbons are burned. In many cases, the fluid relieved is toxic or flammable. In such cases, it is mandatory to discharge the gases through a *closed disposal system* such as the flare. The flare system converts the flammable vapors to less objectionable compounds by combustion.

Components of closed systems

Pressure-relief valve-outlet piping: The flare system starts with outlet pipes from the various pressure relief valves of a unit. These valves are piped together to a common unit-flare header, which is routed to the unit-flare knockout (K.O.) drum.

Unit flare header: Discharge pipes from the pressure relief valves in individual units are connected to the respective unit-flare headers. These headers are either connected directly to the main flare header, or are routed to the flare K.O. drums, which in turn are connected to the main flare header (Figure 1) with a recommended minimum slope of 1:500. All unit flare headers are continuously purged from the upstream end towards the respective K.O. drums to avoid ingress of air into the system. Fuel gas, or inert gases, such as nitrogen are typically used as purge gas.

Unit-flare knockout drum: In cases where the discharge from a unit is expected to contain appreciable quantities of liquids, especially corrosive, fouling and congealing liquids, a unit-flare K.O. drum of a suitable size is mandatory. Another reason for requiring such a drum may be that it is not feasible to have all headers continuously slope toward the main-flare K.O. drum. In this case, the unit flare headers are sloped toward the unit-flare K.O. drums. The vapors from these drums are then routed to the main flare header [2].

Unit-flare K.O. drums are sized to separate particles in the range of 300–600 microns, and hold liquid discharge for 5–10 min from a single source. The liquid collected in these drums should preferably be drained by gravity to the blowdown drum. If a congealing type of liquid is likely to be discharged, the drums should be heat traced or provided with steam coils [2].

Main flare header: The main flare header receives discharge through individual unit-flare headers, or through unit-flare K.O. drums. The flare header should not have pockets and should be free draining toward the nearest K.O. drum, typically with a slope of 1:500.

Although flare headers are normally sized based on pressure drop,

TABLE 1. RELIEF LOAD SUMMARY		
	Relief load, kg/h	
Relief Valve Tag No.	Cooling water failure	External fire
PSV-01	12,870	13,453
PSV-02		6,750
PSV-03	10,536	9,872
PSV-04	14,076	8,970
PSV-05		5,783
PSV-06	12,960	11,423
PSV-07	15,052	6,432
PSV-08		5,764
PSV-09	16,732	8,976
PSV-10		7,432
PSV-11	13,422	5,133
PSV-12		9,984
Total load	95,648	

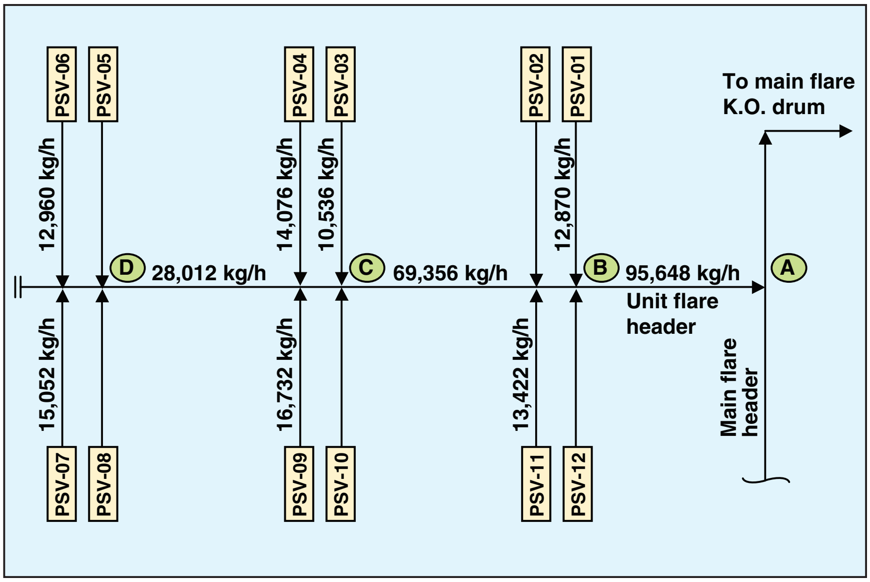

FIGURE 2. This sketch of a typical flare system is used as the basis for the sample calculations explained in the given example

velocity cannot be ignored. A Mach number in the range of 0.2–0.5 is recommended. The third criterion that should be checked is the change in density of flare gases along the length of the flare header. In many cases where flare discharges are at high temperatures, the flare gases cool down due to the length of the flare header. This leads to an increase in density and, correspondingly, a decrease in flowrates. Therefore, while estimating pressure drops in such flare lines, it is a good idea to divide the header into sections and estimate pressure drops separately.

Main-flare knockout drum: In addition to the unit-flare K.O. drum, a main-flare K.O. drum close to the flare stack should be provided. This takes care of condensation in the header that results from atmospheric cooling. Similar to the unit-flare K.O. drums, these drums are also sized to separate out liquid droplets of 300–600 microns in size, and for holdup of 20–30 min [*1*] of liquid release. Pumps are installed with the K.O. drum to transport any collected liquid to a safe location. The pumping capacity should allow the liquid holdup to be emptied in 15–20 min. When congealing liquids are in use, the drums should be provided with steam coils [*2*].

Seal drum: Seal drums are located close to the flare stack or are sometimes integral with the flare stack. These drums protect against flame flashback from the flare tip. The seal drum should have a diameter of at least two times the flare pipe diameter [*1*].

Flare stack: Flare stacks are usually elevated structures designed to burn flammable vapors.

Relief system piping

Inlet piping: The inlet piping from the protected equipment to the pressure relief valve should be sized to prevent excessive pressure loss that can cause chattering with consequent reduction in flow and damage to seating surfaces. The recommended practice is to limit the total pressure drop in the inlet piping to 3% of the safety-valve set pressure [*1*]. The piping is designed to drain towards the protected vessel.

Discharge piping: In case of overpressurization in a vessel, the relevant pressure-relief valve will start to open at the set pressure. At this moment, the downstream pressure at the valve is the superimposed back pressure of the system. The valve keeps opening as the pressure builds up. The resultant flow creates a built-up back pressure on the discharge pipe. As long as the built-up back pressure is less than the overpressure after the valve opens, the valve will remain open and perform satisfactorily. If however, the built-up back pressure develops at a rate greater than the overpressure, it will tend to close the valve. Therefore, proper sizing of discharge pipes is very important in such systems.

Discharge piping and manifolds are sized for the contingency that produces the largest relief load. Pipe sizing is carried out by working backward from the battery limit of the unit flare header up to the outlet of individual, pressure safety valves. The superimposed back pressure of the flare header at the battery limit is defined. Thereafter, based on the relief loads, pressure drop calculations are carried out to arrive at the back pressure of the individual, pressure relief valves. In the course of the calculations, two parameters are checked for compliance:

- The Mach number at each pipe section should not exceed 0.5
- The back pressure at each safety valve should not exceed 30–50% of the set pressure

The isothermal flow equation based on the outlet Mach number is given by API [*1*]. This method calculates pressure buildup backward up to the outlet of relief valves, thus avoiding the need for trial and error methods:

$$\frac{fL}{D} = \frac{1}{(M_2)^2} \times \left(\frac{P_1}{P_2}\right)^2 \times \left[1 - \left(\frac{P_2}{P_1}\right)^2\right] - \ln\left(\frac{P_1}{P_2}\right)^2 \quad \textbf{(1a)}$$

or,

TABLE 2. FLARE DISCHARGE PIPING CALCULATIONS

Segment	Set pressure	Line size	Line size	Flowrate	Pressure P_2	Density	Roughness factor	Pipe length	No. of tees	No. of valves	No. of elbows	Pressure P_1	Pressure P_1	% of set pressure	Mach no.
	kg/cm²g	m	in.	kg/h	kg/cm²a	kg/m³	mm	m				kg/cm²a	kg/cm²g		
A to B		0.30	12	95,648	1.5000	4.2899	0.1	15	0	1	0	1.6234	0.5904		0.4004
B to PSV-01	5.0	0.10	4	12,870	1.6234	4.6428	0.1	30	0	1	3	2.7780	1.745	34.9	0.4480
B to PSV-11	5.0	0.15	6	13,422	1.6234	4.6428	0.1	30	0	1	3	1.8282	0.7952	15.9	0.2077
B to C		0.25	10	69,356	1.6234	4.6428	0.1	15	0	0	0	1.7528	0.7198		0.3863
C to PSV-03	5.0	0.15	6	10,536	1.7528	5.0129	0.1	30	0	1	3	1.8712	0.8382	16.8	0.1510
C to PSV-04	5.0	0.15	6	14,076	1.7528	5.0129	0.1	30	0	1	3	1.9616	0.9286	18.6	0.2017
C to PSV-09	5.0	0.15	6	16,732	1.7528	5.0129	0.1	30	0	1	3	2.0449	1.0119	20.2	0.2398
C to D		0.20	8	28,012	1.7528	5.0129	0.1	15	0	0	0	1.8111	0.7781		0.2258
D to PSV-06	5.0	0.15	6	12,960	1.8111	5.1796	0.1	30	0	1	3	1.9832	0.9502	19.0	0.1797
D to PSV-07	5.0	0.15	6	15,052	1.8111	5.1796	0.1	30	0	1	3	2.0417	1.0087	20.2	0.2088

$$\frac{fL}{D} = \frac{1}{(M_2)^2} \times \left[\left(\frac{P_1}{P_2}\right)^2 - 1\right] - \ln\left(\frac{P_1}{P_2}\right)^2 \qquad \textbf{(1b)}$$

The Mach number at the outlet of each pipe section is given as follows [*1*]:

$$M_2 = 3.293 \times 10^{-7} \times \left(\frac{W}{P_2 D^2}\right)\left(\frac{ZT}{kM_W}\right)^{0.5} \qquad \textbf{(2)}$$

In the next section, a solved example illustrates the procedure.

EXAMPLE

An extractive distillation plant has twelve safety valves. There are two major relief scenarios: cooling water failure and external fire. Table 1 summarizes the relief rates under these two conditions. The governing case is the cooling water failure because it occurs plant wide. External fire occurs only at localized areas and the relief loads come from only a couple of safety valves. Hence, we will consider the cooling water failure case here. For simplicity, we will assume that set pressures of all safety valves are 5.0 kg/cm² g.

The flare network is divided into segments as shown in Figure 2. Segment 1 is a section of the flare header between the battery limit A and point B. Likewise, segment 2 is a section of the flare header between points B and C. Let us assume a superimposed back pressure at point A of 1.5 kg/cm² a.

Piping between points A and B

Data

Flowrate: 95,648 kg/h (Table 1)
Pressure at point A, P_2: 1.5 kg/cm²a
Molecular weight of vapor, M_w: 86
Temperature of vapor: 100°C
Straight length of pipe : 15 m
Number of elbows: 0
Number of valves: 1
Number of tees: 0
Compressibility factor: 0.95
Ratio of specific heats, C_p/C_v: 1.4
Viscosity: 0.000009 kg/m s

Roughness factor, ε: 0.0001m (0.1 mm)
Pipe diameter, D (assumed): 0.30 m (12 in.)

Calculations

Density of vapor: PM_w/ZRT = 4.2899 kg/m³
Volumetric flowrate: 95,648/(4.2899 x 3,600) = 6.193 m³/s
Velocity in pipe: 6.193 x 4/(π x (0.30)²) = 87.61 m/s
Reynolds number, N_{Re}: 0.30 x 87.61 x 4.2899/0.000009 = 12,528,371
Outlet Mach Number, M_2: 3.293 x 10⁻⁷ (95,648/(1.5 x 0.30²)) x (0.95 x 373/1.4 x 86)^0.5 = 0.4003

Fanning's friction factor (to be solved by iteration):
$1/\sqrt{f} = -4\log[\varepsilon/(3.7D) + 1.256/(N_{Re}\sqrt{f})]$ = 0.0038
Moody's friction factor: 4 x 0.0038 = 0.0152

Equivalent length: 17.8 m
fL/D: 0.0152 x 17.8/0.3
Using Equation (1b), P_1/P_2 is calculated to be: 1.08226
P_1: 1.08226 x 1.5 = 1.6234 kg/cm²a
Hence, the pressure at point B is 1.6234 kg/cm²a

Piping between point B and PSV-01, 1st trial

Data

Set pressure of PSV-01: 5.0 kg/cm²g
Flowrate: 12,870 kg/h (Table 1)
Pressure at point B, P_2: 1.6234 kg/cm²a
Molecular weight of vapor M_w: 86
Temperature of vapor: 100°C
Straight length of pipe: 30 m
Number of elbows: 3
Number of valves: 1
Number of tees: 0
Compressibility factor: 0.95
Ratio of specific heats, C_p/C_v: 1.4
Viscosity: 0.000009 kg/m s

Roughness factor, ε: 0.0001m (0.1 mm)
Pipe diameter, D (assumed): 0.08 m (3 in.)

Calculations

(*detailed steps not repeated*)

Density of vapor:	4.6428 kg/m^3
Volumetric flowrate:	0.7700 m/s
Velocity in pipe:	153.186 m/s
Reynolds number, N_{Re}:	6,321,901
Outlet Mach number:	0.6998
Fanning's friction factor:	0.0052
Moody's friction factor:	0.0208
Equivalent length:	40.65 m
P_1/P_2:	2.67214
P_1:	4.3380 kg/cm^{2}a

Hence, the back pressure at PSV-01 is 4.3380 kg/cm^{2}a, or 3.3050 kg/cm^{2}g.

The ratio of the back pressure to the set pressure for PSV-01 works out to 66.10% which is more than that recommend for balanced bellow-type valves. In addition, the Mach number is 0.6998, which is greater than the recommended limit of 0.5. Therefore, we need to increase the line size in the stretch between B and PSV-01. Let us now select a line size of 4 in. for the second trial.

Piping between point B and PSV-01, 2nd trial

Data

Set pressure of PSV-01:	5.0 kg/cm^{2}g
Flowrate:	12,870 kg/h
Pressure at point B, P_2:	1.6234 kg/cm^{2}a
Molecular weight of vapor, M_w:	86
Temperature of vapor:	100°C
Straight length of pipe:	30 m
Number of elbows:	3
Number of valves:	1
Number of tees:	0
Compressibility factor:	0.95
Ratio of specific heats, C_p/C_v:	1.4
Viscosity:	0.000009 kg/m s
Roughness factor, ε:	0.0001m (0.1 mm)
Pipe diameter, D (assumed):	0.10 m (4 in.)

Calculations

(*detailed steps not repeated*)

Density of vapor:	4.6428 kg/m^3
Volumetric flowrate:	0.7700 m/s
Velocity in pipe:	98.03 m/s
Reynolds number, N_{Re}:	5,057,041
Outlet Mach Number:	0.4480
Fanning's friction factor:	0.0049
Moody's friction factor:	0.0196
Equivalent length:	43.31 m
P_1/P_2:	1.71121
P_1:	2.7780 kg/cm^{2}a

Hence, the back pressure at PSV-01 is 2.7780 kg/cm^{2}a, or 1.745 kg/cm^{2}g.

The ratio of the back pressure to the set pressure for PSV-01 is 34.90%, which is acceptable. The Mach number is 0.4480, which is also within acceptable limits.

A summary of parameters and calculation results is given in Table 2.

INSTALLATION FEATURES

Correct installation of relief valves and the associated relief system is very important for their proper operation during upsets to ensure the safety of personnel and the plant. Some useful guidelines follow:

- Pressure relief valves should be connected to the vapor space of the protected equipment
- The inlet line should be self draining back to the process vessel. This is to prevent accumulation of liquid that can corrode or block the system. Likewise, the outlet line from the pressure relief valve should be self-draining to the flare header. To meet this requirement, it is recommended that relief valves are installed at a high point in the system (Figure 3)
- For reliable overpressure protection it is best to install pressure relief valves without any isolation valves. However, pressure relief valves sometimes do not reseat properly and start to leak. Therefore, in many cases, two safety valves are installed to allow replacement of relief valves that are leaking while the plant is in operation. This also facilitates testing and servicing of relief valves regularly without interrupting plant operations
- Whenever two pressure relief valves are installed as mentioned above, isolation valves are provided for each relief valve (Figure 4). This is to facilitate isolation of the "A" valve for maintenance while taking valve "B" online when required. In such cases, a ¾-in. bleeder valve with an isolation valve is recommended in between the isolation valve and the pressure relief valve. This is needed because when the "A" valve has been isolated, the section between the isolation valve and the pressure relief valve is still at the operating pressure of the column. The bleeder is used to depressurize this section before the valve is removed from the line, otherwise it could be an unsafe condition for maintenance personnel [*4*]

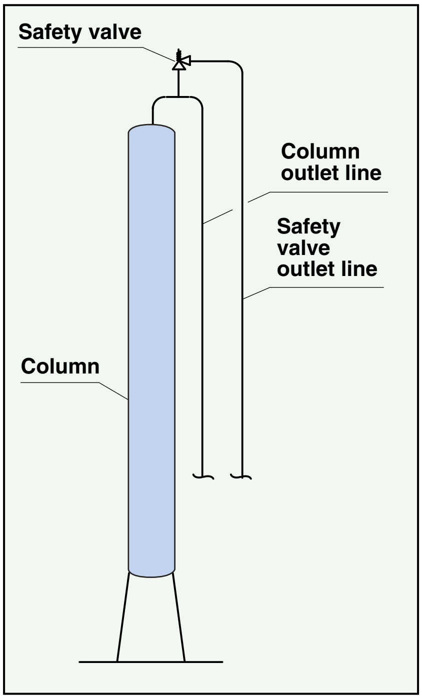

FIGURE 3. **In order to make relief valves self-draining to the flare header, it is recommended that they be installed at a high point in the system**

- Whenever two pressure relief valves are provided, it is mandatory that a mechanical interlock system is installed between the respective isolation valves to ensure that one of the isolation valves is open at all times. This is to eliminate operator error, which might mistakenly create a situation where both the isolation valves are in the closed position, leading to unavailability of either of the relief valves for any particular equipment
- Pressure relief valves in steam, water or air service are connected to the atmosphere through a short vertical pipe. To keep this pipe free from liquid accumulation, a small weep hole is drilled at the lowest point of this pipe
- Whenever a rupture disk is installed upstream of a pressure relief valve, it is important to have a pressure indicator in the section between the

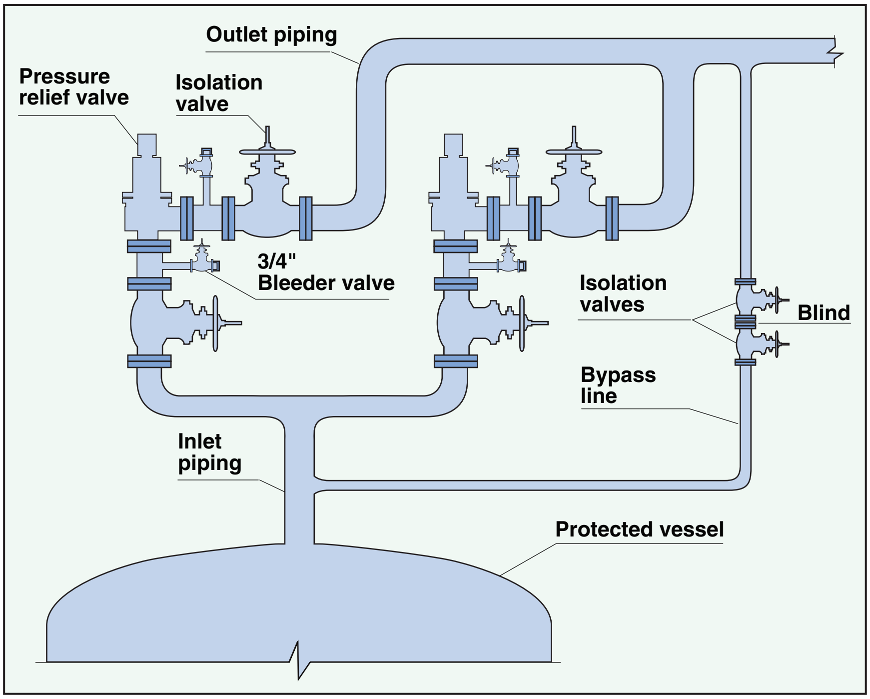

FIGURE 4. When two pressure relief valves are used, isolation and bleeder valves are needed to prevent an unsafe condition

two (Figure 5). The reason for this is that in case of a pin-hole leak in the disk, vapors from the protected equipment would pass through to the section between the disk and the safety valve. After some time, the pressures upstream and downstream of the disk would be the same and the disk would never burst

- The unit and the main flare header should slope towards the main, flare-header K.O. drum. This is to ensure that condensed vapors, if any, do not back up and accumulate immediately downstream of the safety valves ■

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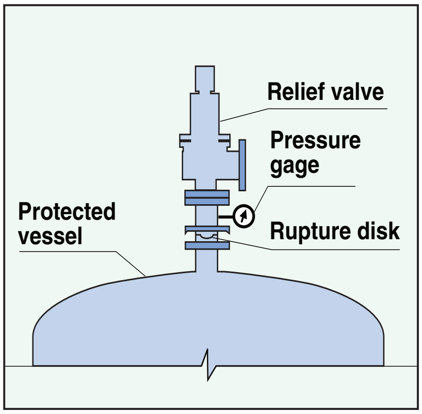

FIGURE 5. When a rupture disk is installed upstream of a pressure relief valve, a pressure indicator is needed between the two

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Condition-Based Maintenance Management Enhances Reliability

Understand reliability, condition monitoring and maintenance management to keep rotating equipment in top form

Sourav Kumar Chatterjee
Hindustan Petroleum Corp.

Management is a process of managing risk; maintenance management is a process of managing risk for operational reliability. Since it is hard to manage what cannot be measured, effective maintenance management demands good data on machine health — a comprehensive condition monitoring program, carried out by skilled and determined personnel, using appropriate tools and technology.

Condition-based maintenance management (CBMM) is a value-adding process based on logical analysis of measured data taken from operating equipment. In today's process plants, maintenance management has become a core function supporting the business needs of the organization. We have moved far beyond the old-fashioned and demoralizing notion that maintenance is simply a cost center. The tasks of modern CBMM include the following:

- align maintenance goals with the organization's business goals
- identify key performance indicators and their target values
- manage and upgrade skills
- use modern tools and techniques to perform maintenance function in a reliable way
- optimize costs
- improve overall equipment effectiveness
- eliminate hazards
- periodically review and benchmark performance

An evolving discipline

The concept of reliability refers to failure-free operation for a defined period of time. There are two basic ways to achieve this. The first is "failure proofing" through high quality in design and manufacture. The second is based on condition monitoring (CM), avoiding breakdowns by allowing maintenance to be carried out in a timely manner. In practice, we combine both these approaches: reliability is designed into the system, sustained by careful operation and monitoring, and supported by planned maintenance.

Approaches to reliability and maintenance have evolved through four generations. The first of these was to run the equipment until it failed, and then carry out reactive or corrective maintenance. The second generation introduced the concept of preventive maintenance, carried out at fixed intervals regardless of whether it is needed or not. The third generation saw the adoption of predictive maintenance and condition-based maintenance (CBM), under which maintenance takes place only when needed. Figure 1 shows how the latter approach reduces the overall maintenance burden while simultaneously improving reliability.

The fourth generation of maintenance management concepts brings together CBM and reliability-based maintenance (RBM). The latter goes beyond CBM in that it involves people, machines and methods, using disciplined, logical tools to identify ways of eliminating failures while utilizing resources in optimal ways. The principal objectives of RBM are to implement a business process for maintenance, improve asset reliability, foster a reliability-based work culture, and adopt the necessary enabling technologies.

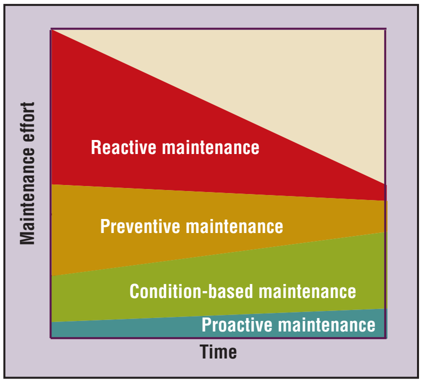


FIGURE 1. The move to condition-based and predictive maintenance is reducing the overall maintenance burden while increasing reliability

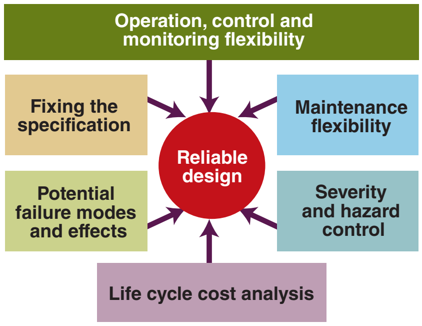


FIGURE 2. Considerations in incorporating reliability at the design stage

A machine that is poorly designed or constructed can never be expected to operate reliably, no matter how much maintenance it receives. For that reason, reliability begins at the design stage. Figure 2 shows some of the factors that should be considered when planning for reliability at the design stage.

Figure 3 shows how reliability can be sustained and improved through condition monitoring, careful maintenance, and the desire to do things better in future.

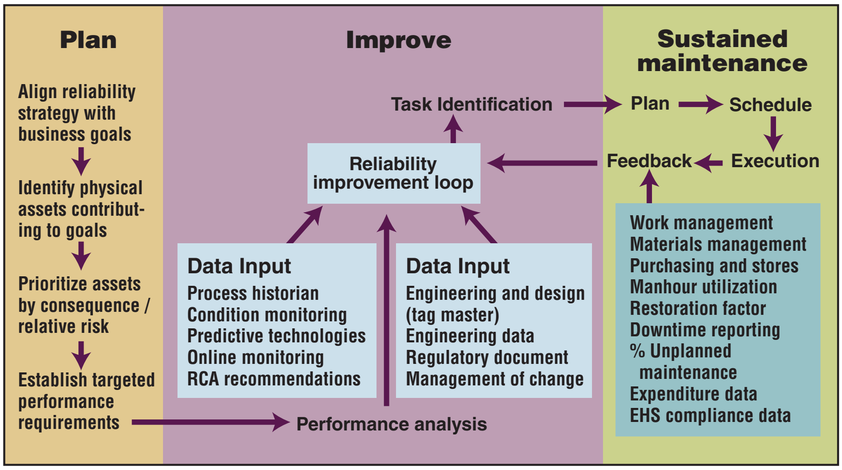


FIGURE 3. Reliability begins with good design, and is sustained through condition monitoring, careful maintenance, and the desire to improve

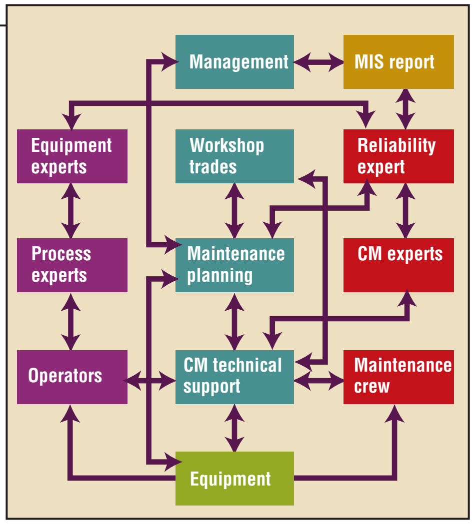


FIGURE 4. Organizational structure for CBM

MTBF and its role in CBM

Mean time between failures (MTBF) is a statistical measure of the likelihood of failure within a given time interval, and an important benchmark when assessing the performance of any maintenance program. For equipment that is not generally repaired, such as light bulbs and bearings, MTBF is more commonly referred to as MTTF (mean time to failure), but the mathematics are the same.

For a constant failure rate L, the probability of failure at time t (the failure density function) is:

$$f(t) = Le^{-Lt}$$

Integrating this gives the cumulative probability of failure within time t:

$$F(t) = 1 - e^{-Lt}$$

and the probability of survival for the same time interval is:

$$S(t) = 1 - F(t) = e^{-Lt}$$

The "probable hazard rate" at time t is the rate of change of cumulative failure probability at time t, divided by the probability of survival at time t:

$$R(t) = \frac{dF(t)/dt}{1 - F(t)} = \frac{f(t)}{1 - F(t)} = \frac{Le^{-Lt}}{e^{-Lt}} = L$$

or in other words simply the failure rate L.

The mean time to failure for an item with failure density f(t) is the average of all time values from zero to infinity, weighted according to the failure density function:

$$MTBF = \frac{\int_0^\infty t\, f(t)\, dt}{\int_0^\infty f(t)\, dt}$$

The denominator will ordinarily be 1, because the device has a cumulative probability of 1 of failing at some time between t = 0 and infinity.

Substituting the value of f(t) from Equation (1) and integrating gives:

$$MTBF = 1/L$$

In other words, this is the reciprocal of the failure rate. Similarly, for dual-redundant systems the MTBF is 3/2L.

The above analysis makes many assumptions, such as the idea that one item of equipment can be truly identical to another, and that operating conditions do not change over the life of the equipment. Since process plants are complex environments in which these assumptions obviously do not hold true, attempts to predict reliability from first principles are of limited accuracy. Measured values of MTBF are, however, valuable in determining whether a CBM program is having the desired effect of increasing overall reliability.

A strategic approach to CBM

Success in CBM depends 20% on technical resources and 80% on people. The most important features for success include the following:

- A skilled and determined facilitator
- A team that communicates and collaborates well
- Genuine support from senior management
- A time-constrained, results-oriented approach
- Scope and methodologies that are manageable with the available resources
- Goals that are smart (specific, measurable, attainable, realistic, and timely), with kpis that reflect the primary objectives of the business (high uptime, quality assurance, low operating cost, no catastrophic failures, resource optimization, goodwill, customer loyalty, employee loyalty, performance management social reorganization)
- Periodic progress tracking and management updates
- "Gap analysis", with appropriate measures when shortfalls are discovered
- Change management to ensure sustained improvement

Launching a CBM program is a strategic transformation that requires support from top management (Figure 4). Many CBM efforts do not yield the desired results and are soon abandoned after losing support. There are several key reasons for failure:

- Condition monitoring and equipment inspections are not rigorously applied
- The most appropriate CM practices are not used
- Operators are not asked for their inputs through a formalized system
- Front-line maintenance staff do not trust recommendations from the CM section and ignore them
- Front-line maintenance staff overreact to recommendations from the CM section
- The CM system relies on one person
- Inadequate training

VIBRATION ANALYSIS FOR BEGINNERS

Vibration occurs in almost every mechanical device found in a process plant. Vibration is fundamental to CBM, especially in rotating machinery. When properly measured, and associated with other data such as noise and operating temperature, vibration can reveal a great deal about the condition of machines and their component parts.

Excessive vibration can result from construction defects in the complete machine or its components, assembly problems, forces or vibration transmitted from pipework or associated equipment, operation outside normal limits, wear, damage, and electromagnetic forces.

The measurable properties of vibration are its plane, frequency, amplitude, and phase. For a rotating machine, the plane of a particular vibration mode — either radial or axial — can be used to distinguish different types of faults (see below).

The amplitude and frequency of vibration can be plotted against one another to produce a "vibration signature" (Figure 5). Typically, there will be one or more peaks at particular frequency values. One of these will correspond to the rotational speed of the machine ("1x RPM"), but there may also be multiples of this fundamental frequency ("2x RPM", "3x RPM" and so on). Fans and motors, whose rotating parts are characterized by multiple blades and poles respectively, may also show peaks at the "blade passing frequency" (BPF) and multiples of it.

Vibration analysis first aims to locate any significant peaks in the frequency spectrum, noting their amplitudes, phases, and relationships to the fundamental RPM and BPF frequencies. The eventual aim is to assign a source to each peak.

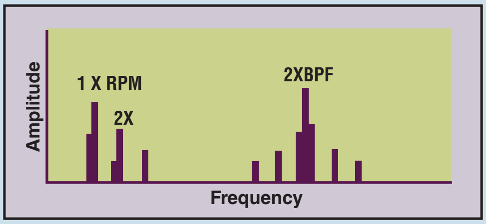


FIGURE 5. Vibration signature of a rotating machine showing peaks corresponding to the rotational frequency and its harmonics, and similarly for the blade passing frequency (BPF)

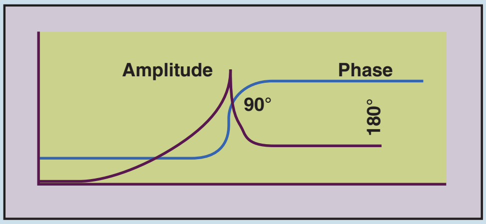


FIGURE 6. At the resonant frequency, the vibration amplitude rises sharply, and the phase changes through 180 deg.

The importance of phase

Phase is the term used to indicate relative motion between two vibrating bodies. Consider an unbalanced rotor, simply supported on two bearings. The vibration spectrum will be dominated by the 1x RPM component, but the vibration will show phase differences depending on where and in which direction it is measured, and on whether the imbalance is static or dynamic.

At a single bearing, vibration measured in the vertical direction will differ in phase by 90±20 deg. from that measured in the horizontal direction.

If the rotor is statically unbalanced, there will be no phase difference across the rotor for measurements taken in the same direction (radial-radial or horizontal-horizontal). At a single bearing, on the other hand, vibration measured in the horizontal direction will differ in phase by 90±20 deg. from that measured in the vertical direction.

If the rotor is dynamically unbalanced, however, there will be a phase difference between the two bearings (radial-radial or vertical-vertical). The size of this difference reflects the angular orientation of the forces causing the imbalance. For instance, if the vibration is due to heavy spots on the rotor that are 180-deg. apart, the phase shift will also be close to 180 deg.

Understanding resonance

Resonance occurs in a vibrating system when the forcing frequency coincides with a natural frequency of the machine or its mounting. Resonance is characterized by large vibration amplitudes and highly directional vibration, in which the phase difference between vertical and horizontal measurements will be close to either 0 or 180 deg.

The best way to detect resonance is by plotting vibration amplitude and phase against speed (a Bode plot), using data measured as the machine runs up to speed or runs down to a standstill. If at a particular speed the vibration increases greatly and also changes phase, then the system is in resonance.

Starting from a speed on one side of the point of resonance, the phase changes through 90 deg. at the point of resonance itself, and then through a further 90 deg. as we move to the other side (Figure 6).

The following cases illustrate some specific machinery problems and the types of vibration that characterize them.

Imbalance

See Figure 7.

- 180 deg. out of phase on the same shaft
- 1x RPM is always present and normally dominates
- Amplitude varies with the square of the speed
- Can cause high axial as well as radial amplitudes
- Balancing requires correction in two planes at 180 deg.

Bent shaft

See Figure 8.

- High axial vibration
- 1x RPM dominant if bend is near shaft center
- 2x RPM dominant if bend is near shaft ends
- Phase difference in the axial direction will tend towards 180 deg.

Angular misalignment

See Figure 9.

- Axial vibration is high, and typically there is a 180-deg. phase difference across the coupling
- Not unusual for 1, 2 or 3x RPM to dominate, and higher harmonics may also be visible
- Coupling and bearing problems can produce similar symptoms. Bearing misalignment (cocked bearing), for instance, will show a 180-deg. phase shift from one side of the bearing to the other, or from the top of the bearing to the bottom

Parallel misalignment

See Figure 10.

- Radial vibration is high, and typically shows a 180-deg. phase difference across the coupling

CBM in practice

The three basic questions in CBM are deciding what, when and how to monitor. In more detail, the approach is:

1. Identify the components that are susceptible to failure.
2. For each component, identify the symptoms that indicate forthcoming failure, and the measurable variables that relate to these symptoms.
3. Set acceptable limits, and if necessary alarms, for these critical measured variables.
4. Train personnel on how to monitor the critical variables and the action to be taken when limits are crossed.
5. Analyze the monitored data to improve understanding of the past and current health of the machine, and predict future failures.
6. As failures approach, take action as necessary (Figure 14, p. 50).

There are two types of CBM systems: online and offline. Online systems are used mainly for critical equipment items and when very rapid response is needed. Offline systems rely on data collection using portable devices and physical observation. Though the technology varies greatly in complexity, the aims and techniques of both approaches are very similar.

The list below sets out the main steps in CBM data collection and analysis. Though the list refers mainly to the modules that make up a typical online CBM system, the same functions can be carried out offline, using

FIGURE 7. Imbalance

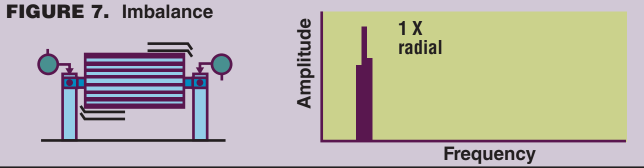


FIGURE 8. Bent shaft

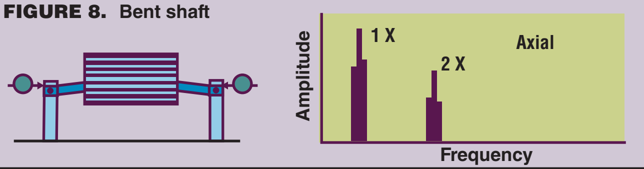


FIGURE 9. Angular misalignment

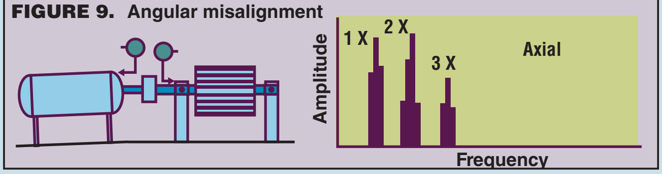


FIGURE 10. Parallel misalignment

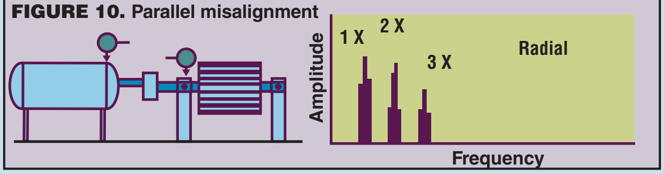


FIGURE 11. Electrical problems

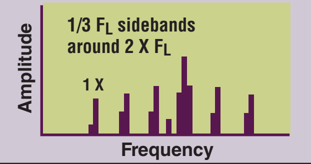


FIGURE 12. Eccentric rotor

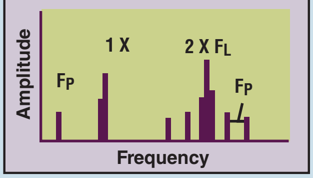
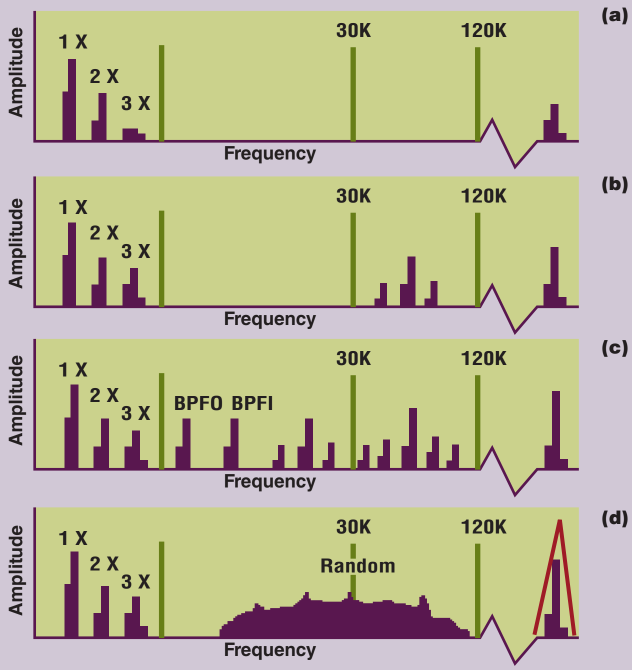


FIGURE 13. Bearing failure



- 2x RPM often larger than 1x RPM; severe misalignment will show higher harmonics
- Similar symptoms to angular misalignment
- Coupling design can influence the shape and amplitude of the vibration spectrum

Loose mounting

A loose mounting will produce phase readings that vary erratically from point to point around the machine train. A single soft foot will usually show a phase difference, often greater than 90 deg., between itself and the foundation. The soft foot will also show a phase difference compared to the other feet of the same machine.

Electrical problems

See Figure 11.

- For electric motors, a poor connection on one phase of the power supply can cause excessive vibration at a frequency of $2F_L$, with sidebands at 1/3 F_L, where F_L is the supply frequency
- The vibration amplitude at $2F_L$ can exceed 25 mm/s if left uncorrected
- Diagnosis is particularly difficult if the connector loses contact only occasionally

Eccentric rotor

See Figure 12.

- A rotor that is mounted eccentrically on its shaft produces an air gap between the rotor and stator that varies in width, and induces pulsating vibration
- It is often necessary to magnify the spectrum before it is possible to distinguish $2F_L$ from a harmonic of the rotational speed
- Common values of the pole pass frequency (F_P) are in the range 0.3–2 Hz

Bearing failure

The earliest indications of bearing failure appear in the ultrasonic range (Figure 13a). Three important measures are the spike energy, expressed in gSE units; high-frequency distribution (HFD); and shock pulse. Spike energy is typically around 0.25 gSE during this first stage.

In the second stage of failure (Figure 13b), the components of the bearing begin to "ring" at their natural frequency, generally in the range 500–2,000 Hz. By the end of this stage, sidebands have appeared above and below the natural frequency. The spike energy increases, typically to 0.25–0.50 gSE.

By the third stage (Figure 13c), specific bearing-defect frequencies and harmonics appear. As wear progresses, the number of sidebands grows. Physical wear is now visible, and may extend around the periphery of the bearing. The spike energy increases to 0.5–1.0 gSE.

In the final stage (Figure 13d), discrete bearing-defect frequencies disappear and are replaced by random broadband vibration forming a "noise floor" as failure becomes imminent; a large peak at 1x RPM can also appear. Both the noise floor amplitude at high frequencies and the spike energy may in fact decrease, and gSE may rise to high levels. ❑

portable instruments, spreadsheets and even paper records.

Sensor module: Provides data either through online sensors or portable measuring instruments.

Signal processing module: Receives data from the sensor module or other instruments and performs functions including filtration, spectrum analysis and resolution demodulation.

Condition monitoring module: Compares data from the sensor and signal processing modules with expected values, judges whether there are significant deviations, and initiates an alert if necessary.

Health assessment module: Uses data from the condition monitoring module to diagnose the condition of the system and its components, generates records and suggests causes for any probable faults identified.

Prognostic module: Predicts the future condition of the system and its verious components.

Decision support module: Recommends and schedules maintenance actions to be carried out.

Documentation module: Creates reports for management information systems and maintenance engineers. Topics include task scheduling, benchmarking and reliability tracking.

When to measure

Deciding on the monitoring frequency to adopt at the beginning of a CBM program requires a knowledge of two things: the equipment criticality, and

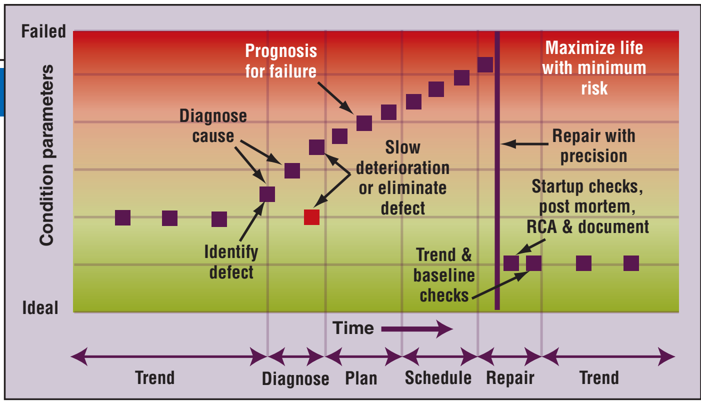


FIGURE 14. Monitoring, diagnosis and repair is a cyclic process

the MTBF, or average probability of failure, derived from historical data. Once the CBM program is in operation, the monitoring frequency can be altered based on subsequent experience (Figure 15, p. 51).

The choice of whether to intervene for maintenance purposes on any particular occasion is made through a knowledge of Overall Equipment Effectiveness (OEE). Defined as the mathematical product of availability, performance, and quality, OEE is the minimum performance from any asset or system required to meet the organization's business needs.

OEE = availability × performance × quality, where:
Availability = (actual available time)/(ideal available time)
Performance = (actual delivery of product in a given time)/(desired delivery in the same time)
Quality = % restoration to rated condition × % maintainability

As an arbitrary example, a plant whose assets have targets of 98% performance, 99% performance and (98% × 99%) quality will have a target OEE of 98% × 99% × 98% × 99% = 94%. If the actual OEE falls below this level, maintenance intervention is required.

Some of the data needed to derive the OEE target will be obtained from the CBM program itself. Equipment items that lack a means of continuous performance monitoring, such as pressure relief valves or pressure switches, must continue to rely on time-based maintenance. Historical MTBF data can be used as a starting point for assigning maintenance intervals.

What to measure

The most important field measurements in a CBM program are generally vibration, temperature, noise,

CASE STUDY: DIESEL-FEED PUMP MOTOR

A large electric motor driving a centrifugal pump in a refinery had been running with high levels of noise and vibration since it was commissioned in 2000.

The pump is a horizontal split-case design with twin impellers, manufactured by KSB. It handles diesel at a rated flowrate of 256 m^3/h and 727 m head.

The driver is a two-pole induction motor rated at 600 kW. It runs at 2,980 rpm from a three-phase, 6.6 kV, 50 Hz supply. The motor bearings at the pump end are of types NU219C3 and 6219C3, and at the free end type NU219C3.

The coupling is a flexible type manufactured by John Crane Metastream. Both motor and pump are mounted on a single steel base frame, whose feet are bolted to the concrete foundation.

The non-driving end of the motor recorded a horizontal vibration component with a maximum amplitude of 13 mm/s. This compares to an acceptable value of 5 mm/s as specified by ISO 2372/10816 (Rev 1).

The company decided to undertake a root cause analysis (RCA) based on vibration analysis using Emerson CSI 1600 and 2120 data collector/analyzers, backed up by field observations, inspection of motor parts after dismantling, and diagnostic tests as required.

Looking at the evidence

Measurement showed that the average value of the horizontal vibration component (7.0 mm/s) was nearly twice the vertical component (3.6 mm/s). This suggested that the problem was likely to lie with the motor frame, the supporting structure or the foundation.

The amplitude of the vibration peak corresponding to the rotational speed of the motor (49.7 Hz) did not vary with the load on the motor. This indicated that rotor eccentricity was unlikely.

The peak corresponding to the second harmonic (100 Hz) of the supply frequency showed sidebands that reveal the presence of vibration caused by electromagnetic forces.

The motor legs were checked for possible distortion causing a soft footing, but were found to be in good order. However, when the motor

This 600 kW motor driving a refinery diesel pump suffered vibration and noise problems. After first dealing with soft footings, mainenance engineers eliminated resonance by adding bracing and new foundation bolts to the steel frame

was uncoupled from the pump and run on its own, dial gauge readings showed that the base frame was distorted diagonally.

The motor was removed and dismantled by a specialist agency. The rotor runout was found to be within normal limits, but severe rub marks were observed on both the rotor and the stator core, spread over both radial and axial directions. The rotor laminations were distorted, leading to inter-lamination clearances that varied around the periphery, and both bearings were damaged.

First analysis

The possible causes were determined to be among the following:

- A soft footing
- Loose rotor laminations
- Vibration transmitted from the pump
- Electromagnetic forces

Since a long outage would be needed finally to identify the cause, the motor was repaired as far as possible, balanced, and put back into service with new bearings. Vibration and noise remained high.

Vibration measured at the motor bearings was seen to be worse when the motor ran uncoupled from the pump. This meant that vibration transmitted from the pump was unlikely to be the problem, and instead suggested that the trouble lay in a soft footing.

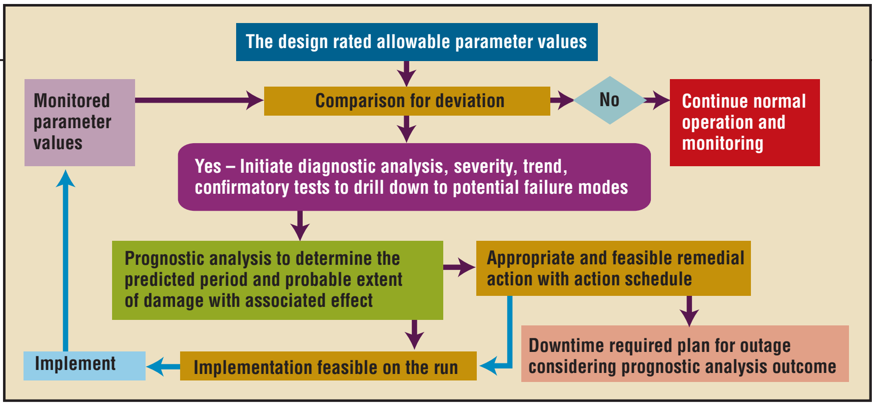


FIGURE 15. A functional approach to CBM

process variables, and lubricant condition.

Vibration can reveal both the rotodynamic and structural stability of a complete machine and of its component parts, including bearings. Vibration Analysis for Beginners (box, p. 48) explains this in detail, with specific examples.

Temperature provides information about the machine loading, bearing condition, lubrication or cooling problems, insulation breakdown, and process deviations.

Acoustic analysis highlights the condition of rubbing surfaces, and problems involving resonance or transmitted vibration.

Process variables, such as flowrate, pressure, temperature, speed and power consumption, provide information on the system within which individual machines operate, especially when loads are varying.

Lubricant condition, including contamination, degradation and changes in appearance, can reveal a great deal about the condition of bearings, rubbing surfaces and seals. ■

Edited by Charles Butcher

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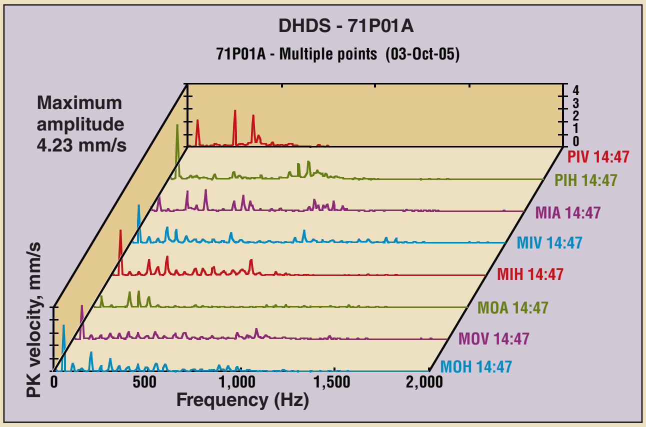

FIGURE 16. Since soft-footing and foundation resonance problems were addressed, the motor has run within acceptable vibration limits

Careful measurement revealed gaps of 0.2 mm causing soft footings on legs two and three of the motor, and a smaller gap of 0.02 mm on leg number four. All four legs were properly adjusted, using single sheets of stainless steel to prevent possible vibration problems caused by multiple layers of shim. The grease in the motor bearings was replaced and the motor given a test run.

Second try

The horizontal vibration component initially fell, but after running for three hours at full load it increased to 9 mm/s at the non-driving end. The vertical component increased too, and so did the noise level, with audible modulation (beats).

The dominant frequency for all vibration components was 49.7 Hz, indicating that the problem likely was with rotor imbalance, resonance, magnetic field imbalance, or an unsatisfactory foundation.

After three hours' running, additional peaks were observed at the second harmonic. This signaled the presence of an electrical defect, a damaged rotor, or a problem related to the rotor-stator air gap.

The phase shift between the horizontal and vertical component at the non-driving end was 200 deg. There was no phase difference between measurements made in the same direction at each end of the shaft, showing that dynamic imbalance was not the problem.

Phase measurement on the newly-adjusted legs of the motor confirmed that there was now no problem with soft footings.

Satisfied that the problem was limited to the motor, the engineering team carried out further tests with the motor uncoupled from the pump. They measured vibration in all three axes and at both ends of the shaft.

As before, the main peak in each spectrum appeared at the first harmonic of the motor speed, with low-amplitude sidebands at twice this frequency. However, vibration at this frequency was also noticed when the motor was stopped or coasting down, indicating the likelihood that vibration was being transmitted from another nearby pump running at the same speed.

With a soft footing already ruled out, the assumption was that either the foundation or the steel base frame was resonating at a frequency corresponding to the operating speed of the motor, and also transmitting vibration from nearby equipment.

Corrective action

The base frame on the motor side was strengthened by welding three segments of I-beam to each side of the frame (photo, p. 50). The free ends of these segments were secured by J-shaped foundation bolts, 2 in. dia. and 4 ft. long, grouted in place. Diagonal braces were also added to the frame at the front and rear of the motor.

The motor was overhauled, with repairs to the rotor laminations, rotor balancing, and new bearings. The bearing housing was insulated to minimize vibration induced by electromagnetic effects.

The equipment was recommissioned in May 2004. At full load, horizontal vibration at both ends of the motor was below 4 mm/s, and noise was substantially less. Figure 16 shows vibration levels when the motor and pump had been operating for 10 months since the foundation modification. The reinforced foundation no longer has a resonant frequency close to the operating frequency of the motor, so it transmits less vibration from nearby equipment and is better able to absorb vibration from the items mounted on it. ❑

Get More From Vertical Thermosiphon Reboilers

The effects of three different heat-transfer-enhancement devices are outlined here

Omid Zadakbar, Ali Vatani
and **Kianoosh Karimpour**
University of Tehran

TABLE 1. EFFECT OF TUBE INSERTS ON VTR DESIGN PARAMETERS

Parameters	Effects
Heat-transfer surface area	Decrease up to 25%
Subcooled zone length	Decrease up to 59%
Maximum temperature of reboiler tube	Decrease up to 2%
Overall heat transfer coefficient	Increase up to 29%
Subcooled zone, overall heat-transfer coefficient	Increase up to 215%
Average heat-flux rate	Increase up to 22%

A very common heat exchanger in the chemical process industries (CPI) is the vertical thermosiphon reboiler (VTR; Figure 1). Due to size and fluid-flow restrictions, however, its heat transfer rate is often quite low. The subcooled region formed at the thermosiphon's tube-bundle base usually causes reduction in the tubes' average heat-transfer coefficient.

Improvements in performance can be achieved with the application of heat-transfer-enhancement devices — specifically wire matrix inserts (Figure 2), twisted-tape inserts (Figure 3) and helically coiled inserts (Figure 4) — in the subcooled zone of a vertical thermosiphon reboiler. These enhancement devices reduce the required heat-transfer surface area, subcooled zone length and maximum temperature of the reboiler tube wall, while increasing the overall heat-transfer coefficient, subcooled-zone overall heat-transfer coefficient and average heat flux rate (Table 1). All together, these benefits translate into a reduction in the size of the exchanger, the area of installation and the initial investment.

VTR opportunities for inserts

Vertical thermosiphon reboilers operate by natural circulation of the liquid (from the still through the downcomer to the reboiler) and the two-phase mixture (from the reboiler through the return piping). The flow is induced by the hydrostatic pressure imbalance between the liquid in the downcomer and the two-phase mixture in the reboiler tubes [*1*]. Hydrostatic pressure on the fluid at the entrance to the tubes causes the formation of a subcooled zone in the VTR tubes. This zone includes a significant number of reboiler tubes, the magnitude of which depends on fluid type. Since convective heat-transfer coefficients in the subcooled zone are significantly lower than boiling heat-transfer coefficients, the presence of a subcooled zone reduces the overall heat-transfer coefficient in the reboiler tubes. Meanwhile, the fluid in this zone is in the liquid phase; so, its high density lowers the velocity of fluid and causes establishment of laminar flow [*2*]. These conditions increase the surface temperature of the tubes and cause fouling to occur.

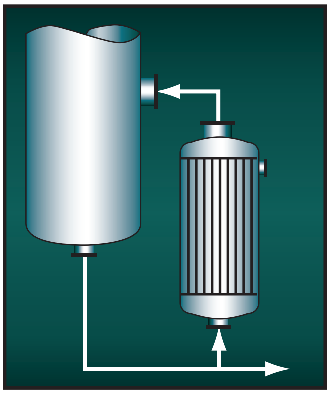

FIGURE 1. Vertical thermosiphon reboilers operate by natural circulation of the liquid (from the still through the downcomer to the reboiler) and the two-phase mixture (from the reboiler through the return piping)

The application of heat-transfer-enhancement equipment increases the overall heat-transfer coefficient inside the tubes of vertical thermosiphon reboilers and significantly improves performance. In fact, these devices decrease the subcooled-zone length (Figure 5) and surface temperature of the tubes, thereby reducing fouling in this zone [*3*]. Meanwhile, the pressure drop in the subcooled liquid zone is reduced and other parameters, such as required heat-transfer area, are improved. The potential benefits of these heat transfer enhancement devices are illustrated in Table 2, which summarizes the results of a study (see Methodology, p. 53) in which various inserts were compared with plain tubes. Note that the results in the study should not be used for choosing between various types of inserts, which is beyond the scope of this article.

Wire matrix inserts

In viscous, single-phase-flow applications, wire matrix inserts are widely used to improve heat-transfer characteristics. More recently, these devices have also been successfully applied for two-phase flow applications, such as reflux condensers and thermosiphon

TABLE 2. EFFECT OF TWISTED TAPE INSERTS, HELICALLY COILED INSERTS AND WIRE MATRIX INSERTS ON VERTICAL THERMOSIPHON REBOILERS*

Reboiler parameters	Twisted tape inserts (y=2)	Helically coiled inserts	Wire matrix insert (low density)	Simple tube
Subcooled region length, m	0.37	0.18	0.31	0.44
Single-phase heat-transfer coefficient, W/m^{2}K	322	769	417	243
Overall heat-transfer coefficient, W/m^{2}K	1,261	1,378	1,310	1,065
Required heat-transfer surface area, m^2	30.80	28	29.80	38.11
Number of tubes	159	147	153	196
Maximum temperature of tube wall, °C	102	100	102	104
Tube pressure drop, kPa	15.4	15.5	15.5	15.3
Single-phase pressure drop, kPa	2.59	1.29	2.29	3.10

* Note that the results in the study should not be used for choosing between various types of inserts, which is beyond the scope of this article.

Cal Gavin Ltd.

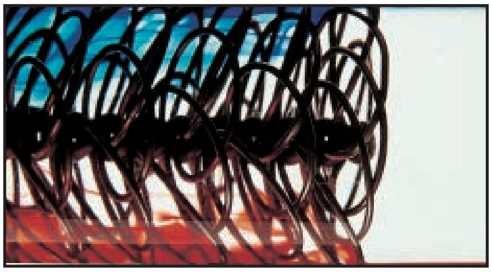

FIGURE 2. Wire matrix inserts create more-ideal-flow conditions within individual tubes by continuously removing stagnant fluid from the tube wall and replacing it with fluid from the center of the tubes

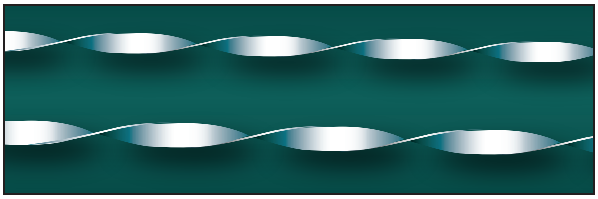

FIGURE 3. Twisted tapes, when inserted into tubes, tend to promote turbulence as well as to intensify mixing of the hot and cold fluid

METHODOLOGY

The effects of using wire matrix inserts, helically coiled inserts and twisted tape inserts were studied on a simulated model (Figure 6). At first, the mean temperature over the cross section of the flow was determined. The mean enthalpy temperature can be determined more simply by experiment, by inserting a mixer. Temperature evens out downstream of the mixer, becoming equal to the enthalpy mean temperature and can be determined by taking measurements at a point.

Next, the distribution of mean fluid temperature, the rate of heat flow, and fluid and wall temperatures along the tube were determined. The length of subcooled zone was determined assuming that the temperature at the end of the subcooled zone becomes equal to the saturated temperature at the local pressure. In order to determine the vapor fraction of the tube outlet using the Furzer equation [*12*], we assumed that the pressure drop along the thermosiphon is less than allowable pressure drop (based on Furzer equation assumptions). Heat transfer coefficients and pressure drop along the subcooled zone were determined by Blasius equation [*13*]. In addition, the equations derived by ESDU and Chen were used to determine the convective heat-transfer coefficients and friction factors corresponding to each insert [*14*]. ❑

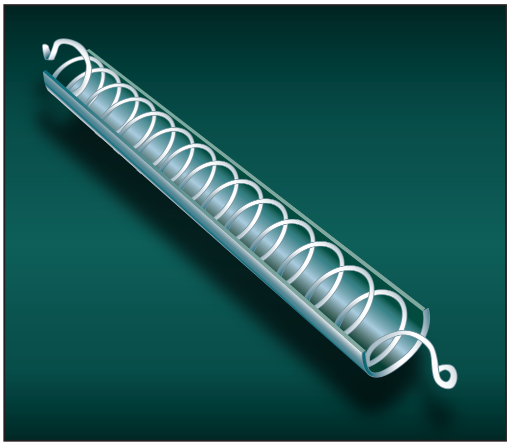

FIGURE 4. The use of a full-length, helically coiled insert can increase the swirl and pressure gradient in the radial direction

reboilers. In all these applications, the boundary layer fluid is continuously displaced from the tube inner surface and remixed with the bulk fluid, thereby improving the convective heat transfer [*4*].

Analysis of the thermosiphon with a wire matrix insert placed inside an individual tube shows that the flow distribution is leveled out across all of the exchanger. The result is a dramatic improvement in heat transfer efficiency with all the installed area now effective.

The inserts create more-ideal-flow conditions within individual tubes by continuously removing stagnant fluid from the tube wall and replacing it with fluid from the center of the tubes. This, in turn, reduces the residence time of fluid in contact with the heat transfer surface and creates a flow regime where the velocity profile across the tube is nearly flat. Although wire matrix inserts depend upon an increase in pressure drop to achieve these flow conditions, the enhancement in heat transfer is much larger than would be achieved by simply increasing tube-side velocities. In fact, heat transfer enhancement is usually achieved at much-lower superficial velocities than would be employed in plain tube designs. Thus, it is often possible to reconfigure a bundle to reduce the number of passes, thereby maintaining or reducing the original pressure drop overall and dramatically increasing the performance of the unit.

Twisted tape inserts

When inserted into tubes twisted tapes tend to promote turbulence as well as to intensify mixing of the hot and cold fluid. This, in turn, improves the heat transfer process. Investigation of enhancement efficiency, heat transfer and friction-factor characteristics of thermosiphon-reboiler tubes that are fitted with twisted tape inserts of different twist ratios indicates that the swirl flow helps decrease the boundary layer thickness of the hot air flow and increase residence time of hot air in the inner tube.

The enhancement efficiency and

Nusselt number (where numbers above 100 indicate a shift toward turbulent flow) increases with decreasing twist ratio (y, which is equal to pitch length based on 180°, divided by tube diameter); the friction factor also increases with decreasing twist ratio. In the case of the twisted tape inserts, the mean Nusselt numbers increase about 188% for $y = 5.0$ and 159% for $y = 7.0$, when compared with the plain tube. This particular study shows that the smaller the twist ratio, the higher the mean Nusselt number. The partitioning and blockage of the tube-flow cross section by the tape results in higher flow velocities. Secondary fluid motion is generated by the tape twist, and the resulting twist mixing improves the convective heat transfer.

Sources of data. Many researchers have investigated the effect of twisted tape inserts on heat transfer and friction in a circular or rectangular, smooth pipe in both experimental and numerical studies. Dutta, Dhal and Saha [*5*] numerically predicted the friction and heat transfer characteristics for laminar flow in a circular tube fitted with regularly spaced twisted-tape elements, which were connected by thin circular rods. Ray and Date [*6*] experimentally investigated correlations of heat transfer and flow frictions in a square duct with twisted tape inserts. Kumar and Prasad [*7*] reported the improved collection of solar energy (*vis-à-vis* water heating) by means of twisted tapes inserted in the water flow tubes. Sukhatme [*8*] experimentally studied the effect of a twisted-tape insert on the heat transfer rate and pressure drop in laminar flow under uniform heat flux. Meanwhile, Duplessis and Kroger [*9*] conducted experimental and numerical studies with the constant wall temperature in laminar flow. Bergles [*10*] provided a correlation of heat transfer inside the tube for turbulent flow.

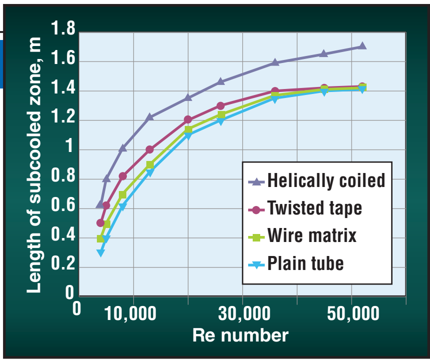

FIGURE 5. These tube inserts decrease the subcooled-zone length of the tubes, thereby improving overall heat transfer efficiency

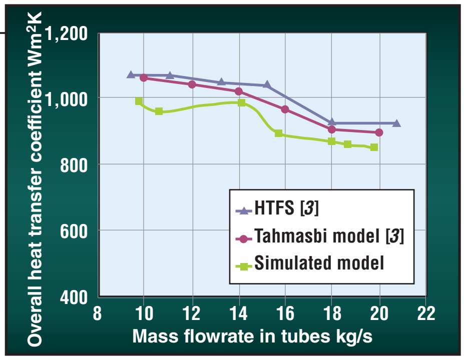

FIGURE 6. This graph compares the results of the simulated model (see box, p. 53) with other simulated model results for plain tubes

Helically coiled inserts

Tubes fitted with the helically coiled inserts give higher heat-transfer rates than the plain tube. The mean Nusselt number increased by about 165% when compared with plain-tube correlations from Sieder and Tate [*11*]. The use of a full-length, helically coiled insert can increase the swirl and pressure gradient in the radial direction. The boundary layer along the tube wall is thinner with the increase of radial swirl and pressure, resulting in more heat flow through the fluid. Furthermore, the swirl enhances the flow turbulence, which leads to even better convective heat transfer. Thus, the higher the Reynolds numbers the greater the Nusselt number. ■

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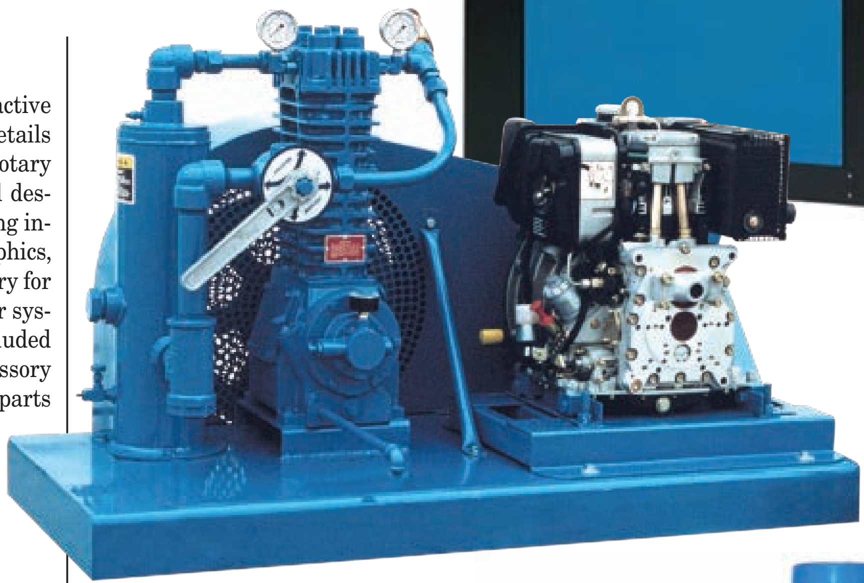

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The Qube blower package (photo), featuring the new Qx blower, is a quiet, low-cost, quick delivery solution for pneumatic conveying applications and more. Benefits include high efficiency with low noise (< 75 dBA); pressures up to 18 psi; a compact footprint; and a powder coated steel enclosure for (24 dBA attenuation). Additional features include integral check valve; discharge from back; and discharge flexible connector. — *Tuthill Vacuum & Blower Systems, Springfield, Mo.*
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Said to be the industry's first intelligent, compressed-air-management program offering plant-wide analysis, realtime process control and pneumatic system design in a single integrated solution, the Norgren IQ program (photo) assesses both supply and demand of compressed air in plants and adjusts output dynamically to ensure continuous, optimal performance. This in turn saves energy, reduces operating expense, prevents downtime and increases productivity. Up to 40% annual energy reductions have been achieved, says the vendor. The program is powered by partnering-firm Pneu-Logic Corp.'s (Portland, Oreg.; www.pneulogic.com) proprietary software, which aggregates and analyzes trend data and tightens parameters over time, essentially "getting smarter as it goes." Unlike competitive products, which are limited to single assessments, Norgren IQ provides continuous monitoring and adjustment. Norgren IQ's open architecture interfaces with a wide variety of air compressors. — *Norgren, Inc., Chicago, Ill.*
www.norgren.com

Go 100% oil-free for high-purity needs

This vendor's line of electrically-powered compressors delivers from 200 to 1,500 cfm at pressures up to 150 psi, producing clean, oil-free air suitable for high-purity applications. The units are also designed with sensitive environmental considerations in mind, with a sound-attenuating canopy to keep noise levels to a minimum. All units are equipped with a 100%, oil-free, two-stage screw compressor, and offer discharge temperatures of only 20° above ambient temperature with built-in aftercoolers. The units require 480-V, three-phase, 60-Hz power and have a flexible operating-pressure range. Meanwhile, the manufacturer offers a full line of refrigerated and regenerative desiccant dryers that can be packaged with all of its compressors

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to provide an unlimited supply of clean, dry air where necessary. For higher pressures, the vendor offers a container-sized air compressor rental that combines diesel-based compression with electric-drive, high-pressure boosting. With electric-drive boosting, pressures can be raised to 600 psi at a flowrate of 900 cfm. — *Aggreko, LLC, Houston, Tex.*
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www.atlascopco.com

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The IntelliView Line of aeration controls and control systems is designed to maximize efficiency of blowers and compressors in wastewater operations. A system can be purchased as a part of the vendor's own aeration-blower system or integrated into third-party installations, including those that are preexisting. Models are available for any type of blower. Positive displacement blowers may be controlled with variable speed drives. Multistage centrifugal blowers may be variable speed or inlet throttled. Single stage centrifugal control options include variable speed, inlet guide vanes, and variable discharge diffuser vanes. All IntelliView blower controllers include equipment health monitoring and safety shutdown as well as process control options. A variety of protocols are available for both serial and Ethernet communications, allowing direct connectivity to SCADA systems and PLC networks. The Dissolved Oxygen (DO) control algorithm was specifically developed for aeration applications. Aeration basin air-flow control, Most-Open-Valve (MOV) logic, and pressure control are among the many options available to optimize the IntelliView system for virtually any wastewater treatment facility. — *Dresser Roots, Houston, Tex.*
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Kaeser Compressors

These blower packages are ready to operate on delivery
For applications ranging from pneumatic conveying to aeration wastewater treatment, this manufacture offers a variety of pressure and vacuum blower packages (photo) that are ready to operate — shipped completely assembled and pre-piped. All packages feature a modular base/discharge silencer, V-Belt drive system, OSHA V-Belt drive guard, motor slide base, and interconnecting fittings. Packages boast premium-brand blowers and motors and top-of-the-line silencer/filter components, controls and accessories. The sturdy elevated bases are heavy gauge reinforced steel plate with rugged ventilated drive guards that can withstand abuse. Two Pressure System Packages, the PSS and PFS, are available in pressures to 15 psi and flowrates ranging from 50 to 2,100 cfm. The PSS Package uses a horizontal inlet silencer and support plus an inlet filter with weatherhood, while the PFS features an integral inlet filter/silencer with weatherhood. Meanwhile, the VDS System Vacuum Blower Package is built with the same premium features using a Sutorbilt Legend vacuum pump with a vacuum relief valve and is available in vacuum ratings to 16 mm Hg. — *Wm. W. Meyer & Sons, Inc., Libertyville, Ill.*
www.wmwmeyer.com

Mobile LPG evacuation is a safe and efficient alternative to flaring
When compared to the traditional method of flaring propane and other liquefied petroleum gases (LPG), these mobile LPG evacuation units (photo, p. 55) offer a more-cost-efficient and safe alternative for removing residual gas from tanks that needed to be moved, repaired or replaced. The units feature the manufacturer's LB Series reciprocating gas compressors — model numbers LB161, LB361 or LB601, specifically. In addition to a trailer-mounted unit, a skid-mounted version is offered for easy transportation in a truck bed or via a small trailer to the destination. The portable liquid-transfer and vapor-recovery units are constructed with a variety of engine drive styles and options. The units are designed with the traditional "LU" mounting style, which includes the compressor, liquid trap, strainer, four-way valve and related piping. LB Series compressors are available with transfer rates from 35 to 700 U.S. gal/min (132–2,630 L/min) and designed to handle transfer and recovery of liquefied gasses like propane, butane, and anhydrous ammonia. All models feature ductile iron pressure parts for greater resistance to both thermal and mechanical shock. — *Blackmer, Grand Rapids, Mich.*
www.blackmer.com ■

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Emerson Process Management

Raytek

Dickson

(Continued from p. 31)

are ideal for food preparation, life sciences, pharmaceuticals, petroleum products, clean rooms, electronics, and field use. The minimum and maximum feature permits viewing highest and lowest readings at any time. — *Control Company, Friendswood, Tex.*
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Wireless transmitters extend their range
Wireless transmitters have been applied to a variety of applications. Some examples are monitoring temperatures in cold rooms (photo); monitoring temperatures in mobile situations, such as in railcars; and temperature measurement in harsh plant environments, such as in steel mills. This company recently announced the expansion of its wireless solutions with the release of the Extended Range Antenna, available on Rosemount 3051S, 648, and 702 transmitters with WirelessHART output. Oil and gas industries and others operate facilities where measurement points are separated by long distances, making wiring and powering of measurement points expensive. The extended-range-antenna option provides a cost-effective way to access this information by increasing the distance between self-organizing points up to a half mile (2,600 ft). — *Emerson Process Management, Pittsburgh, Pa.*
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This alarm thermometer can be used to ensure that temperature-sensitive chemicals stored in both refrigerators and freezers do not deteriorate. Featuring tamper-resistant audible and visual alarms, the instrument comes in a two-probe model (MM125; photo) that can monitor both refrigerators and freezers simultaneously and a single-probe model (MM120). Features include: a visual display of the alarm that remains even if temperatures are no longer out of range, alerting supervisors to the need for remedial action; alarm controls on the back of the unit, making it tamper-resistant once mounted on the outside of the refrigeration unit; large LCD display of current temperatures, minimum and maximum temperatures, alarm conditions and battery levels; and an automatic scrolling display of refrigerator and freezer conditions every five seconds. Both models are continuous, calibrated and certified thermometers that are able to monitor temperatures in the range of –58 to 158°F (–50 to 70°C). — *Dickson, Addison, Ill.*
www.dicksondata.com

High-speed infrared linescanner for noncontact temperature measurement
The new MP150 High Speed Infrared Linescanner (photo) is specifically designed for modern, high-speed manufacturing processes. Featuring the latest electronics, optics, communications and mirror mechanisms, one key feature facilitated by this technology is a scan speed up to 150 Hz, which is three times faster than its predecessor. Another unique feature of the MP150 is the on-board Ethernet TCPI/IP communication capability. During installation, the user connects directly to the linescanner without the need for any controller or connection boxes. A complete suite of software solutions has been enhanced to take advantage of the increased data acquisition capabilities and extended communication properties of the MP150. The system packages allow the user to simply and quickly configure the system to analyze thermal data to monitor and control their manufacturing processes. — *Raytek, Santa Cruz, Calif.*
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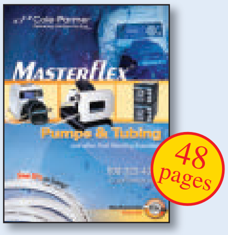

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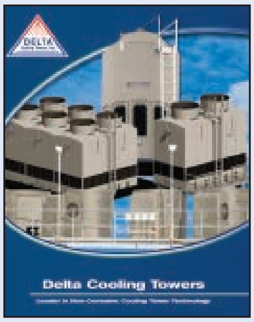

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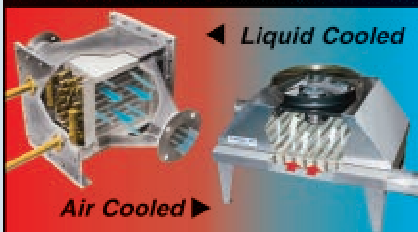

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Applicants for these positions must have a Ph.D. in Chemical Engineering or closely related field. Preferences will be given to individuals with research and teaching interests in the areas of process integration and design, process safety, petroleum and gas processing, environmental engineering and thermodynamics, but outstanding candidates with research interests in other areas of Chemical engineering will also be considered. Prior teaching experience in USA and familiarity with ABET accreditation is desirable. We offer competitive salaries and summer funding is guaranteed. Liberal allowances for professional travel and for relocation to Qatar are provided. Fringe benefits include free furnished housing in one of several gated communities, K-12 education for dependents, group health insurance, annual leave allowance, and a car allowance.

Applicants should send curriculum vitae, detailed statement of research and teaching interests, and arrange to have letters of recommendation sent to: Dr. Mahmoud El-Halwagi, Chair-TAMUQ CHEN Search Committee, Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, Texas 77843-3 122. Call (979) 862-3985 for additional information. The complete dossier should be received by March 31, 2009. Early applications are encouraged since applications will be reviewed as they are received.

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BUSINESS NEWS

PLANT WATCH

Oxea expands carboxylic-acids production, adds butyric acid

October 14, 2008 — Oxea GmbH has decided to produce butyric acid at its North American production site in Bay City, Tex. The existing carboxylic-acids production plant will receive significant upgrading. The changes to the unit are expected to be completed in the 3rd Q of 2009. The expansion in Bay City and process improvements in Marl and Oberhausen (both Germany) will result in an increase of Oxea's global production output of carboxylic acids by 25–30%.

Caloric wins contract for another H_2 plant in France

October 2, 2008 — Caloric Anlagenbau GmbH will provide engineering, procurement and commissioning services for a new hydrogen plant and the corresponding distributed control system (DCS), using Caloric's HC steam-methane-reforming (SMR) hydrogen-production technology. It is anticipated that the hydrogen production plant will be operational by the end of 2009 and will produce 2,200 Nm^3/h hydrogen.

IPS technology to drive new power stations in Chile

October 2, 2008 — Invensys Process Systems (IPS) has announced that it signed a multi-million dollar contract with Maire Tecnimont Group to supply DCS systems and solutions for two coal-fired power stations currently under construction in Coronel, Chile. Each of the new plant's power islands will be made up of one steam generator and one steam turbine generator block. The plants will have an output of approximately 370 megawatts each.

ExxonMobil's MTG technology selected for CTL projects

October 1, 2008 — ExxonMobil Research and Engineering Co. has entered into an agreement with Synthesis Energy Systems, Inc. (SES) that provides SES the option to execute up to 15 methanol-to-gasoline (MTG) technology licenses in its global operations. SES has assigned the first license to a project near Benwood, W. Va. This approximately 7,000-bbl/d unit will be based on commercially proven MTG technology, which incorporates improvements (*CE*, December 2006, p. 11) since the technology was originally commercialized by ExxonMobil 20 years ago (*CE*, March 1986, p. 12E).

HPD to supply salt production and caustic facility to Shintech

October 1, 2008 — Shintech Inc., a wholly owned subsidiary of Shin-Etsu Chemical Co., Ltd. of Japan, has selected HPD (Plainfield, Ill.), a Veolia Water Solutions & Technologies company, to supply a salt crystallization plant and a caustic-soda-concentration system as part of the expansion of its production facility in Plaquemine, La. This expansion will double the output in the existing Plaquemine facility. Current production includes polyvinyl chloride (PVC) resins, 1.0 billion lb/yr of chlorine, 1.1 billion lb/yr of caustic soda, 1.65 billion lb/yr of vinyl chloride monomer (VCM), and 1.3 billion lb/yr of PVC. Shin-Etsu is the world's largest producer of PVC.

Vertellus Specialties to expand vitamin B3 production in China

September 30, 2008 — Vertellus Specialties Inc. plans to expand its vitamin B3 manufacturing capacity in Nantong, Jiangsu. Vertellus is proceeding with the engineering and permitting work to build a 3-cyanopyridine production unit at Nantong with capacity of 7,000 metric tons (m.t.) per year. Vertellus expects to break ground on this project in the beginning of 2009.

UOP technology selected for refinery expansion in United Arab Emirates

September 30, 2008 — UOP LLC, a Honeywell company, has announced that the Abu Dhabi Oil Refining Co., also known as Takreer, has selected UOP to supply technology and engineering services for an expansion at its Ruwais Refinery in the United Arab Emirates. The refinery will produce propylene, unleaded gasoline, naphtha, liquefied petroleum gas (LPG), aviation turbine fuel, kerosene, gas-oil, bunker fuel and other hydrocarbon derivatives. The refinery is expected to be complete in 2014.

Chemtura to boost calcium-sulfonate-grease capacity by 60%

September 29, 2008 — Chemtura Corp. will increase calcium-sulfonate-grease capacity by 60% at its West Hill, Ont., Canada plant. The higher volume is scheduled to go online by Fall 2009.

ABB wins $36-million solar-power order in China

September 25, 2008 — ABB has won a contract with LDK Solar to supply electrical systems, equipment and related engineering and project management services for a new production plant in Xinyu City, China. When completed, the facility in Jiangxi province will be Asia's largest polysilicon plant, with a capacity of 15,000 m.t./yr. The first production line of the new plant is scheduled for completion in the 4th Q of 2008, and 5,000 to 7,000 m.t. of polysilicon are expected to be produced in 2009.

Ticona to add LCP Unit at Nanjing integrated chemical complex

September 24, 2008 — Ticona, the engineering polymers business of Celanese Corp., has announced that it plans to build a new 7,000-m.t./yr liquid-crystal-polymer (LCP) production facility at the Celanese integrated chemical complex in China. Construction is slated to begin in the 1st half of 2009, and the facility is projected to be operational in 2010.

MERGERS AND ACQUISITIONS

SABIC establishes 'SABIC Capital Ltd.' in the Netherlands

October 14, 2008 — The Saudi Basic Industries Corp. (SABIC) has announced the establishment of a new, wholly owned company with a paid up capital of €18,000. The company, SABIC Capital Ltd., is based in the Netherlands. The new company will be primarily responsible for the financing and tax operations of SABIC's investments in Europe and the U.S. following the acquisitions of DSM Petrochemicals, GE Plastics and other acquisitions.

Veolia Water and Mubadala launch a joint-venture company

October 7, 2008 — Mubadala Development Co. (Mubadala) and Veolia Water have announced their intention to create a joint-venture company that will focus on water production and wastewater collection and treatment in the Middle East and North Africa (MENA) region. The joint-venture company will be owned 51% by Veolia Water and 49% by Mubadala. ■

Dorothy Lozowski

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November 2008; VOL. 115; NO. 12

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2008 — 2007

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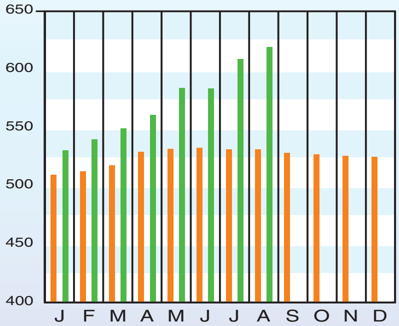
CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Aug. '08 Prelim.	Jul. '08 Final	Aug. '07 Final
***CE* INDEX**	619.3	608.8	531.5
Equipment	761.0	746.4	632.9
Heat exchangers & tanks	784.2	760.1	602.9
Process machinery	680.6	669.5	601.5
Pipe, valves & fittings	881.5	875.5	747.4
Process instruments	457.8	459.0	428.6
Pumps & compressors	872.9	869.9	836.1
Electrical equipment	468.1	468.2	434.5
Structural supports & misc	843.9	815.8	669.9
Construction labor	325.1	322.1	317.4
Buildings	529.7	521.5	478.6
Engineering & supervision	352.3	352.9	356.4

Annual Index:
2000 = 394.1
2001 = 394.3
2002 = 395.6
2003 = 402.0
2004 = 444.2
2005 = 468.2
2006 = 499.6
2007 = 525.4

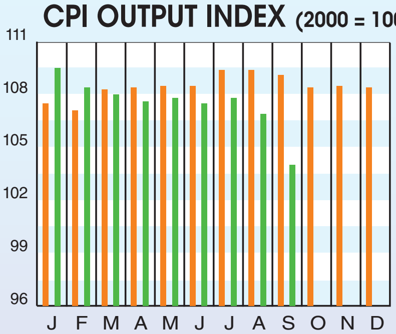


Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics

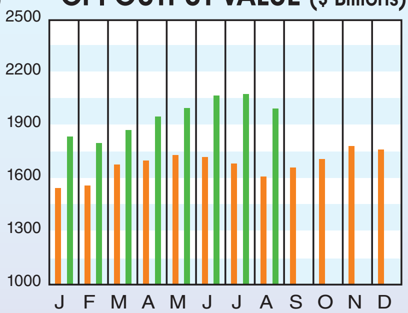
CURRENT BUSINESS INDICATORS

	LATEST		PREVIOUS				YEAR AGO	
CPI output index (2000 = 100)	Sep. '08	= 104.0	Aug. '08	= 106.9	Jul. '08	= 107.8	Sep. '07	= 109.1
CPI value of output, $ billions	Aug. '08	= 1,998.2	Jul. '08	= 2,082.0	Jun. '08	= 2,073.9	Aug. '07	= 1,687.5
CPI operating rate, %	Sep. '08	= 77.0	Aug. '08	= 79.2	Jul. '08	= 79.9	Sep. '07	= 81.6
Construction cost index (1967 = 100)	Oct. '08	= 802.8	Sep. '08	= 796.6	Aug. '08	= 778.4	Oct. '07	= 749.0
Producer prices, industrial chemicals (1982 = 100)	Sep. '08	= 314.6	Aug. '08	= 323.8	Jul. '08	= 304.5	Sep. '07	= 227.5
Industrial Production in Manufacturing (2002=100)*	Sep. '08	= 108.5	Aug. '08	= 111.3	Jul. '08	= 112.3	Sep. '07	= 114.0
Hourly earnings index, chemical & allied products (1992 = 100)	Sep. '08	= 143.9	Aug. '08	= 142.3	Jul. '08	= 142.0	Sep. '07	= 142.5
Productivity index, chemicals & allied products (1992 = 100)	Sep. '08	= 130.2	Aug. '08	= 133.5	Jul. '08	= 132.8	Sep. '07	= 137.8

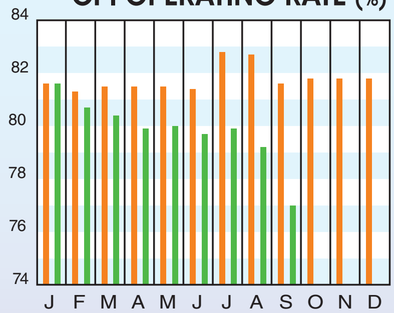
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE ($ Billions)



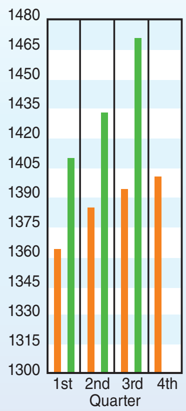
CPI OPERATING RATE (%)



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

MARSHALL & SWIFT EQUIPMENT COST INDEX

(1926 = 100)	3rd Q 2008	2nd Q 2008	1st Q 2008	4th Q 2007	3rd Q 2007
M & S INDEX	1,469.5	1,431.7	1,408.6	1,399.2	1,393.0
Process industries, average	1,538.2	1,491.7	1,463.2	1,452.3	1,445.6
Cement	1,522.2	1,473.5	1,448.1	1,435.3	1,427.5
Chemicals	1,511.5	1,464.8	1,438.5	1,427.9	1,421.0
Clay products	1,495.6	1,453.5	1,429.1	1,415.0	1,408.8
Glass	1,432.4	1,385.1	1,359.7	1,348.8	1,341.8
Paint	1,543.9	1,494.8	1,467.6	1,457.1	1,451.2
Paper	1,443.1	1,400.0	1,377.7	1,369.2	1,364.0
Petroleum products	1,644.4	1,594.4	1,555.8	1,543.7	1,536.2
Rubber	1,575.6	1,537.5	1,512.3	1,500.1	1,494.8
Related industries					
Electrical power	1,454.4	1,412.8	1,380.4	1,374.9	1,359.0
Mining, milling	1,546.2	1,498.9	1,473.3	1,460.8	1,453.2
Refrigeration	1,793.1	1,741.4	1,711.9	1,698.8	1,691.7
Steam power	1,499.3	1,453.2	1,426.8	1,416.4	1,407.4



Annual Index:

2000 = 1,089.0	2002 = 1,104.2	2004 = 1,178.5	2006 = 1,302.3
2001 = 1,093.9	2003 = 1,123.6	2005 = 1,244.5	2007 = 1,373.3

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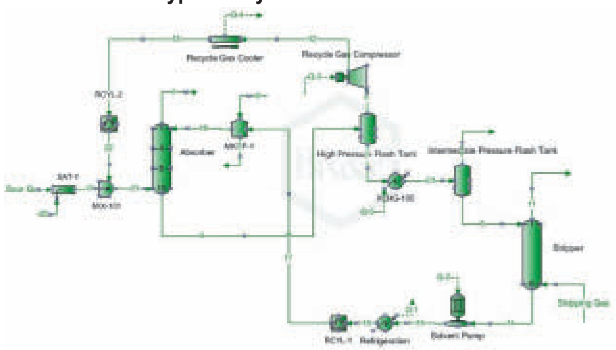
PROCESS INSIGHT

Comparing Physical Solvents for Acid Gas Removal

Physical solvents such as DEPG, NMP, Methanol, and Propylene Carbonate are often used to treat sour gas. These physical solvents differ from chemical solvents such as ethanolamines and hot potassium carbonate in a number of ways. The regeneration of chemical solvents is achieved by the application of heat whereas physical solvents can often be stripped of impurities by simply reducing the pressure. Physical solvents tend to be favored over chemical solvents when the concentration of acid gases or other impurities is very high and the operating pressure is high. Unlike chemical solvents, physical solvents are non-corrosive, requiring only carbon steel construction. A physical solvent's capacity for absorbing acid gases increases significantly as the temperature decreases, resulting in reduced circulation rate and associated operating costs.

Typical Physical Solvent Process



DEPG (Dimethyl Ether of Polyethylene Glycol)

DEPG is a mixture of dimethyl ethers of polyethylene glycol. Solvents containing DEPG are marketed by several companies including Coastal Chemical Company (as Coastal AGR®), Dow (Selexol™), and UOP (Selexol). DEPG can be used for selective H_2S removal and can be configured to yield both a rich H_2S feed to the Claus unit as well as bulk CO_2 removal. DEPG is suitable for operation at temperatures up to 347°F (175°C). The minimum operating temperature is usually 0°F (-18°C).

MeOH (Methanol)

The most common Methanol processes for acid gas removal are the Rectisol process (by Lurgi AG) and Ifpexol® process (by Prosernat). The main application for the Rectisol process is purification of synthesis gases derived from the gasification of heavy oil and coal rather than natural gas treating applications. The two-stage Ifpexol process can be used for natural gas applications. Methanol has a relatively high vapor pressure at normal process conditions, so deep refrigeration or special recovery methods are required to prevent high solvent losses. The process usually operates between -40°F and -80°F (-40°C and -62°C).

NMP (N-Methyl-2-Pyrrolidone)

The Purisol Process uses NMP® and is marketed by Lurgi AG. The flow schemes used for this solvent are similar to those for DEPG. The process can be operated either at ambient temperature or with refrigeration down to about 5°F (-15°C). The Purisol process is particularly well suited to the purification of high-pressure, high CO_2 synthesis gas for gas turbine integrated gasification combined cycle (IGCC) systems because of the high selectivity for H_2S.

PC (Propylene Carbonate)

The Fluor Solvent process uses JEFFSOL® PC and is by Fluor Daniel, Inc. The light hydrocarbons in natural gas and hydrogen in synthesis gas are less soluble in PC than in the other solvents. PC cannot be used for selective H_2S treating because it is unstable at the high temperature required to completely strip H_2S from the rich solvent. The FLUOR Solvent process is generally limited to treating feed gases containing less than 20 ppmv; however, improved stripping with medium pressure flash gas in a vacuum stripper allows treatment to 4 ppmv for gases containing up to 200 ppmv H_2S. The operating temperature for PC is limited to a minimum of 0°F (-18°C) and a maximum of 149°F (65°C).

Gas Solubilities in Physical Solvents

All of these physical solvents are more selective for acid gas than for the main constituent of the gas. Relative solubilities of some selected gases in solvents relative to carbon dioxide are presented in the following table.

The solubility of hydrocarbons in physical solvents increases with the molecular weight of the hydrocarbon. Since heavy hydrocarbons tend to accumulate in the solvent, physical solvent processes are generally not economical for the treatment of hydrocarbon streams that contain a substantial amount of pentane-plus unless a stripping column with a reboiler is used.

Gas Component	DEPG at 25°C	PC at 25°C	NMP at 25°C	MeOH at -25°C
H_2	0.013	0.0078	0.0064	0.0054
Methane	0.066	0.038	0.072	0.051
Ethane	0.42	0.17	0.38	0.42
CO_2	1.0	1.0	1.0	1.0
Propane	1.01	0.51	1.07	2.35
n-Butane	2.37	1.75	3.48	-
COS	2.30	1.88	2.72	3.92
H_2S	8.82	3.29	10.2	7.06
n-Hexane	11.0	13.5	42.7	-
Methyl Mercaptan	22.4	27.2	34.0	-

Choosing the Best Alternative

A detailed analysis must be performed to determine the most economical choice of solvent based on the product requirements. Feed gas composition, minor components present, and limitations of the individual physical solvent processes are all important factors in the selection process. Engineers can easily investigate the available alternatives using a verified process simulator such as ProMax® which has been verified with plant operating data.

For additional information about this topic, view the technical article "A Comparison of Physical Solvents for Acid Gas Removal" at http://www.bre.com/tabid/147/Default.aspx. For more information about ProMax, contact Bryan Research & Engineering or visit www.bre.com.

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