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*Effective change management for control systems is key to avoiding vulnerabilities*

APRIL 2019

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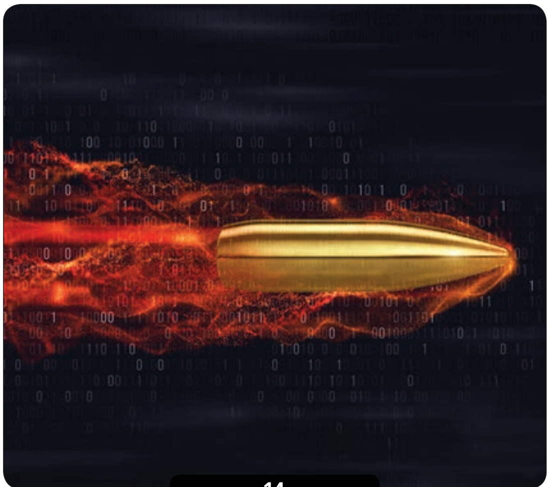

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# Do Your Part to Bolster Safety

Keep up-to-date on relevant issues and incidents

**OUR INDUSTRY** too often has learned lessons about process safety the hard way — by evaluating what went wrong after a disaster. Such analysis can provide insights that can improve the safety of many chemical plants. For instance, a final report issued in mid-February by the U.S. Chemical Safety Board (CSB) on an incident in June 2016 at the Enterprise Products Pascagoula Gas Plant in Pascagoula, Miss., pinpoints the probable cause as thermal fatigue of a brazed aluminum heat exchanger (BAHX) widely used in similar plants. (See: "CSB Cites Thermal Fatigue In 2016 Pascagoula Gas Plant Explosion," http://bit.ly/2XwLrqv.)

The CSB notes that incident stemmed from a major loss of containment in a BAHX. This resulted in release of methane, ethane, propane and several other hydrocarbons. Their subsequent ignition led to a series of fires and explosions that idled the site for almost six months.

"More than 500 gas processing facilities operate across the country and the use of similar heat exchangers is common. Extending the life cycle of equipment at these facilities requires more robust inspection protocols. Operators shouldn't take the risk of waiting to find a leak because, as this case demonstrates, that leak could result in a catastrophic failure," warns CSB Interim Executive Kristen Kulinowski.

The CSB believes that improving the safe use of BAHXs requires more-realistic and updated guidance, and recommended that two trade associations share information related to failure hazards of BAHXs from thermal fatigue. That certainly seems sensible.

Indeed, building more awareness of this potential problem is essential. So, too, is maintaining that awareness over time. The late safety guru Trevor Kletz repeatedly lamented (e.g., in "Bhopal Leaves a Lasting Legacy," http://bit.ly/2El0s68) that the same mistakes recur because lessons get forgotten.

Three elements underpin effective enduring process safety: performing thorough and competent hazard analyses and promptly addressing issues identified (follow-up too often is inadequate, according to "Foil HAZOP Failings," p. 9, http://bit.ly/2JEqjMt); maintaining a corporate culture that puts process safety top-of-mind and makes everyone responsible for it (see: "Make Safety Second Nature," http://bit.ly/2BXAzZH); and broadly sharing best practices and other insights so others don't have to learn the hard way.

A few key resources can give you a sense of what's happening.

As part of a personal commitment to process safety, you should strive to keep current on issues, incidents and insights. Regularly checking a few key resources can give you a good sense of what's happening in process safety. I suggest you visit the websites of the CSB (www.csb.gov.), the Mary Kay O'Connor Process Safety Center at Texas A&M (http://psc.tamu.edu), the IChemE Safety Centre (www.icheme.org/knowledge/safety-centre/) and the Center for Chemical Process Safety (www.aiche.org/ccps).

*Chemical Processing* is another valuable resource. We publish far more process-safety-related content than any other magazine in our field. (Put "process safety" in the search box on Chemicalprocessing.com to see how much.) Moreover, for several years we have presented a series of free process safety webinars in collaboration with the Mary Kay O'Connor Process Safety Center. For details on this year's webinars, go to: http://bit.ly/2ECsoov.

Process safety is too important to be left solely to specialists. ●

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# Comical Processing Celebrates Ten Years

Readers have relished cartoons wryly relevant to their work

The artwork is still hand drawn.

**IN COLLEGE** I had a journalism professor who joked that the only reason people bought the newspaper was for the comics. She then would say that it doesn't matter what gets them to open the paper just as long as they do.

That lesson always stayed with me and it's why I suggested we run a cartoon based on the chemical industry. I wanted to give you another good reason to visit our website — aside from all the award-winning content. So, in April 2009, we launched Comical Processing featuring cartoons created by artist Jerry King (www.chemicalprocessing.com/cartoon-caption).

King's first cartoon was published in his high school newspaper. "When I was younger I didn't say, 'I'm going to be a cartoonist.' I was just bored in class."

He credits a kind teacher who realized he didn't have a knack for the electrical engineering coursework he was taking at the time. "He knew I was struggling but he also knew I was good at drawing. He said 'Maybe we can get you in a class about art because that's where you belong,'" recalls King.

From there, a career was launched. He's illustrated children's books, worked at numerous greeting card companies, spent 20 years as a cartoonist for Playboy magazine and currently creates between 200–300 cartoons per month for myriad publications including *Chemical Processing*. He credits the diversity to his longevity in the business.

"I wanted to be a political cartoonist when I first started out," says King. "They had one gig. Now, the dangers about having one gig, if you lose that gig, you're in trouble."

## CHECK OUT OODLES OF CARTOONS

Over the years we've put together compendia of the most-popular Comical Processing cartoons in several eBooks. You can access PDFs of the eBooks here: http://bit.ly/ComicalProcessingeBooks


A lot has changed since he started his career. "In the old days, I'd have to go to a bookstore and look up magazines and write down the addresses to the editor, send them cartoons and pray that they would get back to me," explains King. "Back then you sent your cartoons in on a piece of paper. Those days were brutal on me. The internet has really saved me."

While all the artwork is still hand drawn, King scans in the outline to his computer and applies the color digitally. His overhead is super low — he uses typing paper bought in bulk and regular pens. "I buy them 20 in a pack for $3. It's great day-to-day but I suffer come tax time," he jokes.

In a world of serious news and day-to-day stress at work, cartoons are a welcome distraction. "I think it gives people an opportunity to be creative. It gives them a little break," says King. The popularity of Comical Processing proves his point. Each new cartoon gathers dozens of captions from our readers.

"The cartoons are a nice way to think about something other than looming deadlines or the latest 'crisis,'" notes Larry Shade, senior production engineer, Chemtrade Logistics. "I generally look at them over lunch." Shade is a regular contributor to Comical Processing. "I became hooked with the first cartoon I saw, 'I think you forgot to carry the 1.' It is still my favorite." (see: https://bit.ly/2EWdUOf).

Agreeing with the pleasant distraction aspect of the cartoon is Jatin D. Shah, technical director, Finornic Chemicals (India) Pvt. Ltd. "Jerry has brought humor to a subject that is pretty serious. It gives [us] a chance to put across our take on the serious nature of our work."

At one point in his life, King wanted to be a professional boxer. In fact, he fought during his tour in the Army. He even won the Golden Gloves in Akron, Ohio. "I love boxing but I'm old and, you know, I'm a cartoonist. I need to stay in my own lane where I belong. I'm going to stick with the cartoons."

We are certainly glad he will continue to knock out cartoons for us. To celebrate his decade of cartoons, King created a special Comical Processing featuring himself. We are asking readers to submit congratulatory captions. You can do so here: http://bit.ly/2Ciy4Bo.

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# Foil HAZOP Failings

Poor preparation and follow-up undermine safety reviews

Why don't regulators review progress?

**APPROPRIATE ACTION** on most items flagged in a hazard and operability (HAZOP) evaluation too often doesn't take place before the next HAZOP. Some key items from the checklist will roll into projects and process studies but the vast majority will get ignored. That's the harsh reality that I've witnessed over and over again for more than thirty years. For instance, two years after a HAZOP, I found plant staff hadn't touched 90% of the items from a chlorine checklist. (By the way, I was able to reduce that number to 10% in only three months.) Why does this happen?

Well, the most obvious reason is personnel are busy and management doesn't have the resources. The HAZOP follow-ups actions just join the existing, usually substantial, backlog of work. Unfortunately, there's little incentive to tackle them. After all, promotions seldom depend on clearing up backlogs. You don't see people listing this as an achievement on their resumés, do you?

In addition, safety management deficiencies also usually contribute.

For instance, consider the way planning typically takes place for a HAZOP. Even though every covered process must undergo a HAZOP every five years, many sites wait far too long to prepare, resulting in a mad rush at the end; people suffer HAZOP fatigue. No wonder the will to complete tasks uncovered during the review usually dissipates.

It's easier to update drawings, files and procedures continually rather than every five years. Why not assign the projects department or the individual process engineer involved in a project with the responsibility for updating the drawings? I can brag here because I always took this up as a personal responsibility. However, I understand the reluctance of many engineers; getting the drawings caught up after years of neglect by lazy engineers can pose a challenge. Management sometimes doesn't help; engineers get re-assigned or leave because of downturns. Managers are hesitant to hand these efforts to experienced engineers — who likely will see them as grunt work — and, so, wind up forgetting to assign them. Yet, there's a good alternative, one that I've mentioned before: entrust engineers new to a site or fresh from college to clear up HAZOP items, update drawings, etc.; it's an excellent way for them to become site-savvy.

Another valuable approach is creating a current material balance — one based on actual laboratory data. This is more important than updated process and instrumentation drawings. Too often, balances are based on models or simplifications that don't reflect reality — and, thus, may endanger people. Lab measurements can reveal flaws in models.

Oversight is another failure. Companies may proclaim safety as their top priority but don't always act that way. Why don't safety managers demand meetings to review progress? Why don't corporations support better oversight? Probably because of lack of foresight, as is apparent in the Arkema accident reported in *The New York Times*: https://nyti.ms/2tP8lfv.

*The Times* article noted that the company failed to update contingency plans. I would bet that procedures and other key operating plans hadn't been revised in many years either. This touches upon an issue that afflicts many sites: inexperienced chemical engineers, quite appropriately, are reluctant to change things they don't understand and don't have mentors to bring them up to speed. As a result, updating gets pushed back or ignored.

Another problem is the lack of practical experience among regulatory staff. Part of this stems from prejudice in industry hiring practices: try getting a job in industry once you've served as a regulator! Ideally, safety inspectors should know as much about the unit operations at a facility as the engineering staff. Industry should promote this by encouraging a free flow of personnel between industry and regulatory bodies. Experience benefits industry; familiarity breaks down walls. Of course, some might worry about potential conflicts of interest. However, state and federal agencies now review documents almost simultaneously, minimizing the risk. Moreover, public agencies must share information via the Freedom of Information Act.

Regulators could help by auditing progress towards completion of HAZOP items. However, this never is done — even at sites where fatal accidents occur. Regulators should review progress every few years for these sites and others they believe deserve attention based on risk, past performance and other factors. I'd suggest regulators consider recent takeovers and downsizings. My experience is that sites in turmoil tend to have more accidents than those that are stable. ●

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# Algae to Biocrude Process Gets a Boost

## Novel extraction method reduces energy needed to separate lipids from biomass

**A SPECIALLY** designed jet mixer underpins a method to turn algae into biocrude oil more economically, say researchers at the University of Utah (UU), Salt Lake City.

Current methods to extract oil-rich lipids from algae require an energy-intensive process in which water is pulled from the algae first, leaving either a slurry or dry powder. That residue is then mixed with a solvent where the lipids are separated from the biomass. What's left is the biocrude, used to produce algae-based biofuel. However, the water extraction requires so much energy that the process uses more energy than the resulting biocrude provides. Therefore, turning algae into biofuel thus far hasn't been practical, efficient or economical, explains UU chemical engineering assistant professor Swomitra Mohanty.

The team's extractor process cuts energy consumption and thus improves the prospects for making algae-based biocrude. It involves a reactor that shoots jets of solvent at algae, creating a localized turbulence in which the lipids "jump" a short distance into the stream of solvent. The solvent is then extracted and recycled for reuse in the process. An article in *Chemical Engineering Science X* contains more detail.

"Harvesting has typically been the most energy-intensive part of algal biofuel production. Use of impinging jet mixers accomplishes the extraction at ambient temperature and pressure, is exceedingly fast (fraction of a second), and uses less-toxic solvents in comparison to alternative techniques. This is the trifecta of extractive harvesting," says Mohanty.

"The key piece here is trying to get energy parity. We're not there yet, but this is a really important step toward accomplishing it," adds Leonard Pease, a member of the research team. "We have removed a significant development barrier to make algal biofuel production more efficient and smarter. Our method puts us much closer to creating biofuels energy parity than we were before."

BIOCRUDE RESEARCHER

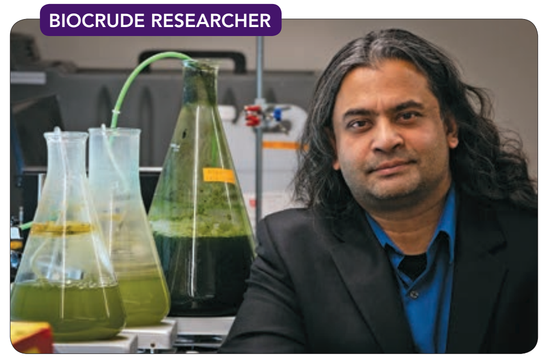


Figure 1. Swomitra Mohanty, pictured with beakers of algae, is part of a team that developed a jet mixer for turning algae into biomass using much less energy than other methods. *Source: Dan Hixson, University of Utah College of Engineering.*

While current research is still at bench scale, the team now is exploring expanding the use of the confined impinging jet mixers for processing other microorganisms, including bacteria and fungi, with lipid oil and potentially partnering with industrial firms for scale-up of the technology. "We have plans to start this work and are preparing proposals to fund it. Ideally, we hope to start additional studies this fall," notes Mohanty. "Depending on the funding available, this could be scaled-up in the few years." Their work already has attracted interest from domestic and overseas companies.

Achieving a scale suitable for industrial use doesn't pose any issues, notes Mohanty. "Overall, we see no reason why the technology could not be proven outside the lab and scaled up," he adds. "Scalability was an initial factor in selecting this impinging jet mixer design over others. However, a rigorous evaluation of scalability has not been performed. In addition, a full-scale design hasn't been built or optimized, so additional technical development would be required. However, the initial costs of the system we published was modest."

Mohanty admits that other portions of the biofuel production process remain a challenge. "Each step needs optimized as a holistic system. We have additional innovations in the pipeline, so stay tuned," he concludes.

TO PARTICIPATE IN THIS MONTH'S POLL, GO TO CHEMICALPROCESSING.COM.

How do you characterize the effectiveness of your site's efforts to capture knowledge from retiring technical staff?


Just over one third of respondents rated their site's effectiveness as moderate.

# Tri-bore Fiber Membranes Enhance Water Treatment

**A NEW** type of hollow fiber membrane stars in a novel water treatment system that potentially may reduce toxic waste and associated waste disposal costs by over 90%, says its developers at the National University of Singapore.

The thermoplastic fluoropolymer membrane, invented by Neal Chung, a professor in the department of chemical and biomolecular engineering, has three hollow cores, allowing for a water flow rate that's about 30% higher than that achieved by other hollow-fiber membranes.

The membrane will feature in a 5,000-L/d pilot plant, which is a joint effort between the Separation Technologies Applied Research and Translation (START) Centre, a national-level facility to develop and commercialize innovative separation and filtration technologies, and Memsift Innovations, a local water technology firm specializing in zero-liquid-discharge water treatment systems.

The pilot plant should start operation in June and run for 18 months. It will get wastewater from a nearby semiconductor facility; if all goes according to plan, the pilot plant will save the company up to 1.6 million L/yr of water and about S$250,000 (≈$184,000) in disposal costs. Currently, the semiconductor maker transports toxic wastewater to an incineration facility.

The pilot process will operate under vacuum at between 50°C and 80°C, notes Memsift founder J. Antony Prince. He believes the tri-bore membrane will help improve the efficiency of the company's patent-pending Improved Membrane Distillation (IMD) process.

"The TS-30 IMD system… can be operated using low-grade waste heat from industries or solar panels. If there is waste heat available, the operating cost can be significantly reduced — to less than 2.5kW/m$^3$ at a reference capacity of 100 m$^3$/day and above," he says.

"We still need to optimize the process for the new membrane and cleaning methods need to be established. The data from this pilot study also is intended to help us to find ways to address other unknowns such as membrane lifetime," explains Prince.

Meanwhile, START already has begun fabricating the tri-bore fiber on an industrial scale (Figure 2).

If the pilot is successful, Memsift will take a full license and commercialize the new membrane system.

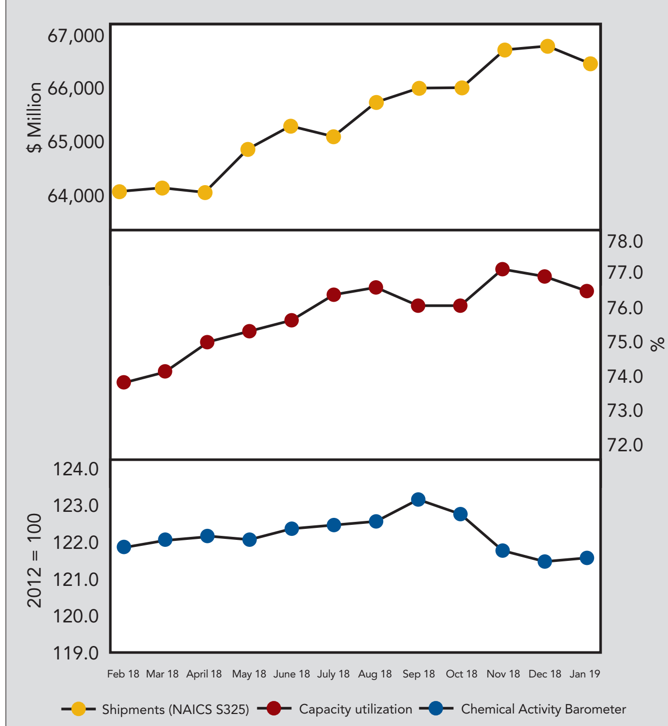
"We believe that the 30% increased efficiency of this membrane will bring Memsift more opportunities in the market place," adds Prince.

MEMBRANE MANUFACTURE

Figure 2. START Centre now is commercializing production of tri-bore membranes, shown here being dried. *Source: National University Singapore.*

Other members of SG-MEM, Singapore's national membrane consortium, also will have access to the tri-bore membrane for commercial collaborations.

ECONOMIC SNAPSHOT




Shipments and capacity utilization slipped slightly but the CAB rose a bit. *Source: American Chemistry Council.*

# Consider a Thermocompressor

This unit offers potential opportunities for improving energy efficiency

The thermocompressor allowed us to maximize power generation, and thus minimize net steam cost.

**I FIRST** encountered a thermocompressor as a young process engineer working at a multiple-effect salt evaporation plant. The device sat at the back of the plant, blending medium-pressure steam (MPS) and low-pressure steam (LPS), to provide intermediate-pressure steam (IPS) for the evaporation train. In the years since then, I've found many other uses for thermocompressors. They are used commonly to satisfy a demand for steam at a pressure that's slightly higher than one of the header pressures in the site's central steam system — generally the low-pressure (LP) header. In most cases, the end user of the steam is a reboiler for a distillation column.

So, what is a thermocompressor, and how does it help us improve energy efficiency?

Bernoulli's Theorem is essentially an energy balance for flowing fluids. In its simplest form, it can be written as: $p+\rho v^2/2$ = constant, where $p$ is the pressure of the fluid, $\rho$ is its density, and $v$ is its velocity. In this form, the equation assumes the fluid is incompressible, which actually applies only to limited cases. However, it does illustrate the key principle of the thermocompressor: assuming no energy enters or leaves a fluid, its pressure falls when its velocity rises, and vice versa.

A thermocompressor consists of a metal casing with three main parts: a motive steam nozzle, a mixing chamber and a diffuser. With no moving parts, it's generally a low-maintenance item.

In the evaporator example, the steam that drives the compression (MPS) is called "motive steam;" the steam that's compressed (LPS) is called "suction steam," and the combined effluent (IPS) is the "discharge steam." The motive steam enters the thermocompressor through the motive steam nozzle, where it expands and accelerates into the mixing chamber. Due to its increased velocity, we know from Bernoulli's Theorem that the motive steam's pressure drops. It reaches a pressure below that of the suction steam, which is drawn into the mixing chamber. The two steam streams intermingle, and the combined flow enters the diffuser, where the velocity falls. The pressure therefore rises, and reaches its discharge value, which lies between the motive and suction pressures.

The same principles also apply to steam jet vacuum systems. These also use steam as the motive medium; however, in this case the suction load is usually either air or a process vapor, at a pressure below ambient.

The usefulness of thermocompressors is tied to the interface between central steam systems and process plants. For example, the utility plant for our salt evaporators also served several other plants, and it provided high-pressure steam (HPS), as well as MPS and LPS. The HPS came directly from the boilers — but the MPS and LPS were obtained by passing HPS through steam turbogenerators. These produced electricity, which reduced the amount of expensive power we had to import from the grid. Our salt evaporation system required a pressure between the MPS and LPS levels. We could have supplied this by passing MPS steam through a pressure-reducing valve, but this would have lost the very significant benefit of power generation between the MPS and LPS pressure levels. This thermocompressor allowed us to maximize power generation, and thus minimize net steam cost.

The steam system at our site was well-balanced, and we didn't often vent LPS. However, there are many sites where LPS venting is a constant problem. In such cases, the LPS used in a thermocompressor reduces the LPS vent. This is usually more valuable than increasing power generation.

Thermocompressors also can be used to compress low-pressure flash vapor. The vapor can be obtained by flashing steam condensate or by flashing an aqueous process stream [1]. On its own, the flash vapor isn't at a high enough pressure to be useful. However, the thermocompressor, can boost it to a pressure for use in process applications such as stripping or reboiling for distillation columns. In this way, "waste heat" can become "useful heat."

However, the practical range of operability for thermocompressors is limited. The percentage of suction steam in the mix decreases as the discharge pressure increases. As a rule of thumb, a thermocompressor can only be justified if the motive:suction flow ratio less than 2:1. In a typical MPS/LPS thermocompressor, this would deliver a discharge pressure about 2 bar higher than the LPS (suction) pressure.

## REFERENCE:

1. Alan P. Rossiter, Glenn T. Cunningham & Bruce Bremer, "Save Energy Without Investing Capital," AIChE Spring Meeting and 12th Global Congress on Process Safety, Houston, TX, April 12, 2016, Paper No. 72a.

**ALAN ROSSITER**, Energy Columnist
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# GAO Evaluates EPA Performance

Government accountability office downgrades agency's progress on assessing toxic chemicals

Greater openness and transparency regarding the EPA's current thinking and approach would be welcome.

**THE U.S.** Government Accountability Office (GAO) released on March 6, 2019, a report titled "High-Risk Series: Substantial Efforts Needed to Achieve Greater Progress on High-Risk Areas." This column discusses the report and its implications on chemical management policy.

The GAO's high-risk program identifies government operations with vulnerabilities to fraud, waste, abuse and mismanagement, or in need of transformation to address economy, efficiency or effectiveness challenges. The GAO's report describes the status of high-risk areas and outlines actions necessary to ensure further progress. The GAO notes that since adding this area to its High-Risk List in 2009, it has made 12 recommendations to the U.S. Environmental Protection Agency (EPA) related to the Integrated Risk Information System (IRIS) Program and the Toxic Substances Control Act (TSCA).

The GAO evaluated the IRIS Program on five criteria to assess progress in addressing high-risk areas: leadership commitment, agency capacity, an action plan, monitoring efforts, and demonstrated progress. The GAO states that, since its 2017 report, four criteria remain unchanged. However, the rating for leadership commitment declined to "partially met."

The GAO evaluated the TSCA on the same five criteria and stated that, since its 2017 report, ratings for capacity, monitoring, and demonstrated progress have advanced to "partially met." The rating for leadership commitment remains unchanged at "met" and for action plan at "partially met."

The GAO has made three recommendations since adding TSCA implementation to its High-Risk List in 2009. To make progress, the EPA will need to implement one open recommendation, along with meeting the high-risk criteria discussed above. The GAO states that the EPA must maintain leadership commitment and ensure it has the resources and plans in place to facilitate progress. The EPA will need, for example, to respond to provisions in the Frank R. Lautenberg Chemical Safety for the 21st Century Act, such as having 20 ongoing risk evaluations by December 2019 and making findings on the safety of all new chemicals. The GAO states the EPA and Congress should consider ensuring resources dedicated to TSCA activities are sufficient to implement the many TSCA reform activities on the EPA's plate.

The latest GAO high-risk report is generally consistent with its prior recommendations concerning actions needed to improve performance under the IRIS Program and TSCA implementation. Several factors contribute to the EPA's downgrade from "met" to "partially met" regarding the agency's leadership commitment to the IRIS Program. These include the lack of a restatement of commitment to the IRIS Program by current EPA leadership, an almost 50% decline in the EPA's budget request for IRIS, and inadequate recent reporting by the EPA on the status of IRIS assessments and changes made. Greater openness and transparency regarding the EPA's current thinking and approach would be welcome.

At the same time, it is unclear if legal requirements for chemical assessments under the TSCA are affecting the EPA's leadership views on resourcing and prioritizing IRIS assessments. These assessments are of value to many stakeholders, domestically and internationally; they can be a critical input to meeting statutory requirements by other EPA offices. The EPA is not, however, legally required to produce IRIS assessments. This situation thus differs significantly from the new TSCA where the EPA is under considerable pressure to meet statutory deadlines for risk evaluations.

Interestingly, the key GAO recommendation pertains to TSCA Section 6 in assessing and regulating existing chemicals. While TSCA Section 6 implementation is a work in progress, the EPA has had to implement and meet the new chemical requirements under the new TSCA Section 5 for almost three years now. We recognize the EPA's commitment to accelerate the pace of new chemical review and applaud its efforts. It would seem, however, that some greater GAO focus in this area is warranted and future GAO reviews should highlight Section 5 action.

Notable for its absence is any mention of TSCA Section 4, the new testing provision that includes new-but-as-yet-untried legal authority to require testing by order. The EPA can't easily meet its broader obligations under the new TSCA in the absence of an appropriately robust program to obtain the toxicity and exposure information needed to inform EPA's scientific and assessment judgments on TSCA chemicals. Previous GAO reports focused on the EPA's limited efforts in implementing Section 4, so the current silence puzzles us. ●

**LYNN L. BERGESON**, Regulatory Editor
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# COMBAT CYBE THRE

## *Effective change management for control systems is key to avoiding vulnerabilities*

By Eddie Habibi, PAS Global

**THE QUEST** for continuous improvement in the process industries always requires change. However, when not managed properly, change can lead to disaster. Chemical makers and refiners often use their industrial control system (ICS) — the cyber-physical assets responsible for automated controls and safety — as the platform for continuous improvement. At most sites, the ICS undergoes more changes than any other production asset. Yet, while operating companies around the world for almost three decades have accepted management of change (MOC) as a best practice when altering physical assets such as valves and pumps, many processors have failed to consistently apply the same level of rigor to managing configuration changes to the ICS. Investigations into several major plant accidents by the U.S. Chemical Safety Board and the U.K. Health and Safety Executive have identified improper modifications to ICS

# RSECURITY ATS TO PROCESS SAFETY

alarms, control loops and safety instrumented systems (SISs) as either a major contributing factor or a root cause of the incident.

Meanwhile, the fast-growing threat of cyberattacks initiated by nation states or criminals seeking ransoms has created an urgent need to lock down and protect the ICS configuration. Furthermore, unmanaged change initiated by internal actors — employees and contractors — can lead to the same catastrophic consequences that an external bad actor can impart on a production facility.

Boards of directors today recognize the risks to their process safety, profitability and brand reputation posed by unprotected cyber-physical assets. The good news is that defining and implementing a basic cybersecurity strategy that includes change management of the ICS configuration will go a long way in protecting against cyber vulnerabilities, both external and internal.

## A CRUCIAL ELEMENT

ICSs comprise field instruments (sensors and actuators), distributed control systems (DCSs), SISs, supervisory control and data acquisition (SCADA) systems, process historians, advanced applications, process analytical systems, and more. An ICS plays a number of key roles:

*Repository for intellectual property (IP).* The ICS is the real-time container of IP, the collective knowledge essential for effective performance and safety. For instance, a DCS may hold details such as the highly proprietary recipe for a polymer product or a complex strategy for controlling the outlet temperature of an ethylene furnace. The configuration of a DCS

represents important and highly valuable company IP. Its configuration also includes operational, safety and equipment design operating limits. So, protecting the trade secrets embedded in the configuration of a DCS must be a top concern to a corporation's general counsel and chief financial officer.

*Defender of safety.* The basic process control loop function in a DCS provides protection against process disturbances in real time, preventing a minor upset from becoming a major abnormal situation. The DCS alarm management system notifies the console operator when intervention is required to correct a process or equipment anomaly. The SIS is designed to prevent significant equipment damage as well as catastrophic incidents by detecting unstable and out-of-control conditions and initiating a graceful shutdown of the process. Mechanical relief systems go to work in situations where the SIS has failed to effectively contain an abnormal situation.

*Protector of equipment.* Operational, safety and design boundaries configured in the DCS ensure that automated control loops can push the process to its farthest limits without violating critical constraints. The DCS provides this protection automatically, 24/7.

*Platform for continuous improvement.* The ICS is like a fine bottle of wine: it becomes more valuable as it ages. That's because control and production engineers are constantly modifying the configuration of the system to enhance controllability, safety, quality and yield. Continuous improvement requires continuous change to the system. It's not unusual for a control engineer to alter the configuration of a system multiple times a week.

## CHALLENGES IN MANAGING CHANGE

Change can deliver improvement only if it's managed methodically and consistently. Ensuring effective MOC for ICSs requires grappling with a number of difficult issues. These include:

*Disparate and multigenerational systems.* As a result of plant expansions, acquisitions and modernization projects, a typical process plant today may rely on ten different classes of ICS systems and applications, from five major automation vendors, representing three different generations of technologies.

*Highly complex and proprietary structures.* ICSs are inherently complex because they contain detailed configuration and logic programs for automatic control of the process. ICSs also are highly proprietary. Each control system type has a unique architecture, communication protocol, hardware and operating system. Interoperability among control systems from different automation vendors is achievable but difficult to implement and maintain due to the proprietary nature of each system. In fact, different generations of control systems from the same automation vendor usually require special gateways to communicate. Proprietary ICSs generally aren't designed to operate third-party applications. The complexity and challenges of interoperability among ICS devices has created considerable engineering and operational challenges for owner operators.

*The human factor.* The control system administrator at many process plants also serves as the process control engineer. As such, that person often is the designer, implementer, quality assurance engineer and trainer for improvements to the ICS configuration. Even a seasoned engineer who is deeply trusted by the organization is human and prone to error. Human error is a significant contributing factor in most industrial accidents. Additionally, the number of qualified professionals to manage the ICS continues to decline due to an aging workforce and a diminishing pipeline of qualified engineers. Many companies struggle to attract new college graduates to manage and maintain 30-plus-year-old technology.

*ICS cybersecurity.* This is one of the greatest risks threatening the industrial sector today. Cybersecurity has attained the same level of priority in the minds of industry executives and board members as safety has over the past three decades. The threat of a cyberattack on an ICS no longer is viewed as a hypothetical possibility — and there's widespread recognition that potential instigators include far more than a few grungy hackers in some dark basement. Legitimate experts and governmental threat intelligence professionals have traced several attacks on the ICS within critical infrastructure to nation states.

Meanwhile, criminals see an opportunity in ransomware attacks such as the one against the city of Atlanta in 2018. Boards of directors now appreciate the cyberthreat to their production assets as a serious risk to safety and profitability. They are demanding plans from CEOs and executive staff to proactively manage that risk.

### LESSONS FROM PROCESS SAFETY

In 1992, the U.S. Congress passed the Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) 29 Code of Federal Regulation (CFR) 1910.119 for operators and handlers of highly hazardous chemicals. The sixteen articles of the PSM have become a standard compliance practice etched into the culture of most process companies worldwide. What makes this regulation unique is its broad acceptance and ubiquitous practice by the industry. The fact that OSHA regulators sought industry's safety best practices and incorporated them into the regulation has made 1910.119 the darling of professional safety practitioners. One of the most prominent articles of 1910.119 is Article 8, Management of Change.

Most companies have implemented some level of MOC procedures to avoid incidents caused by mistakes resulting from modifications to the configuration of the ICS. These MOC procedures are designed to prevent inadvertent errors by well-intentioned employees. However, managing change on the ICS has become more difficult because companies now must consider change initiated by two new adversaries: the malicious insider and the third-party bad actor. The consequences of a faulty configuration change to the ICS are the same regardless of the source. Operating companies must take configuration change management seriously and implement work processes to ensure the integrity of the ICS. A robust MOC program for the ICS must underpin any ICS cybersecurity strategy.

Just as MOC has become an integral part of the safety culture in most process companies, it now must become a cohesive component of cyber-physical asset management.

### THE PATH FORWARD

Industry executives recognize the crucial role of the ICS in process safety and operations. They also have come to understand that ICS vulnerability to cyberattacks is a real

and potentially significant business risk that must be managed accordingly. Many leading operating companies have launched corporate-wide programs to systematically manage their exposure to ICS cybersecurity risk. Others currently are developing their strategy to tackle this risk. Addressing the cybersecurity risk is a considerable undertaking.

Success depends upon building a solid foundation in two ways: acting with urgency and engaging the executive team.

The current state of ICS cybersecurity is not unlike where PSM 1910.119 was in 1992. With one exception, 1910.119 was a regulation with a five-year grace period to attain 100% compliance. Cybersecurity has no grace period. It's a real and immediate business risk but one that's stealthy and unpredictable. Like a known safety gap left unmitigated, it continues to pose a risk to the business. It demands urgent action.

A successful ICS cybersecurity risk management program starts with the support of the board of directors and the executive management team. In addition, it requires high-level accountability for the overall cybersecurity program and its execution.

Then, with urgency and executive engagement, an ICS cybersecurity program, at a minimum, should focus on the following five critical steps:

*1. Know what you have.* Treat your ICS cyber-physical assets as the invaluable assets they are to your process safety and production. First, establish an accurate inventory of the ICS assets throughout the enterprise. The inventory must encompass the mix of disparate mission-critical devices that make up the ICS, including operator consoles, process controllers, input/output cards, smart field instruments, programmable logic controllers and other devices. At minimum, capture hardware make and model, operating system and firmware version/revision, software applications and other relevant information for each device. Additionally, include the physical location of each asset. A complete and accurate inventory of the ICS assets is an essential first step toward everything else in the program.

*2. Understand your risks.* Conduct a risk assessment. Make it a high priority. The purpose of an ICS risk assessment is to identity, classify and prioritize security gaps that can impact the

availability and proper functioning of the ICS. Remember that the ICS includes the SIS. If your SIS contains critical vulnerabilities such as bypass of a trip function, it may fail to safely shut down the process under hazardous conditions.

Risk assessment is another area where ICS cybersecurity can benefit from the proven practice of process hazard analysis outlined in PSM 1910.119. The premise here is that not all devices are mission critical and not all vulnerabilities can result in a safety incident or lead to production loss. To that end, giving different classifications to cyber assets based on threat exposure, vulnerability and consequences is the proper approach to assessing risk.

*3. Tackle vulnerabilities.* Immediately address known vulnerabilities with high impact on critical devices. At the highest level, two categories of vulnerabilities exist: known and unknown. ICS vendors issue patches for known vulnerabilities; operating companies must act with urgency in dealing with any such high-impact vulnerabilities. Obviously, a company can't address unknown vulnerabilities.

*4. Manage change.* Attackers take control of the process by making changes to the configuration of the ICS. Generally, ICS hackers have deep knowledge of the targeted system. They also know the environment they are attacking, whether an ethylene furnace or an electric grid. Through social engineering and information readily available on the Internet, they can map their target and act with precision to create unsafe conditions. Types of attacks include manipulating control functions to immediately trip a process or modifying code to disable or bypass a function that is required in the future. Disabling a critical alarm, for instance, denies the operator the notification of an emerging hazardous condition requiring immediate action. In another example, bypassing a trip function works as a ticking bomb in the SIS.

What is needed first is a rigorous MOC policy. Stakeholders such as engineers, operators and technicians must receive training on the policy. Next, the automation system team must capture a baseline of the system. A baseline represents the golden standard against which to evaluate future changes to the system. Changes beyond those the console operator needs to apply to run the process must require adherence to the MOC policy. Changes to control strategies, critical alarm settings and safety systems must begin with documenting the current configuration, proposed changes, what-if-analysis of what can go wrong, approval by appropriate staff, training of operators, and other standard procedures defined in the MOC procedure.

*5. Automate backup and recovery.* Companies must assume their ICS will be compromised at some point, just as they assume a safety incident will occur despite all the mitigation measures. Incident response is a critical part of an effective ICS security strategy. It's absolutely critical to maintain an up-to-date version of the system configuration that is no older than the rate of change typically implemented on the device (weekly for assets modified on a day-to-day basis, monthly or bi-monthly for devices altered less frequently). As discussed earlier, change to the control system's configuration is the vehicle for implementing many continuous process improvement ideas. It's also the mechanism used by bad actors to hijack an ICS and inflict harm. Automated backup of the system is essential to rapid recovery from a shutdown.

## FINAL THOUGHTS

The ultimate intention of bad actors attacking critical infrastructure isn't to move bits of digital information but to move molecules and electrons in a manner that causes physical harm. Documented cyberattacks on critical infrastructure in every case have included configuration changes to the ICS that led to physical harm. It is hard enough to avoid safety incidents initiated due to inadvertent errors by well-intentioned people in the organization. Now, we also must consider changes implemented by those with bad intentions. ICS security is a safety challenge. The effective consequence of a successful cyberattack by bad actors is no different from that of an actual safety incident. Process industries executives must address the ICS cybersecurity challenge in the same manner they have successfully dealt with the ever-present challenge of process safety. ●

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# Take a Fresh Look at Your Distillation Columns

**Many towers may benefit from potential improvements**

By Seán Ottewell, Editor at Large

**OPPORTUNITIES ABOUND** for enhancing the performance of tens of thousands of distillation columns in use worldwide today. However, that requires looking at every aspect of their operation, maintenance and management, say experts.

Jose Bravo, President of Fractionation Research Inc., Stillwater, Okla., points to a variety of energy saving measures that have been — and still are being — implemented in distillation systems worldwide. They encompass three broad areas: process integration, peripherals, and advanced control and optimization.

Process integration can take advantage of a range of technologies. For instance, he cites dividing wall columns and notes that hundreds of such columns now operate at chemical plants and refineries. (For more details on the technology, see: “Consider Dividing Wall Columns,” http://bit.ly/2OgwW6a). He also mentions several dozen projects for recovering heat from condensers to preheat feed, a similar number involving lower pressures in main fractionators at refineries, and the use of advanced packings and re-traying to reduce pressure drop.

The second category includes developments such as enhanced surface tubes for condensers and reboilers. In the third group, he counts technologies such as smart controls, adaptive controls, model-based controls and on-line continuous optimization.

Importantly, however, he notes that energy alone usually isn’t a large enough economic incentive.

“All these projects are always associated and justified with other drivers as well, energy being only one. The others are, generally, lower capital for expansion or new capacity, safety or reduction of carbon dioxide footprint. Combined, they often give a positive economic outlook that allows the plants to invest,” he emphasizes.

## IMPROVING EXISTING OPERATIONS

Henry Kister, senior fellow and director of fractionation technology for Fluor, Aliso Viejo, Calif., has experience with all these drivers. However, one crucial issue often overlooked is making the most out of existing equipment, he notes.

“Troubleshooting, revamping and eliminating waste can offer

huge benefits in capital investment, downtime, carbon dioxide emissions and energy use. Unfortunately, the attention paid to this resource in the energy-saving literature has been too little to reflect its tremendous potential," he stresses.

Kister points to a broad range of examples in Norman Lieberman's book "Process Engineering for a Small Planet: How to Reuse, Re-Purpose, and Retrofit Existing Process Equipment" as a perfect demonstration of how subpar engineering, poor troubleshooting, and wasteful practices guzzle energy, generate carbon dioxide, and waste the earth's resources.

In one, Lieberman describes a case in which modifying trays and downcomers in a fractionator as well as adding mist injection to the overhead compressor could have circumvented erecting a giant new fractionator with a new oversized overhead compressor. "Just the compressor oversizing was estimated to waste the amount of crude oil that 400 families use daily. Fabricating the new steelwork and structures consumed immense amounts of energy and emitted tons of carbon dioxide, all of which were unnecessary," says Kister.

In another, Lieberman recounts how he was tasked with designing a new, $4-million pre-flash tower to replace an existing

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one that experienced flooding. "Instead, he spent one day eliminating the flooding in the existing tower by reducing the bottoms liquid level (high levels caused flooding), and blowing the level taps on the reflux drum water draw-off boot, unplugging them to prevent refluxing water which caused emulsion and flooding on the trays," Kister points out.

A third example he mentions involves Lieberman being tasked with designing another new tower to recover diesel from the bottoms stream of a refinery crude fractionator. Instead, he opted to troubleshoot, measuring zero pressure drop across the fractionator bottom trays, and observing that stripping steam rates did not affect diesel recovery. "Both indicated missing stripping trays. Repairing the trays fully solved the problem and modifying the steam entry prevented recurrence, circumventing the unnecessary new tower with its steelwork, energy waste and associated carbon dioxide emissions," Kister adds.

"Lieberman presents a book full of similar experiences, with different degrees of management support to his troubleshooting endeavors. In the examples cited above, managements set their minds on the new column solutions in preference to troubleshooting: jack hammers to crack nuts," notes Kister.

Kister's own book "Distillation Troubleshooting" illustrates similar issues. For example, one case study describes an olefins debutanizer receiving two feeds. The larger feed contained only 8% $C_4$s and was the bottoms of a stripper that removed $C_3$s; with good design that column also would have stripped the 8% $C_4$s. When at one time the larger stream was bypassed around the debutanizer, the steam consumption dived to less than half. As Kister notes: "Whatever does not enter the column does not consume energy."

Another describes how direct-contact compressor intercoolers provided poor cooling for many years, causing excessive compressor energy consumption. This only was noticed after plant rates were raised and the inadequate cooling began restricting throughput. A close review showed that the tower's pipe distributors had a quality rating index as low as 13% (>75% is good). Debottlenecking with well-designed, inexpensive spray distributors and improved shed decks reduced compression energy and debottlenecked compressor capacity.

Such long-term issues waste huge amounts of time, money and manpower — as further illustrated by the case of a refinery where for 11 years about 2% of the crude oil that should have been recovered as valuable diesel product ended up in the much-less-valuable residue from a crude tower. This also wasted energy because the diesel in the residue was vaporized in a downstream fired heater. A simple water leak test at the turnaround revealed that the diesel draw pan was leaking; seal-welding the joints recovered the lost diesel yield. "Excellent troubleshooting," comments Kister.

Then, too, there's the case of a retray project at closer spacing that increased tray count by 50%. This successfully improved product purity — but the new trays operated right at their capacity limit. Because the plant wanted to raise throughput by 15% at the

next turnaround, engineers planned to replace the new trays with structured packing. The tower was large, so the replacement would require tons of steel and lots of money. Getting the energy balance to close by solving flowmeter issues revealed that the reflux and reboil were much higher than design, meaning the trays fell well short of achieving their design efficiency. "Modifying the trays solved the problem without the extra steel and expense of the structured packings," Kister explains.

"In last three cases, managements supported making the troubleshooting solutions: there was no need for sledge hammers," he emphasizes.

In another experience, a small packed stripper tower was erected to purify a wastewater stream destined for cooling water makeup. The entering wastewater poured above the hats of the liquid distributor. The oversized hats filled most of the cross-section area, leaving little area for vapor ascent simultaneous with liquid descent. The resulting high vapor velocities between the hats blew the incoming water upwards, causing flooding. "Two different consultants studied the problem, the first offering an incorrect diagnosis and an ineffective fix, the second, based on an extensive simulation study, incorrectly concluding that a bigger tower was needed. The plant gave up and junked the tower, with wastewater still going to sewer. Good troubleshooting, and a nickel-and-dime job of modifying the hats and feed pipe, would have produced good water," he points out.

"Finally," says Kister, "a new hydrocarbon gas absorber (not by Fluor) flooded at reflux rates exceeding two-thirds of the design due to premature downcomer choke induced by excess foaminess. Based on this diagnosis, we were requested to provide new trays with enlarged downcomers. Our response was: 'Do we have to?' Performance is judged by product purity, not reflux. Upon adequate testing, the overhead gas impurity was found tenfold below design. The absorption was good thanks to the colder-than-design reflux. Here the 'don't worry, be happy' approach, based on good troubleshooting, saved resources, energy, and money."

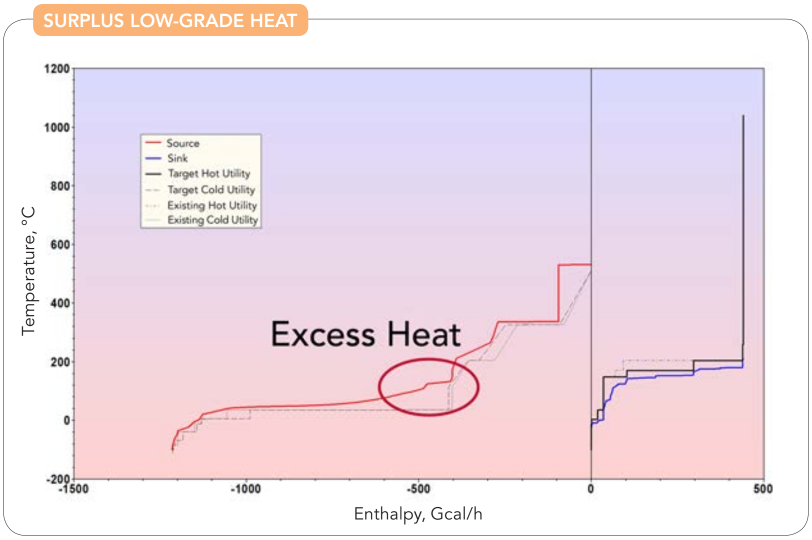



Figure 1. Complex 1 had the potential to supply very low pressure steam and hot water. *Source: KBC.*

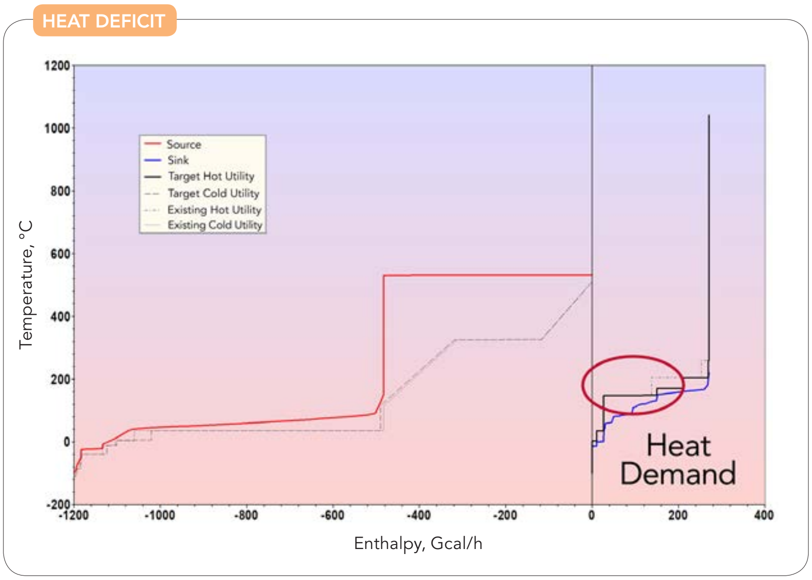



Figure 2. Complex 2 had a large demand for low grade heat. *Source: KBC.*

### PROCESS SIMULATION SUCCESSES

The experiences of KBC Advanced Technologies, London, a Yokogawa company, amply illustrate the potential benefits of Bravo's third category, process control and optimization.

When considering energy in distillation revamps, process simulation built on rigorous thermodynamics, such as KBC's Petro-SIM, should serve as the fundamental tool for evaluating revamp options, stresses KBC business development executive Andrew McIntee.

"This type of tool can be used to assess all the engineer's options and calculate the potential for making improvements. Adding heat pumps, side condensers/reboilers and low-grade heat recovery can be fairly straightforward; however the challenge is that

there are many options, and the best solution is usually very specific to the application," he explains.

Pinch analysis enables strategically evaluating options, he notes. These could involve, for example, modifying column pressures to fit in with the background heat availability, and investigating if a heat pump brings any net benefit if it doesn't recover heat across the pinch. In addition, column pinch analysis allows systematically looking at feed location, temperature and side reboiling/condensing.

"Using powerful and accurate tools, users can consider all the interactions of the column and its equipment with the surrounding asset and complex. Combining these unlocks greater potential than local optimization," adds McIntee.

As an example, he cites the experience of a client wishing to optimize integration to save energy and capital at a world-scale integrated petrochemical site. Two large facilities there (Complex 1 and Complex 2) had been optimized individually — but TotalSite pinch analysis revealed many valuable opportunities for integration.

For example, the analysis found that Complex 1 potentially could supply very low pressure steam (VLPS) and hot water (Figure 1). However, that facility didn't have much demand for these. Meanwhile, in Complex 2, Cracker 2 lacked sufficient supplies of low-grade heat (Figure 2).

Complex 2 had been designed with a heat pump on the $C_3$ splitter. Seen in isolation, this was a rational design because Cracker 2 had a heat deficit and could use a heat pump to recover energy from the condenser. However, the integrated design utilizing hot water from Complex 1 provided both operational savings (6 MW for the heat pump compressor) and capital ones (eliminating the cost of the compressor).

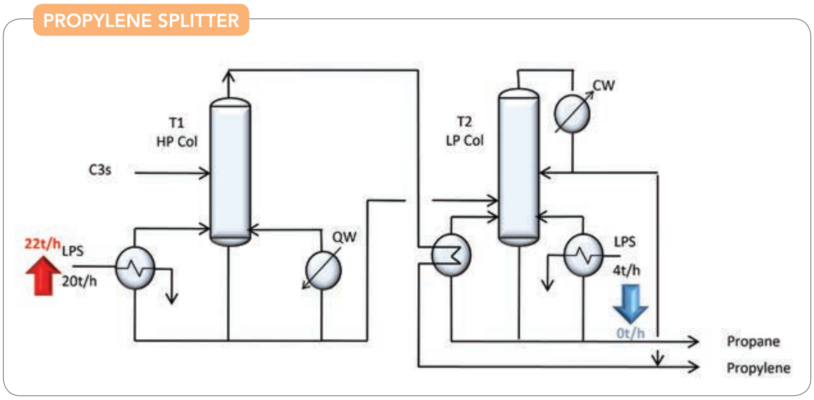



Figure 3. Analysis led to a recommendation for a shift in duty between the two towers. *Source: KBC.*

"Overall, the complex was able to generate 22MW of power from low-grade heat, while revised driver selection improved steam balance and reduced capital costs.

An operational quick win was identified through examining the whole distillation train. Modelling it allowed clear assessments of the potential energy saving operation while ensuring the process was not compromised," says McIntee.

Another example involves a propylene splitter (Figure 3) where a shift in duty between towers was recommended.

Here, $C_3$ separation columns were well integrated with overheads from the first, high-pressure tower (T1), used to reboil the second, low pressure column (T2). Heat input to T1 was used twice. The analysis showed that an increase in duty (supplied by low pressure steam, LPS) in the T1 reboiler reduces the duty of the T2 reboiler by factor of two. This led to a recommendation to maximize LPS use on T1. The overall saving is 2 t/h of LPS worth $450,000/y; a plant trial has confirmed this saving.

A third called for resequencing of debutanizer columns. Here, the original design called for steam reboilers on De-$iC_4$ + De-$C_4$ columns. Due to significant change to alkylation feedstocks and rate during the front-end engineering design, the energy use and, therefore, operating cost rose by nearly 160%.

Pinch analysis and considering the entire plant including the utilities showed a resequencing of the columns (from De-$iC_4$ + De-$C_4$ to De-$C_5$ + $C_4$ splitter) could reduce overall energy use.

The first column utilized excess high-pressure steam while the second column could be fitted with a heat pump.

"Overall energy use returned to near original levels with the cost savings totalling $27.6 million/y," says McIntee.

Digitalization promises new technologies in the area of distillation energy efficiency improvements, he believes. For example, digital twins and improved data analytics directly integrated with closed-loop advanced process control can identify unusual column operation.

"KBC is completing proof of concepts with multi-period proactive optimization, where energy cost is optimized over a time period. For example, the process is adjusted so that low-priced energy can be stored for better financial benefit later on," he notes.

"On the grassroots design front, Pinch fully integrated into simulation is almost here, and the next steps are for AI [artificial intelligence]-driven option evaluation and opportunity identification to allow continual optimization by considering all the other changes happening during the design. This moves the process from a linear step to continual iteration and a global optimum," he concludes.

# CHECK SAMPLE SYSTEM PRESSURE DROP

Correctly calculating and managing the loss is crucial for proper performance | By Randy

**THE FINAL** step in designing sample lines for your analytical sampling system is to assess whether enough pressure differential exists between the process tap and the return point to drive the flow you want through the lines. If the differential isn't sufficient, you may have to apply a different design strategy.

At this stage of the design process, you already will have made numerous decisions related to your system layout and performance. You've decided on whether to use a single-line system (Figures 1a and 1b) that disposes of samples via a vent or drain, or a fast-loop system (Figures 1c and 1d) in which the sample returns to process (see: "Choose the Right Sampling System Transport Line," http://bit.ly/2QdgAzx). You've estimated your time delay and made adjustments to meet your acceptable target. You've made design decisions related to fluid velocity and flow, and found whether laminar or turbulent flow (Figure 2) occurs in your sample lines (see: "Consider Flow Regime's Impact on Sample Analysis," http://bit.ly/2EBrc2f).

Now, you're ready to determine the pressure loss in your sample lines. Multiple factors, including line length and diameter, the number of bends in a system, elevation changes, friction, sample fluid density, flow velocity, and other factors, cause pressure drop. If your sample lines require more differential pressure than currently available, you won't achieve the desired sample velocity. You may need to install a sample pump or move the process tap to a higher-pressure line.

To compute the pressure loss in your sample lines, you must use the Darcy equation. We'll review this

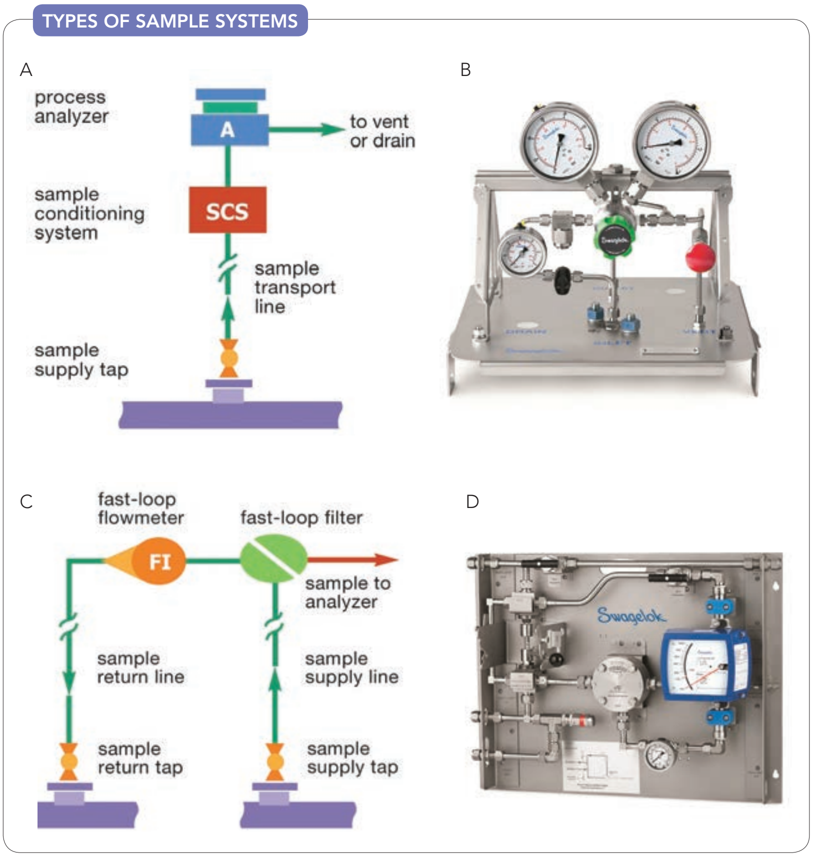
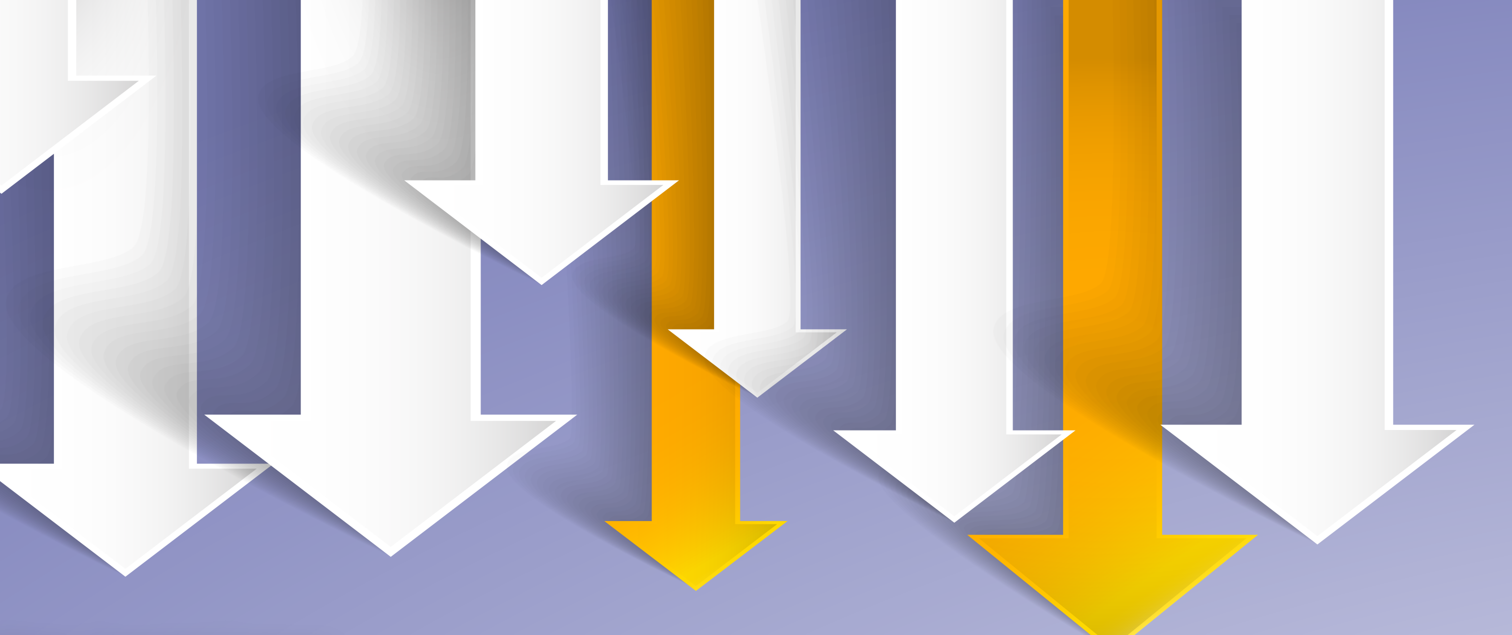



Figure 1. Single-line system (a, b) disposes of sample while fast-loop system (c, d) returns sample to process. *Source: "Industrial Sampling Systems."*



Rieken, Swagelok Company

equation and provide some guidelines for maintaining a suitable pressure differential in your system.

### FINDING PRESSURE LOSS

The Darcy equation allows you to determine if enough pressure difference exists between the sample tap and return point to achieve the desired response time for your sampling system. If not, you'll have to modify the design, perhaps by using a larger return line. If excess pressure is available, you might choose to use smaller sample line sizes or to absorb the excess pressure across a needle valve.

If you design your sample lines to absorb all the available pressure, you can save the cost of a flowmeter and needle valve. However, you won't be able to check the performance after installation, except by recalculating the flow rate and time delay based on the actual pressures observed during startup.

Either way, you must calculate the required differential pressure using the Darcy equation:

$$\Delta P = (f L \rho u^2)/2D \qquad (1)$$

where $\Delta P$ is change in pressure (Pa), $f$ is friction factor (dimensionless), $L$ is line length (m), ρ is fluid density ($kg/m^3$), $u$ is flow velocity (m/s) and $D$ is line diameter (m).

Entering all values in coherent SI units yields a $\Delta P$ value in pascals (Pa). A shortcut version of the equation accepts the line diameter ($D'$) in millimeters and returns the pressure drop ($\Delta P'$) in kilopascals (kPa):

$$\Delta P' = (f L \rho u^2)/2D' \qquad (2)$$

When making any adjustments to your system, your design work will focus on the flow velocity ($u$) and the line diameter ($D$) because application conditions fix the other variables. Keep in mind that the friction factor ($f$) isn't a constant. It varies with operating conditions; you must account for any condition changes that may alter the friction factor and how it's calculated.

**FLOW REGIMES**

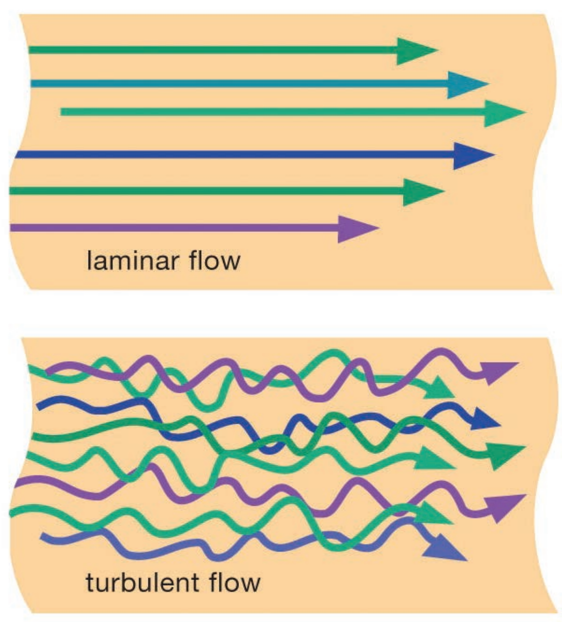



Figure 2. Turbulent flow encourages good sample mixing. *Source: "Industrial Sampling Systems."*

### MANAGING SAMPLE SYSTEM FLOW

This article is the third in a three-part series on the topic. It was adapted from "Industrial Sampling Systems: Reliable Design and Maintenance for Process Analyzers" (2013), a process sampling textbook authored by Tony Waters and published by Swagelok Company. For more information, visit www.industrial-sampling-systems.com.

EQUIVALENT LENGTHS

| Line | Fitting | L/D* |
|---|---|---|
| Tube Fittings | 45° tubing bend | 15 |
| | 90° tubing bend | 20 |
| | 90° elbow | 60 |
| | Tee – branch | 60 |
| Pipe Fittings | 45° elbow | 16 |
| | 90° elbow | 30 |
| | Tee – run | 20 |
| | Tee – branch | 60 |

* Multiply by the line internal diameter (m) to get the equivalent length (m).

Table 1. Add the equivalent length of all fittings to actual line length for a value to use in the Darcy equation. *Source: "Industrial Sampling Systems."*

### APPLICATION TO GAS SAMPLES

Strictly speaking, the Darcy equation doesn't directly apply to gas samples because their density and velocity both change as the pressure drops along the line. However, in typical sampling lines, gas samples have very little pressure drop, so the accuracy of the calculation usually isn't an issue. If your initial calculation yields a significant line pressure drop, you can improve accuracy by averaging the inlet and outlet pressures and repeating the calculation.

*Allowing for bends.* Each sharp bend in a line will incur some additional pressure loss that you must account for in your calculations. When possible, install lines with gradual bends because they barely will affect the pressure drop. If this is impractical and you must use pipe or tube fittings, or bends formed with tube benders, it's convenient to assign an equivalent length to each bend to represent the pressure drop it causes.

Table 1 lists some typical equivalent lengths expressed as multiples of the internal diameter. Multiply the appropriate length-to-diameter ratio (*L/D*) by your line bore to get the equivalent length of each tube bend or fitting.

For example, ½-in. tube has a bore of about 10 mm and a 90° tubing elbow has an *L/D* ratio of 60. Therefore, each elbow tube fitting adds an extra 0.6 m to the effective length of the line:

$$0.01 \text{ m} \times 60 = 0.6 \text{ m}$$

You also must account for various pipe fittings and valves in the system. You can obtain equivalent lengths for these components from available resources, such as the International Electrotechnical Commission standard IEC/TR 61831 for pipe fittings and valves, as well as manufacturers' $C_v$ values for valves and other flow components.

Total the equivalent lengths of all the bends, fittings and components in your lines. Then, add this sum to the actual line length, and use this value for $L$ in the Darcy equation to calculate the pressure drop. If you don't have enough $\Delta P$, you may need to reduce the number of bends.

*Allowing for elevation change.* Liquid samples lose pressure when raised to a higher elevation and gain pressure when coming down. Often, the pressure lost going up equals the head gained when returning to grade. The net result is a wash. Even so, always check that enough source pressure exists to reach the higher elevation.

To calculate the static head gained or lost from an elevation change ($h$), use the following equation:

$$\Delta P = h\,\rho\,g \qquad (3)$$

where ρ is the liquid mass density (kg/m³) and g is the acceleration due to gravity (9.81 m/s²).

As a memory aid, note that water at 4°C has a mass density of 1,000 kg/m³. When a cold water line rises 10 m to an overhead pipe rack, its pressure drops by 98 kPa (about 1 bar):

$$\Delta P = 10 \text{ m} \times 1{,}000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 = 98{,}000 \text{ Pa}$$

Elevation usually doesn't affect gas samples to any significant degree because it takes about 100 km of elevation to create an ambient air pressure of 1 bara.

*Using a larger return line.* Most fast loops have supply and return lines about equal in size and length (Figure 1d), making the pressure drop the same in each. This arrangement produces a convenient and simple design when enough pressure is available to drive both lines. However, when you must contend with limited available pressure differential, you can't afford to waste half of it on the return.

A useful strategy to minimize the pressure absorbed in the return line is to increase its diameter because the velocity of a fluid drops when it enters a wider line. For example, going from a supply

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line with 10.2-mm internal diameter (½-in. tube) to an equal-length return line with 15.8-mm internal diameter (¾-in. tube) will split the pressure drop such that only about 10% occurs in the return line. The other 90% of $\Delta P$ goes to moving the sample to the analyzer. The friction factor of your system may alter this effect slightly. However, in general, when the return line is one line size larger than the supply line and is about equal in length, it's safe to assume that approximately 85% of $\Delta P$ is available to drive the sample to the analyzer.

When dealing with marginal available $\Delta P$, fast loops using larger return lines often are less expensive to install than same-size designs and consume far less flow. For example, you can match the response time of a fast loop with low differential pressure that uses 1-in. tubing by opting instead for ½-in. supply tubing and ¾-in. return tubing. The alternative system would run at only 25% of the original flow rate, making it a better design choice because it's cheaper to install, uses less sample material and is less likely to interfere with process operations.

When using a fast loop, ensure enough flow exists to drive your fast-loop filter; manufacturers specify a minimum flow rate for self-cleaning filters.

Using a larger return line also makes sense when a common return line serves multiple fast loops. In this case, choose a line size that can handle the total flow with a pressure drop that's acceptable for each of the fast-loop supply lines. To calculate the pressure drop, estimate the density and viscosity of the mixed return fluid. Keep the pressure drop in the return line as low as possible so the return pressure doesn't vary with the number of fast loops running — otherwise you may affect the performance of the analyzers.

*Using a smaller return line.* When you have ample pressure differential, it's possible to install a smaller return line to maximize sample pressure to the analyzer. This rarely is done, though. Instead, most designers opt for a needle valve to allow flow and pressure adjustments, and minimize their design risk.

## WATCH THE BUBBLE POINT

When transporting a volatile liquid, you must ensure high enough pressure at every point in the line to suppress bubble formation. When a liquid flows through horizontal lines or gains elevation, its pressure drops, thus reducing its bubble point temperature. If the pressure falls enough, the liquid will start to bubble or boil and may begin to foam. In an elevated line, vapor lock might occur and prevent further liquid flow.

Check for the lowest pressure in the transport line system, not forgetting its highest elevation. If the pressure dips too low, you must modify the design to cool the liquid or increase its source pressure at the sample tap before the pressure drop occurs.

To cool the sample flow, use a heat exchanger. Don't assume the liquid will cool sufficiently as it travels down a bare line.

If you opt for a pump to increase pressure, install it at grade close to and below the process nozzle, and put a larger line on its suction side. Never mount a pump at a higher elevation than the sample tap. Also, keep in mind that the gear pumps typically used for sample lines are positive displacement devices that create a constant flow. Because the pump controls the flow, you can't install a needle valve in the fast loop to do the same thing.

## FINAL THOUGHTS

To ensure your analytical sampling system delivers adequate flow to meet your desired response time, you must have a sufficient pressure differential between the supply tap and return point. Too little pressure differential will delay your analysis and potentially create issues like bubbling of a liquid sample. Use the Darcy equation to calculate the pressure differential your system design needs and then determine if you must adjust any variables to achieve your desired target. Don't be surprised if you must make changes. The design process is iterative. Therefore, it's useful to enter your system data and the equations into a spreadsheet so you can review a variety of options before arriving at an optimal system for your application. ●

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# Jumpstart Your Digital Transformation

## Taking ten steps in a pilot project can lead to better results

By Will Goetz, Emerson Automation Solutions, and Niv Weisenberg, operations consultant

**AS SENSING** technology continues to become more ubiquitous and affordable, chemical processors have come to rely on quantifiable data collected from their assets to bring new products to market and optimize the production of current ones. Not only within the plant but across the entire enterprise, chemical makers are looking to digitalization to help ensure safety and deliver greater mechanical availability with lower maintenance costs. These improvements in turn increase utilization rates while lowering operating costs — a critical differentiator in a highly competitive marketplace.

Flexible, scalable and powerful, digital transformation technologies and strategies — coupled with a well-planned and executed pilot initiative — are driving a step change in plant performance (Figure 1). Companies that make the commitment to embark on a digital transformation reduce downtime by up to 70% and lengthen asset lifecycles by over 15%.

A small digital transformation initiative implemented with the right strategies can provide opportunities to build momentum and knowledge across the organization from a small initial investment.

PERFORMANCE IMPROVEMENT

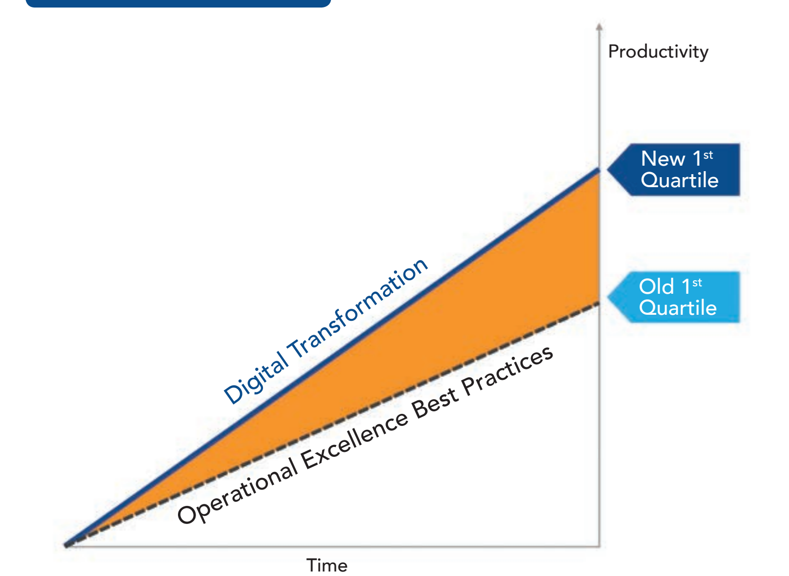


Figure 1. Digital transformation can deliver results that surpass those of operational excellence best practices.

### KEY STEPS FOR SUCCESS

By leveraging ten critical steps, companies running a digital transformation pilot can avoid common roadblocks, helping deliver better implementations of any size. Let's look at each of these steps.

*1. Clearly define success criteria.* Prescriptive analytics can glean new insights from data (Figure 2). However, because prescriptive analytics strategies are new, many organizations are skeptical about their impact. While caution is healthy when implementing new technology, undue skepticism sometimes can lead implementation teams to focus too much on technology and not enough on business goals. This can result in a rushed or poorly planned pilot implementation that incorrectly

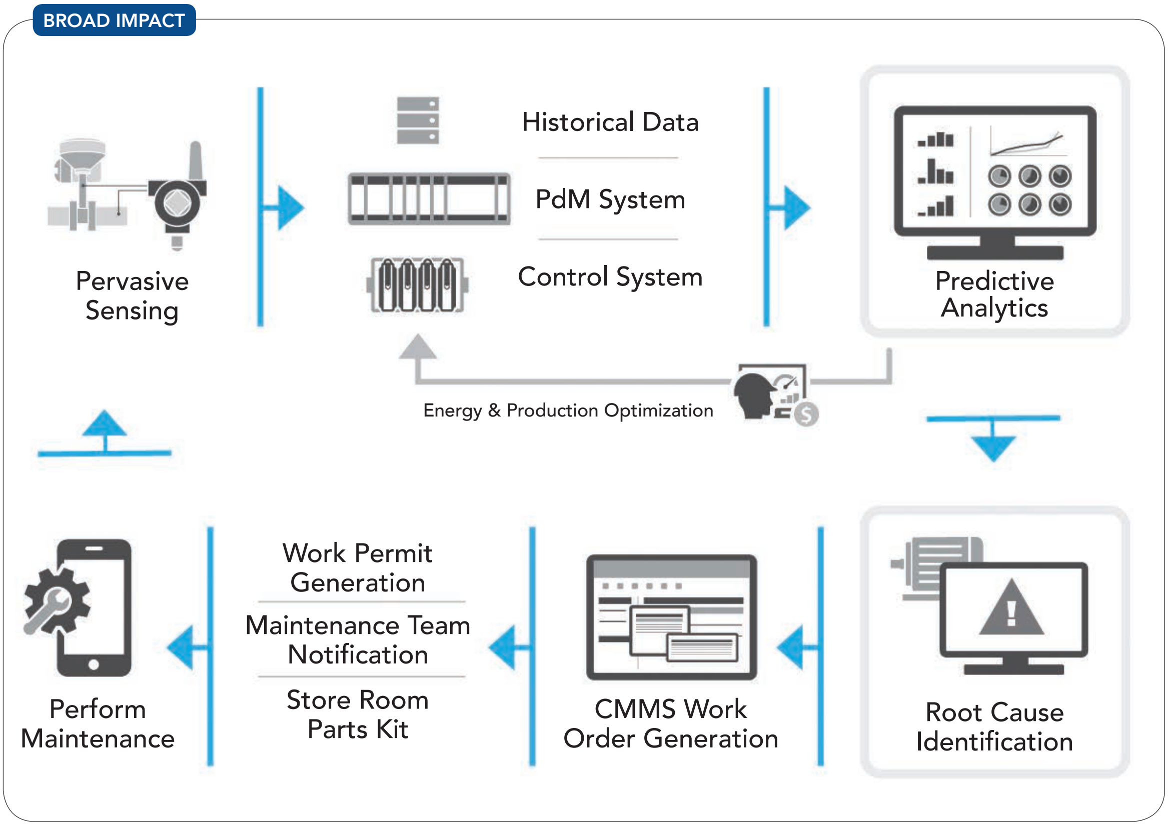


Figure 2. Predictive analytics can provide insights to improve operations, energy efficiency and maintenance.

confirms a company's worst fears and creates the mistaken conclusion it isn't ready for digital transformation.

Operations leadership can navigate around this potential pitfall by understanding key performance indicator (KPI) goals and using those goals to drive decisions on pilot implementation. A gap analysis allows a company to see opportunities for improvement. These opportunities then drive business goals, helping teams create pilot projects with return-on-investment (ROI) impacts that are easy to quantify and demonstrate.

Setting goals matters. Consider the experience of one life sciences company that embarked on a pilot program to determine if digital transformation technology was right for a plant. Its reliability team focused primarily on data availability, assuming the best assets to test were those with the most instrumentation that also were common throughout the organization.

The problem with this approach was that the chosen skids are extremely stable pieces of equipment. Because these skids had few reliability issues, the data the team collected showed very few problems. Without problems, there were no solutions and no savings, making it hard to build a business case centered on the success of the pilot.

Planning for success also is essential. A large refinery determined that injecting a chemical into the oil refining process could enhance efficiency and lower costs of crude processing. Although the change potentially could significantly improve the refining process, it also ran the risk of very high temperature spikes. The company needed analytics to identify the perfect injection level to accomplish higher yield and better efficiency without compromising safety and production in the unit.

The company knew it could test four KPIs:

- safety;
- energy consumption;
- optimization of production; and
- increase in equipment reliability.

Focusing on these specific, measurable KPIs underscored to the team the business opportunity related to the project. If the injection process had no or negative KPI impact, the project clearly wasn't suitable. On the other hand, any positive impact on one or more KPIs would show the injection program had promise.

*2. Understand current systems and solutions.* Chemical makers often have many legacy systems that were put in place over decades of operation. Over time, these systems form a complicated web that can make integration of digital transformation appear difficult (and also complicate cybersecurity efforts: see "Combat Cybersecurity Threats to Process Safety, p. 14, http://bit.ly/2HSK00c).

A company can overcome the complication of interconnected legacy systems with an assessment of current equipment and practices. An architecture gap evaluation can help all stakeholders understand what systems are in place, the synergies between these systems, and what integration options exist.

Getting a clearer understanding of the successes and shortcomings of how the plant currently operates not only can simplify digital transformation but also provides value for numerous other initiatives. Armed with this knowledge — and the grasp of how any implemented technologies must meet cybersecurity and hazardous environment risk standards — the team can develop small pilot initiatives for integration into even the most complex system configuration.

*3. Identify relevant stakeholders.* As integration of information technology (IT) and operational technology (OT) gets more complex and as plants shift toward more industrial Internet of things (IIoT) infrastructure, additional stakeholders become relevant in digital transformation projects. Before implementing a project, an organization should reach out to relevant stakeholders to ensure that misunderstandings or corporate policies don't impede successful execution.

Reaching out provides tangible benefits. Consider what happened at a global chemical processor ready to move on a large-scale digital transformation project. The implementation team had completed plans, set a timeline and even made purchases. However, the project ran into a roadblock because the team hadn't communicated its plan to corporate leadership.

The team discovered that IT required validation of any new digital systems before implementation, per corporate restrictions. Waiting for this approval put the project on hold — mid-execution — for nearly three months. The brand-new equipment sat stagnant. Moreover, significant momentum for the project was lost, complicating scheduling, training, and startup further down the project path. Reaching out to the IT department before implementation would have saved the team substantial delay and frustration.

Implementation teams also must consider the end users as stakeholders. High quality, regular training should include how to use the new tools, where to use them, and how to maintain systems. Comprehensive training will give operators and maintenance staff the confidence to be effective and efficient, while drastically reducing the temptation to continue operating with old habits.

*4. Redefine workflows.* Before beginning a pilot implementation, a company must fully understand workflows that are already in place, and which of those the implementation of new systems will impact or remove. Cataloging critical workflows helps organizations define pains and needs. With these pains in mind, operations leadership can create customized solutions.

Teams can use information gathered from a workflow study to develop documentation, rules and key personnel as well as determine which old workflows have become redundant and need replacing. Such data also help define business needs because the results often show areas where work hours or resources are wasted on unnecessary, impractical or outdated maintenance procedures.

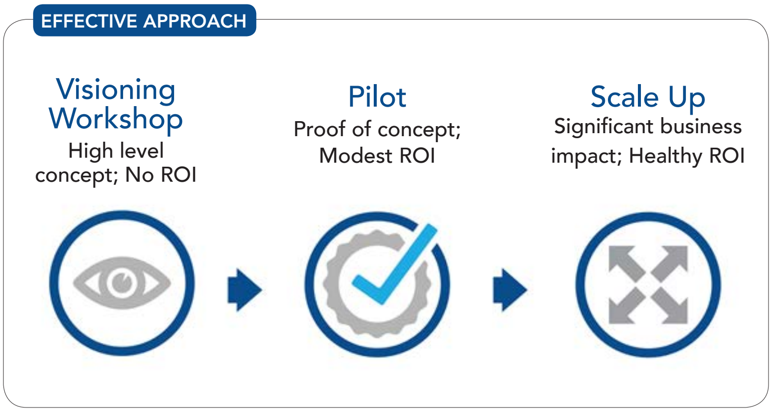


Figure 3. Developing a vision for digitalization and running a pilot with a clear business value underpin successful scaleup.

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*5. Design a solution architecture.* Using the new KPIs developed from examining workflows and identifying stakeholders, an organization can begin to determine a path toward a successful pilot. In this step, engineering design —implementing new systems on top of the systems that currently exist — begins. Finding points of seamless integration is critical at this stage; successful programs needn't be based on entirely new technology. By leveraging capabilities and equipment the company already has, coupled with new technologies and direction from solution providers, it's possible to augment existing systems to deliver returns on investment (ROIs) that initially may not have been considered.

*6. Chart the path.* Always remember that positive change is about more than just putting new technologies in place and forgetting about them. Successful digital transformation pilots require proper planning, execution and documentation. Based on the data collected from previous stages, an organization must redefine the roles, responsibilities and relationships of personnel to drive success from digitalization, creating a foundation both for the success of the new technology and for the people who must operate it.

*7. Start adopting new technology.* Once all planning is complete and the transformation team is confident that it has accounted for redundant workflows and practices, a company can begin to integrate new processes and practices into the daily routine.

*8. Deploy, operate and test the system.* Monitoring progress allows detection and correction of any course deviations before they become instilled in the culture of the company, helping to ensure the work of putting together a predictive maintenance system doesn't go to waste.

Three common methods exist for validation:

- Backwards validation involves reviewing historical data to ensure any new prescriptive maintenance technologies are catching the failures that happen in the plant. Typically, this is done by checking records to identify anomalies and then seeing if the predictive maintenance system caught them.
- Side-by-side validation takes advantage of old workflows and technology to check the performance

of the new system. Many organizations choose to keep these in place for a predetermined period after implementing new predictive maintenance technologies. If these old but familiar procedures — often performed via visual inspection or with handheld analyzers — catch problems that were missed by automated systems, the team knows it must fine-tune prescriptive maintenance. However, it's important to set a timeline for retirement of old workflows to avoid unnecessary expenditures on redundant analysis.

- Stress testing deliberately introduces failure into non-critical parts of the system to see if the prescriptive maintenance equipment catches it. This process offers the most control but also is the most invasive method of testing. It can be used either on its own or alongside another validation method.

No matter which method an organization chooses to confirm successful adoption, validation is necessary both to ensure safety and productivity and to show management and the workforce that the new systems are working. For a chemical maker looking to start small and gradually scale its pilot programs into global initiatives, validation is particularly important because it generates buy-in for better efficiency in the plant and faster approval for future projects.

*9. Drive adoption.* Getting the most from a digital transformation pilot requires employee buy-in on all levels. So, the transformation team should develop and implement a strategy to collect feedback from users at every level — and to apply that feedback in a measured, reliable way to make appropriate adjustments as the project progresses.

*10. Plan to scale up.* Mine the pilot program for ways not only to improve the processes that have been put in place but also for areas of the plant ripe for similar expansions. Use gathered ROI data to build a case for expansion of successful programs, remembering to look for opportunities everywhere (Figure 3).

## ACHIEVE A LASTING IMPACT

As with any step-change initiative, a company may experience potential roadblocks on the path to a digital transformation. However, the adoption benefits of a well-implemented digital transformation program of any size outweigh the costs and time spent. Starting with a pilot focused on leveraging the processes, technology and people already in place, and using those resources in a way that suits the unique needs of your facility can build the foundation upon which to create a scalable, business-need-driven program. Such a program not only can provide benefits today with potential availability improvements of 20% or more but also can drive improvements in operations across the lifecycle of your equipment. ●

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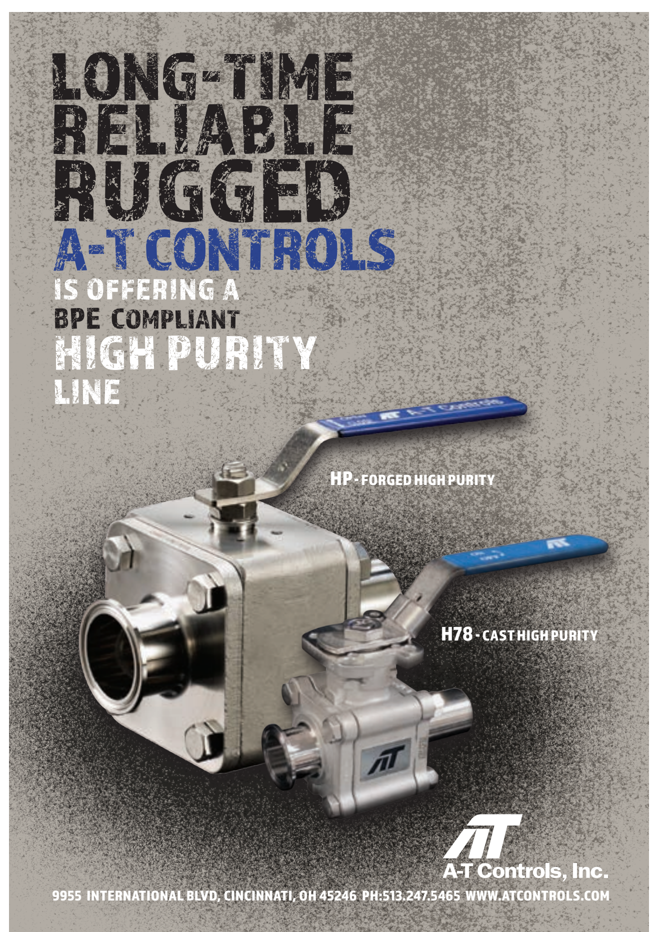

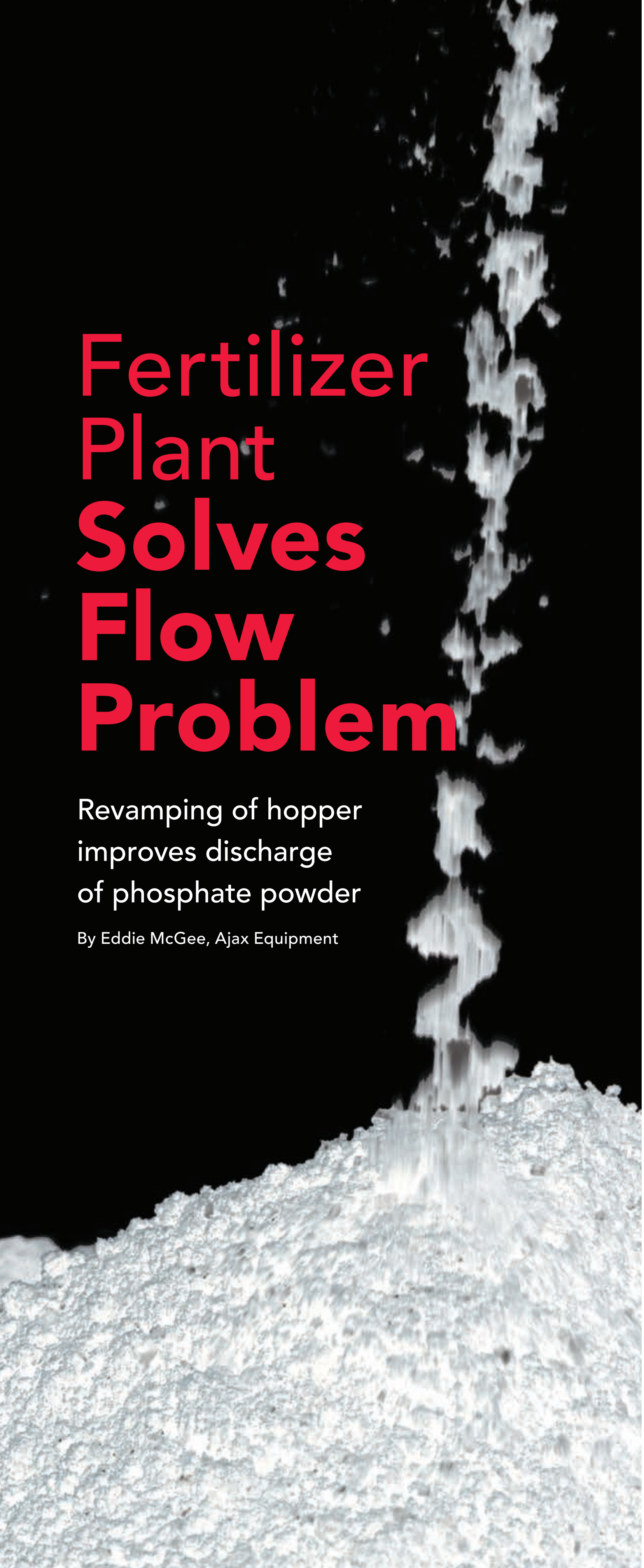

# Fertilizer Plant **Solves Flow Problem**

## Revamping of hopper improves discharge of phosphate powder

By Eddie McGee, Ajax Equipment

**THE HOPPER** at an Egyptian fertilizer plant caused erratic flow and bridging, disrupting production. The hopper receives phosphate powder from a milling process via a pneumatic conveyor. Feed from the silo must be regulated so that the acidulation process can be correctly proportioned; an unpredictable feed rate makes the process very difficult, if not impossible, to control.

The plant experienced flow problems shortly after start-up with material hang-ups and occasional flushing. Its process equipment supplier, Bradley Pulverizer, installed aeration pads in the hopper to blow low volume air into the powder to encourage material flow. However, this resulted in more uncontrollable flow and flooding of downstream equipment.

The flow regime generated in the hopper, so-called funnel flow, exacerbated the problem. This type of flow arises when the converging wall inclination is too shallow to induce the contents at the walls to slip as the hopper empties. A narrow flow path forms from the outlet to the surface, creating a "last-in, first out" phenomenon, so freshly milled material comes out first; original fill material may remain against the walls for a long time, deteriorating in flowability.

In response, in 2016, Bradley Pulverizer asked Ajax Equipment to find a way to improve flow. Ajax determined the fix was to convert the hopper flow regime to mass flow. This would

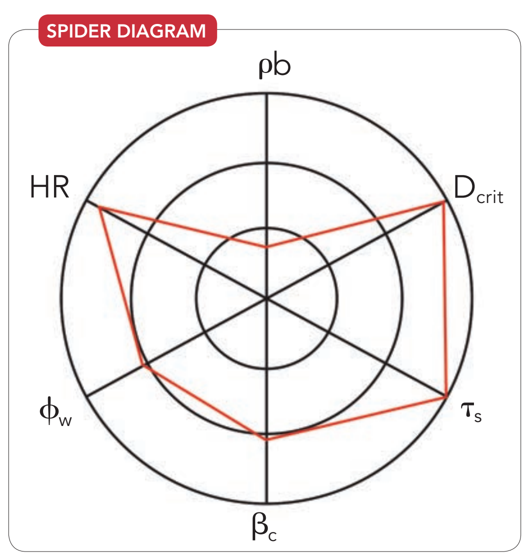


Figure 1. High values for shear strength and wall friction angle mandate steep hopper walls and a large outlet for reliable flow.

ensure all hopper contents moved together during discharge so that "first in" material is "first out" and would avoid extended storage time of some of the contents.

### FINDING THE CULPRITS

A common approach to predicting powder flow behavior is to use a single number as a guide. However, this approach is fraught with problems. For example, there's no obvious reason why a powder with high friction properties also should have a strong cohesive tendency or vice versa; while the situation for flow may worsen when both these attributes are present, they aren't necessarily correlated.

A better approach to predicting flow behavior is to use the measured characteristics of wall friction ($\phi_w$), shear strength ($\tau_s$) and bulk density ( $\rho_b$) along with three further factors: hopper or reactor wall angle ($\beta_c$), outlet size ($D_{crit}$) and Hausner ratio (HR), which is the ratio of tapped to loose bulk density. (As the HR increases, the powder becomes more sensitive to vibration and, hence, its flowability worsens.) These factors enable producing a "spider" diagram comprising a series of three concentric circles divided by axes for each of the characteristics. The smallest diameter circle shows the specific values of the characteristics that provide "easy flow" while the larger diameter circles define "modest" and "poor flow," respectively. This allows presenting idealized situations for an "easy flow" material and a "poor flow" one with the in-filled part of the "web" detailing the particular characterization attributes.

TWIN-SCREW FEEDER

Figure 2. Unit features special extraction geometry and draws from the full width and length of the new hopper bottom.

Spider web diagrams can provide more than a qualitative indication if you can use data from tests on a large number of materials to define the "easy," "modest" and "poor" flow circles.

Note that the bulk density axis is the reverse of the others because decreasing bulk density usually means poorer flow. For example, most milling operations lower bulk density and worsen flowability of powders when they are stored.

Testing of the fine phosphate powder revealed that the powder flow properties, together with variability in the composition, residence time and consolidating pressures in the silo, caused the problem. The measured flow properties and calculated hopper parameters were:

- bulk density, $\rho_b$, 989 kg/m$^3$;
- critical diameter, $D_{crit}$, 102 cm;
- shear strength, $\tau_s$, 3,574 N/m$^3$;
- hopper wall angle, $\beta_c$, 69°;
- wall friction angle, $\phi_w$, 21.9°; and
- Hausner ratio, HR, 1.47.

A spider diagram (Figure 1) of the phosphate powder identified high shear strength and wall friction values that demand steep hopper walls and large outlet sizes for reliable flow.

Wall friction testing allowed Ajax to determine the hopper wall inclination needed for mass flow; it would increase residence time in the hopper and enhance de-aeration. The wall friction measurements also identified significant slip benefits with 2B finish stainless steel over the existing mild steel surface.

SUGGESTED PARAMETERS

| Circle | Wall Friction, ° | Bulk Density, kg/m$^3$ | Shear Strength, N/m$^2$ | Hausner ratio | Outlet Size, cm | Mass Flow Wall Angle, ° |
|---|---|---|---|---|---|---|
| Easy flow | < 20 | 1,200 | 300 | 1.1 | 15 | 65 |
| Average | 25 | 800 | 1,000 | 1.25 | 50 | 73 |
| Poor flow | > 30 | 400 | 2,000 | 1.5 | 100 | 80 |

Table 1. Tests conducted for thesis [1] led to these recommended values.

### THE SOLUTION

Because converting the entire hopper to mass flow would have been expensive, Ajax proposed replacing a 2-m-deep bottom section of the hopper with a vee-shaped section to exploit plane flow benefits as well as a large outlet fitted with a twin-screw feeder of special extraction geometry (see Figure 2) to draw from the full width and length of the new hopper bottom. Another proposed alteration was the incorporation of a flow insert to enhance de-aeration and extend the flow benefits into the unaltered higher region of the hopper. These changes would result in a more-even residence time of the contents and a large reduction in the flow velocity (spread over a wider area) to further favor de-aeration. Moreover, the minimal plant modifications would ensure reliable operating performance.

It only took five months from quote to delivery and installation of the equipment in Egypt.

A careful re-commissioning process was carried out to progressively assess each section of the retrofit. The changes resulted in steady and reliable flow without arching or flushing and created a consistent feed stream for subsequent plant operations.

A large proportion of the previously static hopper contents now flows during discharge. A further benefit of fitting the insert is that it prevents a direct flow path and forces material to draw from the peripheral areas near the walls with even shallower wall angles than required for a conventional mass-flow hopper. This results in increased working storage capacity and a more-uniform residence time and stable reliable flow. Indeed, the feed rate variation has decreased from more than 30% before the modifications to better than 0.5%. This means that the acidulation process can be carried out properly.

"Since the equipment has been installed, the performance of the process has significantly improved. By providing complete control over the flow of phosphate powder, Ajax's equipment has enabled production of the high-quality product desired, a welcome improvement to plant performance and 'the magic solution' according to the plant operator," comments Ian Hancock, operations manager at Bradley Pulverizer. ●

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**EDDIE MCGEE** is managing director of Ajax Equipment, Ltd., Bolton, U.K. Email him at eddie@ajax.co.uk.

### REFERENCE

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# Head off Heat Exchanger Headaches

Finding the best way to maintain temperature in a new tank requires better analysis

### CHECK YOUR DESIGN PREMISE

One bit of information that's missing is the cost of the old heat exchanger; depending how long it's been installed, it may have depreciation value in the economic analysis. Also missing are more details on the new heat exchanger. It's difficult to compare the two options fairly without evaluating reliability. A cheap shell-and-tube heat exchanger without an expansion head may work well for a few years — but then suffer catastrophic failure, erasing any savings in capital expenditure. Making such a comparison often is a challenge because quality improvements and reliability improvements are based on estimates. Maybe corporate knows something you don't know and doesn't want to buy a very expensive heat exchanger like, say, a spiral one.

Developing design data, such as U, from trend data can be risky. Presuming fouling is a problem — which it probably is — if the estimated U is only 56 BTU/hr-ft$^2$, then what makes you think the fouling won't affect your hydraulic calculations for sizing the pump? Most sizing software relies on the Darcy-Weisbach equation, which assumes Newtonian fluid. Maybe you need another type of pump than the tried-and-true centrifugal. Another issue is the borrowed part. Used equipment, regardless of whether it comes from an external or internal source, can pose issues based on past abuse; consider conducting a hydraulic test at a manufacturer's shop before accepting it as good as new.

Let's consider constructability of the project. This could be how you sell your idea to corporate. Using the existing exchangers involves at least two tie-points, likely four, and perhaps more if there are cleaning connections. Always figure tie-points at time-and-a-half, perhaps double-time — and that's assuming the existing isolation block valve doesn't leak. Construction in racks can be expensive, requiring erection and disassembly of scaffolding. Power supply to the welder in the racks will rack somebody's brain. Then there's lighting. Issues like those help explain why 60% of capital projects miss their budget targets. If you build fresh, all you must worry about is the area around the new tank; you can work on straight time and probably avoid high scaffold work by making tie-points near the ground.

As for loading up the duty on the existing heat exchangers, I really don't see a problem. If you can switch back and forth between exchangers, then you possibly can use the two heaters to maintain three tanks. If you have problems, raise the setpoint of the heaters and look into added insulation. You may want to optimize on the level by heating and raising the level in the tank; this will provide more mass that should retain heat better between heat-ups. I'm not sure what you can do about the controls. Some kind of batch control with priority based on which tank is closest to the melting point might work.

*Dirk Willard, consultant*
*Wooster, Ohio*

## THIS MONTH'S PUZZLER

We want to expand our existing storage capacity for biphenyl by adding another, larger tank. We now use a shell-and-tube exchanger to keep the biphenyl in a molten state in the two current tanks. We maintain the temperature between 169°F and 205°F. Properties at the two temperatures are: density, 0.99 g/cm$^3$ and 0.97 g/cm$^3$, respectively; viscosity 1.42 cP and 1.03 cP; heat capacity, 0.382 BTU/lb-°F and 0.397 BTU/lb-°F; and thermal conductivity, 0.077 BTU/hr-ft-°F and 0.076 BTU/hr-ft-°F. The biphenyl's flash point is 237°F. We use 30-psig steam with a 30°F superheat to heat the biphenyl and don't allow tank temperature to get within 30°F of the flash point because of past incidents.

The current tanks are 28-ft high and 32-ft in diameter with 4 in. of fiberglass insulation on their sides. The new tank is 32-ft high and 42-ft in diameter with 6 in. of insulation, including on the top. Typically, we run the tanks at about 75% level after a production run. The winter design temperature is 0°F with a 10-mph wind.

We lack data on the heat exchanger but determined its flow rate is about 140 gal/min instead of 180 gal/min in the spec., and the heat transfer coefficient U is only about 56 BTU/hr-ft$^2$.

I'm concerned about whether the exchanger can cope with a third tank. In the winter, the heater already runs about 17 hr/d to heat the two existing tanks. Moreover, the piping is over 300-ft back and forth to the new tank — and it's overhead.

Corporate managers want to rely on the current heat exchanger and put in a new pump and piping (at $22,000 for the new pump and $348/linear ft for piping). I instead suggested installing a dedicated heat exchanger for the tank and using a pump we can borrow from another plant. The new heat exchanger would cost $23,000 and require only about 150 feet of new pipe. How do I sell my idea to corporate? Am I missing some reason why they want to only use the existing heat exchanger? Can you suggest any way to improve the system?

# JUNE'S PUZZLER

Our plant decided to make some repairs to the top trays in the main fractionating tower above the light cycle oil (LCO) stripper in our fluid catalytic cracker. We suspected trays were leaking based on the temperature profile and high level in the LCO stripper below the trays. We scheduled repairs during an outage. During that shutdown, we found corrosion of stainless-steel/carbon-steel welds affecting four trays. When we got inside, I noticed several weld repairs that didn't appear in the maintenance files. I then talked to people about past weld repair work on the system and recorded what I could find (see Figure 1).

A severe thunderstorm caused the power to fail for half a day during the hydrostatic test, delaying the startup. So, staff rushed commissioning to meet the turnaround window. Although tower performance has improved, it's still not quite where it should be. The liquid level in the LCO stripper seems high and the pump-away motor amps seem low. The temperature elements in the middle-bottom of the column don't seem right because the difference between the trays is small. The pressure transmitter above the reboiler isn't working correctly.

In fact, when reviewing the commissioning records, I noticed that many transmitters weren't checked in an effort to cut startup time. I'd like to run a simulation but don't have any reliable data above the feed tray for comparison.

The unit superintendent blames the corrosion on the wash procedure that maintenance uses. Maintenance says corrosion from periodic washing is impossible. Our process group says the concentration of caustic used for washing is high and the wash temperatures are too hot. (We use 10-psig steam reduced from a 450-psig system.) However, they agree with maintenance that the washing isn't the culprit.

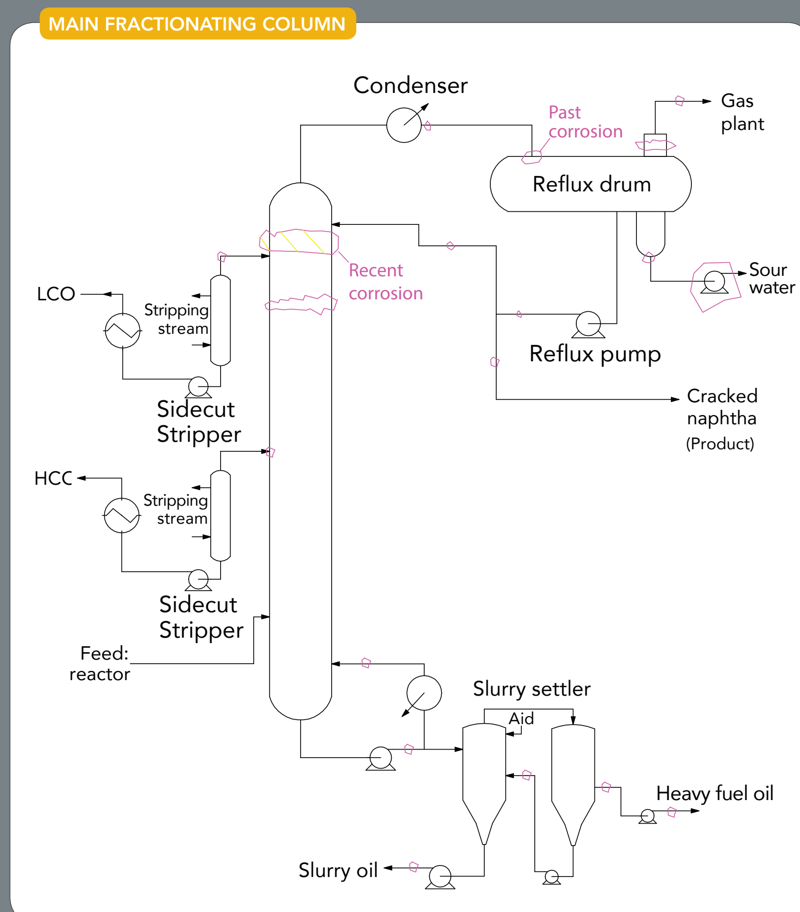


Figure 1. This tower in a fluid catalytic cracker unit suffered from corrosion.

This is as far as I've gotten in my investigation. Have I missed anything? What else should I look for? Is there room for improvement in the wash procedure? Should I worry about corrosion reported at the bottom of the tower? (Maintenance says this is normal.)

Send us your comments, suggestions or solutions for this question by May 10, 2019. We'll include as many of them as possible in the June 2019 issue and all on ChemicalProcessing.com. Send visuals — a sketch is fine. E-mail us at ProcessPuzzler@putman.net or mail to Process Puzzler, *Chemical Processing*, 1501 E. Woodfield Rd., Suite 400N, Schaumburg, IL 60173. Fax: (630) 467-1120. Please include your name, title, location and company affiliation in the response.

And, of course, if you have a process problem you'd like to pose to our readers, send it along and we'll be pleased to consider it for publication.

# Identify Orifice Plate Issues

Various culprits can compromise flow measurements

Somewhat buckled orifice plates often are installed.

**ORIFICE PLATES** abound at many plants because they provide a simple and inexpensive way to measure flow rate. An orifice plate induces a pressure drop in a fluid that should accurately correlate to its flow rate. If the orifice plate meets established standards for its geometry and is correctly installed in the process line, then, as long as we know the properties of the fluid, we can get flow measurements to within 1% accuracy.

However, in practice, many factors can lead to flow rate errors of up to 15% or more. These include mis-location of the instrument, improper installation, damaged plates, blockages and unexpected flow regimes (laminar versus turbulent or two-phase versus single-phase).

One of my very first troubleshooting assignments was attempting to determine fuel consumption and efficiency for a number of large thermal cracking furnaces. The complex fuel gas system at the plant had evolved over decades. Fuel compositions varied over time and in location — and composition wasn't continuously measured. Additionally, branches of the system used different flow meter types; some branches lacked any flow meters and, thus, required mass balance calculations based on data from meters installed elsewhere. Adding to the challenge, meter maintenance was sporadic and poorly documented. Apparent errors for fuel consumption on some heaters exceeded 30%. In other cases, two meters in series on the same pipe gave readings that differed by more than 15%.

Every time an eager new-hire engineer was between assignments in the plant, that person was tasked with trying to sort out the fuel system. Long-established history had shown the assignment to be thankless and progress only occurred in small steps; my experience bore that out. Nevertheless, I did learn some important lessons. Today, we'll focus on those related to orifice plates.

First, most orifice plate errors, except for installing one that's too small, tend to give flow rates lower than actual.

Backwards installation of an orifice plate is a classic error. For a reasonable beta ratio (~0.5) and in turbulent flow, expect an error of 12–15% too low a flow rate. Orifice plates have a specific installation direction that should appear on the tab on the orifice plate along with dimension information. If you can reach the orifice plate, this is easy to check. Accessing the plate may be a problem, though. Accurate measurement may require a length of straight pipe upstream equivalent to up to 90 upstream pipe diameters for sufficient flow conditioning (see: "Think Straight About Orifice Plates," http://bit.ly/2U2Qksx). This length of straight run often only occurs in pipe-racks, making getting to the orifice plate difficult and time consuming. Additionally, in rare cases, the plate stamping is on the wrong side, which easily can lead to backwards installation.

Orifice plates should be flat but can undergo buckling or bending during manufacture or transport. Badly buckled plates are easy to spot, so rarely get installed. Somewhat buckled ones often are installed, though. If the plate is buckled toward the upstream direction, the flow rate will err high, while one buckled toward the downstream direction will err low. When installed in bolted flanges, the buckling usually decreases due to the flange forces on the plate. However, don't count on this. Errors due to buckled and bent plates usually are 7–8% or less.

Plates have a specific edge geometry on the orifice. Pay particular attention to the shape of the edge and measure the dimensions carefully to make sure the plate is acceptable. If the sharp edge isn't manufactured correctly or is damaged, the discharge coefficient of the orifice changes. This tends to result in low flow errors in the 4–6 % range. If enough wear occurs, then the entire orifice size changes and errors can get much larger.

Deposits may accumulate on the plate surface or edge. Deposits also may build on the pipe on either side of the plate. Errors from these problems can reach nearly any value. A surface deposit only on the plate likely will lead to an error of 4% or less. Deposits on pipe that interrupt flow to or from the orifice can cause errors exceeding 15%, which can be high or low depending upon where the deposits are.

Problems with orifice plates often prevent plants from closing material balances within acceptable error ranges. However, they aren't necessarily the only causes. As in all troubleshooting, start by assessing available data and only use correct information.

**ANDREW SLOLEY**, Contributing Editor
ASloley@putman.net

## App Simplifies Signal Converter Configuration

Operators can connect to temperature transmitters with a smartphone or tablet using near-field communication (NFC) or Bluetooth and configure through the new INOR Connect app. Using wireless communication means operators don't need to remove the signal converter from the process. Now available are the INOR 330 series temperature transmitters, and the INOR 530 series, fully compatible with HART 7. The app offers the same configuration options as the company's existing ConSoft transmitter software, but with an improved user-friendly interface. Automatic updates provide users with the latest features. The app is available for Android and iOS devices (Bluetooth only).

**INOR Process AB**
978-826-6900
www.inor.com

## Level Sensor Handles Challenging Conditions

The NCR-84 non-contact 80-GHz radar level sensor is designed for reliable measurement in demanding liquid conditions including excessive steam, vapor, condensation or surface foam. The signal focus's very narrow beam angle allows for precise aiming to avoid obstructions in the tank such as agitators, mixers, fittings or heating coils. It also is appropriate for use in tanks with turbulent product surfaces, viscous media and slurries. This sensor comes in threaded, flange and hygienic versions for a variety of industries and applications, plus a plastic antenna option for use in low pressure or temperature ranges.

**BinMaster**
800-278-4241
www.binmaster.com

## HMI Offers Multi-Touch Operation

With a true glass touch-screen for clear information display and easy operation, the CP600-Pro human-machine interface (HMI) operates within a wide environmental temperature range of -4 through 140 °F. Its design suits multiple applications in landscape or portrait format and offers IP66 protection. Available in 5-, 7-, 10.1-, 15.6- and 21.5-in. screen sizes, the panels provide comprehensive HMI functions with multi-touch operation. Three Ethernet interfaces, one with 10/100/1,000 Mbit, support up to three networks. With an OPC UA server and client protocol, the CP600-Pro is well prepared for time sensitive network connectivity. It can be configured and programmed with Panel Builder 600, which allows the easy creation of graphical HMI pages.

**ABB**
800-435-7365
https://new.abb.com/us

## Gear Pump Drive Offers Flexibility

The compact Cole-Parmer console gear pump drive offers simple variable speed control for many fluid handling applications. When coupled with an appropriate gear pump head, the drive handles system pressures up to 21 bar, differential pressures greater than 5 bar, and flow rates as high as 5,850 mL/min — suitable for pressure filtration and other industrial-scale, continuous-duty flow applications. Its 100:1 speed control delivers fluid over a wide flow range. A separate power switch enables the pump operator to maintain the speed setting when turning the drive on or off. Remote control of start or stop is available via a DB9 connector on the back of the drive.

**Cole-Parmer**
800-323-4340
www.coleparmer.com

## Weight-Loss Feeder Needs No Calibration

Model 405-105X weight-loss feeder's exclusive dissimilar speed double concentric metering mechanism provides highly accurate and reliable feeding of a range of dry solids materials, says the company. The feeder features a compact 22 × 32 in. footprint and a permanently calibrated and adjustment-free weighing system. The company's Ratiometric Digital Weight Resolver instantly generates an unamplified, non-integrated real-time weight signal with no delay for precise feed rate control. Feed rates range from several pounds to about 2,000 lb/hr (based on product weighing 40 lb/ft$^3$) with continuous metering accuracies ranging between ±0.25 to 1% or better

(error) at two sigma based on a given number of consecutive one minute sample weighments.

**Acrison, Inc.**
201-440-8300
www.acrison.com

## Scrubber Removes Particulates

The Series 9000 preformed spray scrubber is designed to simultaneously remove solid and gas particulates from dryers and other processing operations. It features a specially designed fine droplet scrubbing liquid spray zone

within a confined involute section that eliminates any bypass of untreated gas. A fully open, cyclonic entrainment removal section without internal droplet removal components makes the scrubber highly reliable with extremely low maintenance. The scrubber consumes less energy than a venturi scrubber, is designed to meet PM 2.5 and PM 10 regulations for particulate in the 1 to over 5 micron range, and is available in sizes to handle gas volumes from 1,000 through 75,000 cfm.

**Bionomic Industries, Inc.**
201-529-1094
www.bionomicind.com

## System Eases Machine Monitoring

SKF Pulse combines an easy-to-use handheld sensor with a new mobile app, allowing users to quickly monitor rotating equipment and machine health to predict issues and improve reliability before operations are im-


pacted. For more advanced analysis, users can request an SKF Pulse Check directly via the app. The request goes to an SKF diagnostics center where experts remotely analyze the machine data and respond with recommended corrective actions to improve equipment performance, if required. An intuitive visual interface guides users through the data collection process. Users enter asset information that automatically configures alarm thresholds based on ISO standards. Thresholds can also be customized if desired.

**SKF USA Inc.**
267-436-6836
http://skfusa.com/skfpulse

## Flow Controller Measures Multiple Gases

The DPC series precision digital mass flow controllers provide accurate and stable control of mass flow rates of process gases. They support 90 different gases and gas mixes, and simultaneously display mass flow, volumetric flow, pressure and temperature parameters. The flow controllers feature two programmable mass flow rate totalizers


with batch processing mode (0.5% RD + 0.2% FS) standard accuracy, 200:1 turn-down ratio and less than 150-ms response time. A user-defined mixture functionality allows for creating and storing up 20 custom gas mixes with up to 5 different gases each. Also available is an optional Modbus RTU network interface with isolated RS485 transceiver.

**Aalborg Instruments**
800-866-3837
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## Process Oxygen Analyzer Measures Trace Levels

The OXYvisor process oxygen analyzer optically measures oxygen in either the gas or liquid phase. In the gas phase, the analyzer measures from trace (0.5 ppmv) to % level oxygen,

and in the liquid phase, it measures dissolved oxygen from 1 ppb to ppm. It detects oxygen in flare gas, nitrogen headers, and hydrocarbon and other process streams. It is commonly used to detect oxygen to prevent the corrosion of capital equipment and to ensure product quality. The unit provides supervisory-type monitoring capabilities with advanced diagnostic, auto calibration and remote validation capabilities. This allows users to take significant process actions on alarm conditions at remote locations.

**Barben Analytical**
775-883-2500
www.BarbenAnalytical.com

## Membrane Boasts High Rejection

The Lewabrane HP (high performance) membranes boast an enhanced brackish water membrane to serve applications in which high rejection and energy efficiency are important. Using the new types in combination with monodisperse Lewatit ion exchange resins provides high quality produced water at lower operational cost. The membranes for reverse osmosis feature an average salt rejection of 99.7% (at 2,000 ppm NaCl; 225 psi) and high permeability. Controlling the degree of polyamide cross-linking during production process provides a small effective "pore size" that results in high rejection of solutes, regardless their charge.

**LANXESS Corporation**
412-809-1000
http://lanxess.us/

## Dual VSD Vacuum Pumps Conserve Energy

The LRP 700-1000 VSD+ range features three vacuum pumps developed for wet, humid and dirty applications. Each pump is a compact, high performance, energy-efficient system enclosed in a rugged noise-attenuating canopy. Ensuring efficiency, the dual variable speed drive (VSD) system operates in harmony within the pump. The primary VSD maintains required vacuum levels by controlling the operating speed of the pump, matching pump performance to process demand and saving energy. The second VSD regulates the water circulation pump in response to operating conditions. Optimizing water flow within the pump element provides performance and stability at all vacuum levels and operating speeds, the company says.

**Atlas Copco Compressors**
803-817-7434
www.atlascopco.com/air-usa

## Air Conveyors Transport Over Longer Lengths

Available in 2-½ in. (64mm) and 3 in. (76mm) sizes, these 316 stainless-steel line vacs are in-line conveyors that transport high volumes of material


through ordinary hose or tube. They are designed for areas requiring Type 316 stainless steel and offer chemical and corrosion resistance, performance in high or low temperatures, long service life and low maintenance. The two sizes enable conveying more material over long vertical and horizontal lengths. The material conveying rate is easily controlled with a pressure regulator. An optional bracket permits easy mounting. No moving parts or electricity ensures maintenance-free operation.

**EXAIR Corporation**
800-903-9247
www.exair.com/108/lg316sslv.htm

## Drum Dumper Handles Difficult Materials

This Tip-Tite drum dumper suits poorly-flowing or agglomerated materials, providing rapid transfer of free- and non-free-flowing bulk solid materials dust-free. Similar in performance to open chute dumpers but with total dust containment, the outlet on the downstream end of the dumper nearly equals the area of the drum opening, allowing agglomerated materials and large chunks to be discharged with minimal possibility of material bridging. At full rotation, the transition outlet mates with the gasketed square inlet on the hopper lid or downstream process equipment, allowing a pneumatically-actuated slide gate valve to open and close for total or partial discharge.

**Flexicon Corporation**
888-353-9426
www.flexicon.com

## Remote Monitor Features Compact, Modular Design

The 19-in. Visu-Net IXD 2100 remote monitor is designed for outdoor use in IECEx/ATEX Zone 1/21 rated hazardous locations. It features a marine-grade aluminum housing that can withstand extreme temperatures up to 60°C, and thermally hardened glass for high impact

resistance. The unit is available either as thin client or as PC. Its modular design comprises three main components: the display, computer and power supply. Operators can easily disassemble the modules on-site and replace components independently in the event of a fault. This makes field maintenance quick and easy, and reduces costs associated with downtime, the company says.

**Pepperl+Fuchs**
330-486-0002
www.pepperl-fuchs.com

## Software Delivers Business and Industrial Analytics

Dream Report industrial reporting software version 5.0 contains significant enhancements, such as additional dashboard technology tailored for use in front office applications — busi-


ness analytics, database connectivity and dynamic filtering. The software delivers both local and Internet connectivity to all major HMI/SCADA, historian and business data sources through either proprietary or industry standard drivers. With the new dashboard option, the software now delivers both industrial and business analytics to satisfy all plant operations and management personnel. Additional enhancements include Internet of Things connectivity through a new MQTT/JSON interface, analytics sharing with other automation solutions through an OPC DA Server, and XML output data formats for data transfer with automated systems.

**Ocean Data Systems**
610-202-3940
www.DreamReport.net


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The HI 6200 series single-channel weight processors feature industrial Ethernet-based communications, Industrial Internet of Things compatibility, remote diagnostics and a user-friendly color touch screen interface. The 2-in. wide and 3-in. high processors install on standard 35-mm DIN rail, allowing for high-density panel design over traditional weighing instrumentation, reducing both machine cost and control cabinet footprint. A simplified touch-screen user interface allows anyone with basic scale knowledge to set up and operate the instrument without having to read a manual or receive instruction, the company says. The high-definition color TFT display provides crisp easy-to-read measurements and instrument status. Waversaver filtering technology and 24-bit processing ensure fast, stable readings in adverse conditions.

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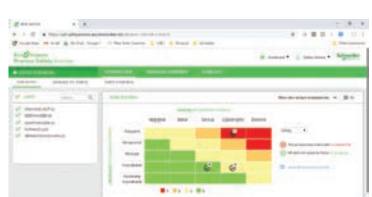
The EcoStruxure Process Safety Advisor, an IIoT-based digital process safety platform and service, enables



users to visualize and analyze real-time hazardous events and risks to their enterprise-wide assets, operations and business performance. The system aggregates data from every site into a secure cloud platform, with a single searchable interface for a dynamic view into enterprise-wide operating risks. Users can then drill down to visualize risks related to individual sites, process units, hazards, protection layers and safety device integrity. The system also identifies the need to take corrective action via easy-to-understand performance dashboards and leading indicators for safety health, then documents the entire process using an embedded SIF audit trail that supports safety compliance.

**Schneider Electric**
978-794-0800
www.schneider-electric.us/en/

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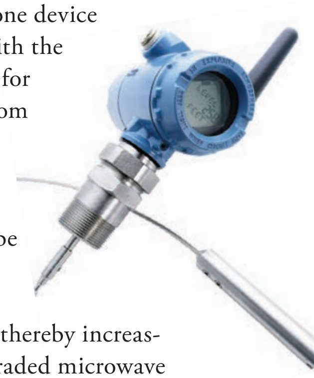

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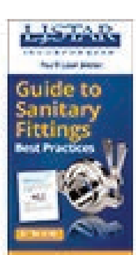


In the pharmaceutical and biotech world, the routine activity of disassembling, cleaning and reconfiguring clamp connections is essential to maintaining proper function without compromising sterile process control. Download this white paper for helpful tips.
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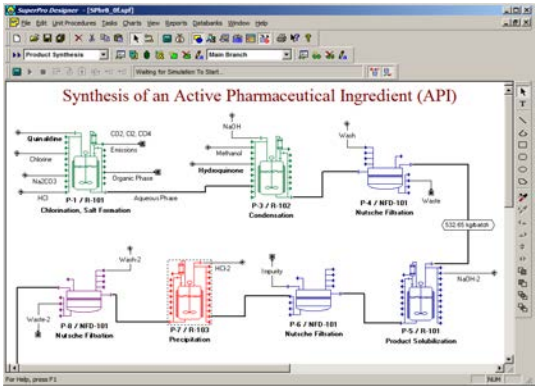


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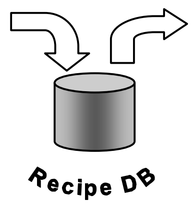


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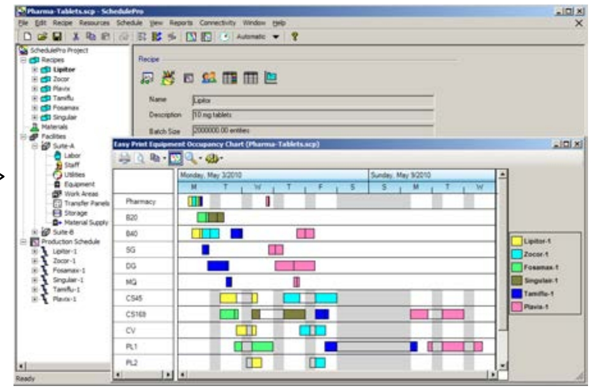

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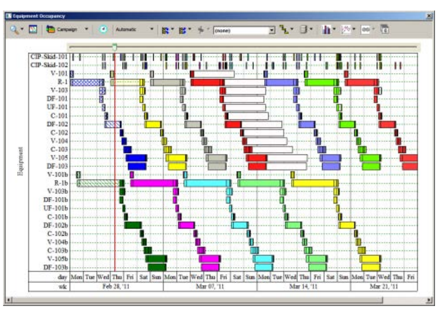

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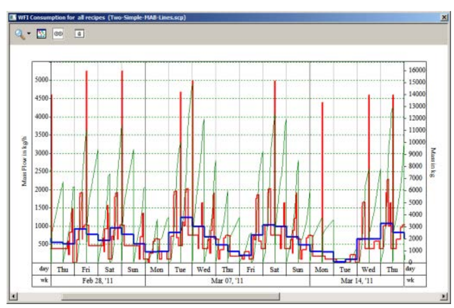

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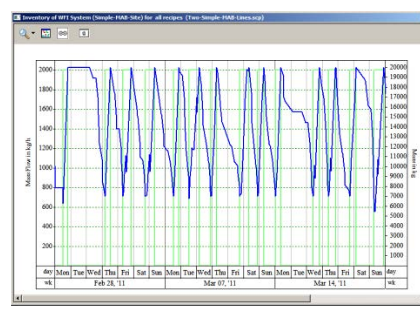

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ADVERTISER INDEX

# Enhanced Organic Solvent Filtration Beckons

Synthetic approach improves structural and chemical stability in liquid separation

Solvent permeability is almost an order of magnitude higher than that of other polymer membranes.

**RESEARCHERS AT** King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia, have created covalent organic crystal networks that act as high-selectivity and high-flux membranes for organic solvent filtration.

They believe such structures could lead to future industrial membranes that will help treatment technologies meet increasingly stringent environmental controls while being cost-effective to produce and operate.

Organic solvent nanofiltration typically involves polymer-based membranes that feature tiny pores, but form dense and amorphous networks. Well-ordered microporous materials, such as zeolites and metal-organic frameworks, perform significantly better in various separation processes; however, they're not suitable for extensive use in liquid separation because of their poor structural and chemical stability in liquids.

Now a team led by Zhiping Lai, a professor of chemical and biological engineering, has developed a synthetic approach using covalent keto-enamine linkages to produce well-ordered microporous materials. The linkages result from the reaction between amine and aldehyde functional groups of organic compounds.

"In our process, we have used a β-keto-enamine-based reaction based on the very active precursors 1,3,5-triformylphloroglucinol and 9,9-dihexylfluorene-2,7-diamine for the formation of covalent organic framework (COF) membranes. These precursors are stable in both aqueous and organic solvents," notes Lai.

The team chose the β-keto-enamine route after a careful literature review into how best to generate good crystalline COF membranes. This helped formulate defect-free crystalline COF structures in powder form.

To convert the powder into crystalline COF thin films, the team used the Langmuir-Blodgett (LB) method to transfer Langmuir films — or monolayers — from the liquid/air interface to solid supports as these are passed vertically through the monolayers.

The LB method reliably produced large-area thin films of well-defined thickness using the amphiphilic aldehyde and amine precursors. The researchers deposited the precursor mixture solutions on a water surface to form weakly bound two-dimensional hexagonal structures. Once the solvent evaporated, they compressed the films laterally and added an organic acid to the mixture, transforming the reversible bonds into covalent keto-enamine linkages and sealing the hexagonal structures in place.

"The special reaction we chose here produced β-keto-enamine-based COF membranes that are thermally as well as chemically stable in any media, i.e., acid, base and aqueous," adds Lai.

The new membranes outperformed amorphous analogues fabricated using the same method and the best polymer-based systems.

"They share the same chemistry as polymer analogues, resulting in similar hydrothermal, chemical and mechanical stabilities, but their fluxes are higher," says postdoctoral fellow Digambar Shinde, lead author of a paper published about the work in the *Journal of the American Chemical Society*.

The new membranes' organic solvent permeability is almost an order of magnitude higher than that of the best-reported polymer membranes, he adds. In addition, the membranes were more stable than metal-organic frameworks; more cost-effective than inorganic membranes; and could separate mixtures of dye molecules differing in molecular weights and sizes.

The team now is working to extend use of the membranes to numerous applications. "The pore sizes of these membranes are suitable for seawater desalination pretreatment, food processing, purification of pharmaceutics and medical processes, such as hemodialysis," says Shinde. The membranes also can help eliminate heavy metals, viruses and bacteria.

Current work also includes tuning the porous structure for more energy-intensive separation systems, improving the mechanical strength of the film, developing a better chemical approach to simplify the membrane fabrication process on porous supports, and exploring possible methods for membrane scaling up.

"The current membrane fabrication process can make membranes with a size suitable for niche applications... but not suitable for large-scale applications. A novel approach is yet to be developed to make the membrane on flat-sheet or hollow fiber supports. ...The wide application of such membranes will also rely on our ability to scale up the synthesis of all precursors — most of which are currently custom-designed from our lab. We also need to study in detail the membrane formation mechanisms," he explains.

Nevertheless, Lai points out the industrial significance of the separation technology is clear: "Once we overcome the scaling-up issues, most of our membranes will find industrial applications straightforward." ●

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