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TURN UP PROCESS SAFETY PERFORMANCE

Implementing an effective operational discipline program can help

OCTOBER 2019

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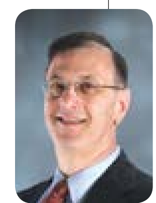
Keep Enhancing Process Safety

Industry must never accept current performance as good enough



We're doing our part to help you improve process safety.

THIS MONTH'S Mary Kay O'Connor Process Safety Center 2019 International Symposium (http://bit.ly/2kJFVTd) testifies to the importance our industry places on process safety — and to the need for continual improvement. We must strive relentlessly for that unachievable goal of absolute process safety.

One hopeful sign since last year's symposium is an apparent change in attitude by the Trump Administration. After its repeated attempts to defund the U.S. Chemical Safety Board (CSB) were thwarted by Congress, the White House now has nominated Katherine Andrea Lemos to become its chair; she has a background in aviation and previously served on the National Transportation Safety Board. The terms of the three remaining board members expire in 2020, and this may lead to significant changes at the CSB. We'll be following what happens and the implications.

Meanwhile, a survey released in mid-August by Sphera, Chicago, underscores the need for more action. "The State of Process Safety and Operational Risk Management: Stuck in the Status Quo" (http://bit.ly/2kpLIgx) emphasizes that a large gap exists between process safety intent and what occurs in everyday operations. Indeed, the survey — the fourth (earlier ones were done by Petrotechnics, which Sphera acquired) — provides some telling results. While 84% of respondents call safety part of their company's corporate values, only 70% cite a defined roadmap and goals for improving safety performance, and just 63%, say their organization has good leading and lagging safety indicators. Moreover, merely 40% claim their company proactively manages process safety. This, the report notes, corresponds to previous surveys and suggests lack of progress in proactively managing risks.

A number of factors exacerbate the situation: 69% of respondents admit to a regular shortfall in completing scheduled asset-integrity inspections; 49% cite an exodus of experienced staff; and 45% point to conflicts between policies and procedures and frontline working practices.

Digitalization offers crucial help, stresses the report. However, the survey finds that companies are struggling to effectively take advantage of it: 75% of respondents say siloed data and piecemeal insights hamper efforts.

Chemical Processing is doing its part to help you improve process safety. For instance, we partner with the Mary Kay O'Connor Process Safety Center on an ongoing series of free webinars (see: http://bit.ly/2kF8RLZ). In addition, we regularly publish safety-related content — this issue includes two such articles.

Our cover story, "Turn Up Process Safety Performance," p. 14, http://bit.ly/2kUPnmu, focuses on the importance of an effective operational discipline (OD) program. Author Jim Klein stresses: "If a company isn't satisfied with its process safety performance, a new or renewed effort on OD may represent one of the best opportunities for improvement."

Continuing advances in safety instrumented systems offer another avenue for boosting performance, as "Hazardous Process Gets Important Improvement," p. 37, http://bit.ly/2lXWsD6, illustrates.

As I've noted before ("Here's a Safe Bet," http://bit.ly/2k9SCGq), *Chemical Processing* publishes far more safety-related information than any other magazine in our field. That's a deliberate decision on our part. So, you can count on regularly seeing such valuable content. ●

MARK ROSENZWEIG, Editor in Chief
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Podcast Focuses on Process Safety

A new series strives to help you keep your plant safe

We aim to discuss current process-safety issues and offer insights into mitigation options.

WE RECENTLY launched a podcasts series — Process Safety with Trish & Traci. Obviously, I'm the Traci in the duo. Trish Kerin, Melbourne, Australia-based director of the IChemE Safety Centre, is my partner. In this series, we aim to discuss current process-safety issues and offer insights into mitigation options and next steps.

In the premiere episode ("Educated Workforce Key to Safety in China"), we talk about the role an educated workforce plays in achieving better process safety. Several catastrophic incidents in China led to this discussion and Kerin offers some thoughtful analysis as to why it seems so many issues arise.

"Everywhere I go around the world, I constantly hear questions or comments about competency and the challenge in developing, establishing and maintaining competence of our people to do the tasks we need them to do safely," says Kerin. "I don't think China is any different in that space. I think they, too, have some competency related issues just like we do in the U.S.A., in Australia, in the U.K., all around the world.

"I think there're probably far more instances of people not knowing how to do the right thing rather than deliberately doing the wrong thing." She notes that universities around China are dedicated to improving process safety education. "They're really trying to make efforts and strive to do these improvements, which does need to be commended."

This episode also points out that all chemical processing facilities must continue to strive to really work to build that competency. "To make sure we have the right equipment in place and to drive that inherently-safer-design concept so that we actually make it much, much harder to make a mistake. It becomes easier to stumble into getting it right."

Helping listeners get it right is the goal. And it seems a lot of work needs doing. According to a survey cited in Mark Rosenzweig's editorial this month ("Keep Enhancing Process Safety," p. 7), a large gap exists between process safety intent and what occurs in everyday operations. That survey underscores the need for more action.

Action, indeed. This podcast is just another way "we're doing our part to help you improve process safety," if I may borrow from Mark's column.

In upcoming episodes we will tackle inherently safer design, whether regulations make us safer, how to achieve better safety training, and deciding if safety checklists are a good or bad idea. And as incidents occur around the world, we will discuss missteps and how to avoid future events.

HOW TO LISTEN

You can access this podcast and our other series — The Minute Clinic — via this link: chemicalprocessing.com/podcasts/. Each series is available for download on several podcast apps including Apple (formerly iTunes), Google Play, Stitcher and Spotify. Don't worry if none of those sound familiar to you — you can also listen right from the ChemicalProcessing.com website.

WHAT'S THE MINUTE CLINIC?

Chemical Processing's Minute Clinic podcast series is designed to tackle one critical issue at a time — giving you hard-hitting information in just minutes. This series is also hosted by me and covers several topics including operator performance and reliability and maintenance.

Have a topic you'd like covered for either series? Send me an email at tpurdum@putman.net. And if you are a subject matter expert who would like to participate in the Minute Clinic or join Trish and me to talk about process safety, use the same email address to pitch your ideas.

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ISSUE ARCHIVES

Did you know you can digitally access more than a decade's back issues of *Chemical Processing*? Just go to chemicalprocessing.com/issues/ and scroll through the years. Each issue features links to all the articles and columns that appeared that month. You can also download the PDF of the issue. First-time visitors to this page will be asked to register for access. Once you fill out the quick form, you won't need to register again.

Clean Up Your Process Engineering

Don't ignore the need for cleaning and the resulting waste streams

I thought of all the cleaning situations that went wrong.

THE CONTRACT welder threw his helmet 30 feet against the wall and let out a string of insults against my company. He was furious. He'd been burned by caustic soda several times because our operations group thought that blowing a line out was cleaning it. I sided with him on this one. It was late. We were sunburned and the temperature exceeded 90°F. We'd been trying to get the final weld done for an hour and the sun was hitting the tree line. We took a break and talked about beer.

We worked out a solution. We tilted the long length of pipe upward and shot cold water in; we did this repeatedly until the pipe was full, mostly with water. Water sputters but doesn't spit hot caustic. The weld wasn't pretty but it held. It was dusk when the welder drove away and I trudged back to my office. I thought of all the cleaning situations that went wrong.

Cleaning pipe and equipment is as much a part of process engineering as equipment design and system controls but nobody really covers it. Let's get started.

As I said in last month's column (see, "Make Your Outage a Success," http://bit.ly/2L40unK), you need plans in place for cleaning. First, it's foolish to clean an entire system from a feed tank to a product tank. So, build in a system of blocks that allow you to clean only what actually requires attention. Blowing a product back to storage is a good idea — it's only a first step. The next step is neutralizing the pipe, gently. Generally, do this with water; it's important to avoid conditions that affect corrosion, like low pH, or cause phase changes, like foaming or sedimentation. Evaluate the impact of temperature: if a fluid reacts violently, chill the purge liquid; or if the fluid clouds or waxes up, think about heating, either indirectly or more efficiently by steaming. Consider doing some lab tests.

Adding caustic to water can make sense; food and pharmaceutical processes often rely on caustic to break down cell walls. The trouble is that high pH causes trace sulfates and nitrates as well as more common carbonates, those typical in well water, to precipitate on pipe walls.

A course of inhibited hydrochloric acid (HCl) at a warm (not hot!) temperature might alleviate this problem. Citric acid has been used as a chelating compound to help with descaling. Keep the temperature below 115°F for straight-grade stainless steel pipe; I recommend using low-carbon (L-grade) because it resists weld pitting.

Plan for where to dump the contaminated liquids from cleaning. I suggest flowing water in through a hose connection — it's best to install a back-flow preventer — and pumping it to a rental tank for disposal using an air diaphragm pump connected to the pipe being cleaned. With caustic and acids, a pH strip will tell you when the water's pH matches that of the plant water; I prefer on-the-spot pH measurements to analyzers because they require maintenance (which usually is done badly).

Reactive, or toxic fluids pose a significant problem. When I worked with titanium tetrachloride, we neutralized (killed) the tank by slowly adding water after putting in a thick blanket of defoamer. The water tube was inserted into the foam and we watched the tank temperature to avoid eruptions of toxic HCl and titanium oxides; a vent system scrubbed the vapors. The treatment was complete when the temperature reached that of the plant water. As with most toxic chemicals, the liquid was slowly evaporated away with the remaining solids going into drums for disposal.

Certain processes, such as those in paper and dye making, pose a particular problem with color in their discharge. Dilution isn't necessarily the answer. Water restrictions only allow so much dilution. The best solution seems to be a treated sand filter if you can identify the reactivity of the chemicals in your waste stream or cleaning solution; this analysis can be pretty extensive and even frustrating if you fail to pinpoint all the potential bad actors.

A possible alternative is passing a side-stream through a bed of activated carbon to remove color. The idea is to clean enough of the colored stream to comply with regulatory requirements.

Bio-remediation might be another option although I'm not aware of its use to remove color from wastewater. However, elevated levels of chlorides and high or low pH undermine the effectiveness of bio-remediation. ●

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Carbon Utilization Gets a Boost

Carbon monoxide electrolysis promises attractive route to amides

A RECENTLY developed process that creates carbon-nitrogen bonds during electrochemical carbon monoxide reduction offers a new route for producing a variety of acetamides, say researchers from the University of Delaware (UD), Newark, Del., along with collaborators from the California Institute of Technology (Caltech), Pasadena, Calif.; Nanjing University, Nanjing, China; and Soochow University, Suzhou, China. The process could further advance carbon capture and utilization (CCU) and extend its promise to the pharmaceutical industry among others, they note.

"This has significant impact down the road, I think, to partially address carbon dioxide emission issues," says Feng Jiao, an associate professor of chemical and biomolecular engineering at UD, and the associate director for UD's Center for Catalytic Science and Technology (CCST). "Now we can actually utilize it as carbon feedstock to produce high-value chemicals," he adds.

The process involves feeding an electrochemical flow reactor with both carbon monoxide and ammonia. The ammonia's nitrogen in the presence of a copper catalyst reacts with carbon at the electrode/electrolyte interface at ambient conditions to form carbon-nitrogen (CN) bonds. "This actually provides a unique way to build large molecules which contain nitrogen from simple carbon and nitrogen species," notes Jiao.

"In the field of electrochemical carbon dioxide or carbon monoxide reduction, only four major products are reported, including ethylene, ethanol, acetate and n-propanol. While these commodity chemicals have values, their market prices are not that high. Our previous study of techno-economic analysis of carbon dioxide electrolysis technologies suggested we target high-value chemicals because of the significant cost of electricity in the United States. Chemicals for pharmaceutical industries often contain heteroatoms, such as nitrogen and sulfur. This motivates us to look into ways to build these heteroatoms into the products that we can produce electrochemically from abundant sources such as CO_2 and ammonia," explains Jiao.

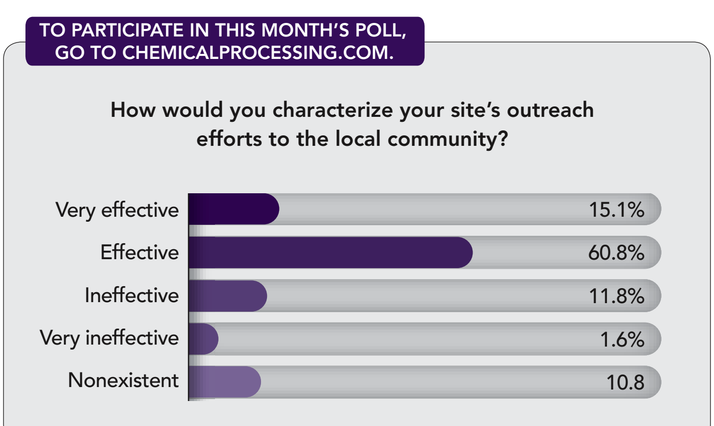
"The important insights obtained from this work include the identification of ketene as a key intermediate in copper-catalyzed carbon monoxide reduction reaction and the possibility to form carbon-heteroatom bonds by co-feeding a nucleophilic agent with carbon monoxide. The collaboration with Caltech further enabled us to establish a detailed reaction mechanism, a critical knowledge towards rational design of advanced catalysts. For example, we can tune the property of the catalyst and make it more favorable for one reaction pathway than the other. Such a catalyst design requires us to know which intermediate holds the key for product selectivity," he adds.

The team performed an 8-hr electrolysis test to determine the stability of the copper catalyst and susceptibility to poisoning. Results showed no loss of catalyst activity and selectivity. "We also examined the structural stability of the catalyst … Of course, more studies will be required to investigate catalyst stability at a much longer time scale for practical applications," admits Jiao. "We also haven't tested other potential contaminants that could be present in common carbon monoxide or carbon dioxide sources. This will be something for future studies," he notes.

The researchers reported in *Nature Chemistry* acetamide selectivity of nearly 40%. "The work we just published is the first demonstration of CN-bond formation in electro-reduction of carbon monoxide in the presence of ammonia (or amine). There is plenty room to improve the selectivity, which is important to minimize product separation costs," comments Jiao.

The team will next examine possibilities to form other products using this process. "We are also interested in investigating the role of the catalyst in the CN-bond formation, which is an unexplored area at the moment," says Jiao.

The researchers have filed an international patent through UD based on this discovery. Jiao and Gregory Hutchings, a former graduate student, have formed a startup company to potentially commercialize the technology and are looking for industrial partners.



More than three-quarters of respondents rated outreach efforts as effective or very effective.

Sustainable Methanol Production Beckons

A MODIFIED indium oxide catalyst developed by researchers at ETH Zurich, Switzerland, with sponsorship from Total, La Défense, France, efficiently converts carbon dioxide and hydrogen directly into methanol. It offers an attractive option for green production of methanol, they say.

The efficacy of indium oxide in this role originally was demonstrated by ETH Zurich professor of catalysis engineering Javier Pérez-Ramírez and his team in 2016. At that time, the researchers reported high activity, 100% selectivity and "remarkable" stability for 1,000 hours using indium oxide supported on zirconium dioxide under industrially relevant conditions. However, further work revealed the catalyst's level of activity necessitated quantities of indium oxide that precluded industrial viability.

Now, the team has come up with a new approach that involves treating the indium oxide with a small quantity of palladium, a known hydrogen gas splitter.

After investigating different treatments, including coating the catalyst with palladium, the scientists discovered that introducing palladium into the indium oxide crystal lattice structure aided the formation of palladium clusters on the lattice surface. These, in turn, gave the best conversion results: space-time yield (STY) started at 1.01 g methanol/hr/g catalyst and still remained at 0.96 g/hr/g after 500 hours onstream. More details appear in a recent article in *Nature Communications.*

The methanol STY, say the researchers, is 15% higher than that achieved by the best performer reported previously. Moreover, residence time is roughly 60% shorter, enabling a 60% reduction in reactor size, which is a strong plus for prospective industrial processes, they note.

The boost in catalyst activity doesn't incur adverse effects on either selectivity or stability, the researchers add.

Unlike other methods currently under development to produce green fuels, the technology has the great advantage that it's almost ready for the market, says Pérez-Ramírez. All it needs is a supply of carbon dioxide and hydrogen from renewable sources.

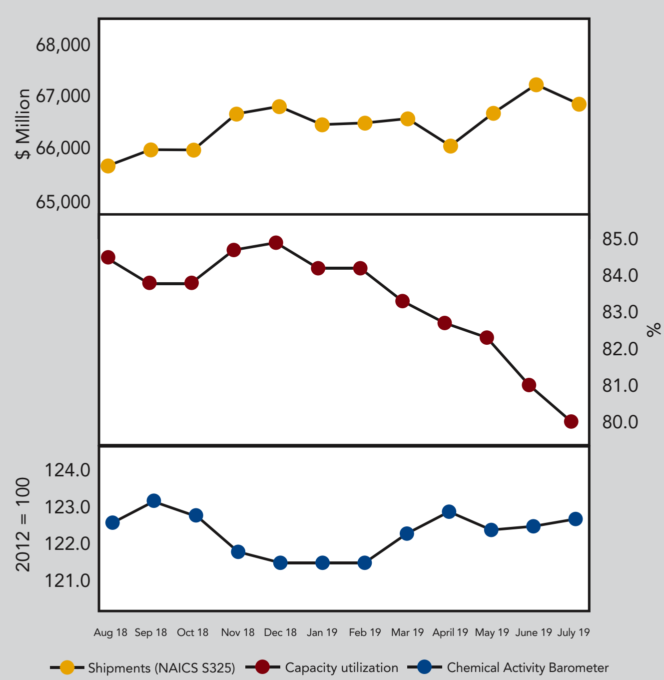
ETH Zurich and Total jointly have filed a patent on the technology. Total now plans to scale up the approach and potentially implement the technology in a demonstration unit over the next few years. While the investment and timescale for the project remain confidential, Pérez-Ramírez notes the unit likely will be located at a Total facility.

SUSTAINABLE METHANOL

Figure 1. Synthesis spurred by new catalyst enables recycling carbon dioxide and hydrogen. *Source: ETH Zurich/Matthias Frei.*

"Now we are starting to look into designing catalysts that operate as efficiently as the one reported, but at a significantly lower pressure. This is a challenge, but it will reduce the energy consumption of the process due to lower compression costs," he says.

ECONOMIC SNAPSHOT



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

Take a Closer Look at Interstage Pressure

Follow these guidelines for monitoring multistage compressors

Interstage pressures are good indicators of a compressor's mechanical health.

MULTISTAGE COMPRESSORS with intercooling are common in processes demanding high pressure ratio compression. Their widespread application mainly stems from the energy savings multistage compression provides over single stage, even though they are more capital intensive, less reliable and require more floor space.

Key considerations made in designing multistage compressors include deciding the number of stages and fixing the interstage pressures. Limits associated with allowable gas discharge temperature and material temperature limits of the components decide the number of compression stages. The values for interstage pressures are chosen to achieve the minimum energy demand condition.

The procedure involves differentiating the general equation for the work done by any two consecutive stages of a multistage compressor with respect to the interstage pressure. Equating the derivative to zero gives the minimum work condition. The result shows that the work done by the compressor is minimized when the pressure ratio across each stage is equal. The pressure ratio across any stage is defined as the ratio of the discharge pressure to the suction pressure, with both values expressed in absolute units.

The result shows that, for any multistage compressor, the minimum work condition is achieved when:

$$PR_{stage}=(PR_{overall})^{1/n}$$

where, PR_{stage} is the pressure ratio across each stage; $PR_{overall}$ is the ratio of the final stage discharge pressure to the first stage suction pressure; and n is the total number of compression stages.

The interstage pressure, P_i, is obtained using the equation:

$$P_i=P_{s\text{-}u}\times PR_{stage}$$

where, $P_{s\text{-}u}$ is the suction pressure of upstream stage. (Note: Each pressure value is in absolute units.)

Multistage compressors are thus designed and built to achieve the above conditions. Optimum energy consumption is indicated when such compressors operate with the same pressure ratio across each stage.

Thus, the interstage pressures of any multistage compressor provide an important indicator. When the pressure ratio across each stage is the same, the interstage pressure values for this condition can be calculated and then compared with actual pressure indications on the compressor. When there is a good match for every stage, the gas compression is efficient.

Interstage pressures, along with consumed motor current, can help determine the mechanical health of the compressor stages. A change in actual values of interstage pressures from the expected values is a definite indicator of underperformance of the stages.

As an example, consider a 2-stage reciprocating compressor handling air. It takes suction from atmosphere and discharges at 6 barg. Using the above equations, the expected interstage pressure is 1.6 barg (2.6 bara). Values higher or lower than this value clearly warrant a look at the health of the stages.

Interstage pressure below that expected implies that mass flow rate from the upstream (low pressure – LP) stage is lower than normal. The interstage volume (volume between the two stages) is fixed. When mass delivered in this volume is less than normal, the interstage pressure will be lower. The inference is that the LP stage isn't performing as expected and needs further analysis to identify the cause.

On the other hand, interstage pressure greater than the expected value reveals that the high pressure (HP) stage can't intake the normal mass flow rate being discharged by the LP stage. Underperformance of the HP stage would lead to accumulation of mass in the interstage, resulting in a higher interstage pressure.

This brings us to a simple and easy to remember rule. If the interstage pressure is *lower*, there is a problem with the LP stage, when it is *higher*, the HP stage needs attention.

Maintenance personnel and field operators often mark the expected values of the interstage pressures and motor current on the pressure and ampere meter gauges. Deviations from the normal values are the first indicators of sub-optimal performance and compressor health issues.

The interstage pressure parameter is thus a useful early-warning parameter in multistage compressors. ●

PARESH GIRDHAR, Guest Contributor
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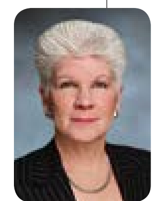
Editor's note: This article was written by a colleague of our regular columnist, Alan Rossiter (pictured). Paresh Girdhar, principal engineer at the Asset Technology Centre in SABIC, KSA, is a rotating machinery specialist with experience in maintenance, operation and reliability enhancement of rotating equipment in the petrochemical and refining industry. He has authored books on performance evaluation of pumps and compressors, predictive maintenance techniques and centrifugal pumps.

Court Nullifies New York Disclosure Program

Ruling declares initiative didn't follow state rulemaking procedures



Many in industry questioned the legality of the program.

IN A significant victory for industry, on August 27, 2019, the State of New York Supreme Court invalidated the New York Department of Environmental Conservation (NYDEC) Household Cleansing Product Information Disclosure Program. The program is an example of the newest trend in state "information disclosure" programs intended to force product manufacturers to disclose the ingredients in products sold to consumers. This article discusses the program and explains why the court rescinded it.

BACKGROUND

On June 6, 2018, NYDEC released in final its disclosure program, containing the Household Cleansing Product Information Disclosure Program Certification Form and Program Policy. The disclosure program as issued required manufacturers of cleaning products sold in New York to disclose chemical ingredients and to identify any ingredients that appear on specified authoritative lists of chemicals of concern on their websites. New York stated when it issued the program that it "will be the first state in the nation to require such disclosure and the State's program goes beyond initiatives in other states by requiring the robust disclosure of byproducts and contaminants, as well as chemicals with the potential to trigger asthma in adults and children." NYDEC posted the program components and a response to comments at the time.

The program from the start raised significant industry concerns. First, the compliance date was quite short and manufacturers scrambled from the beginning to understand the program and comply with the requirements. The start date was delayed in response to some of these concerns (see, New York Disclosure Program Hits a Snag, http://bit.ly/2lWkK0f).

Second, the program diverged from a similar cleaning products disclosure program enacted in California (SB 258) shortly before New York's rolled out. The lack of alignment understandably caused considerable concern among product manufacturers, both from compliance and commercial disruption perspectives.

Third, the program was quite demanding and required a level of detail and specificity that many thought excessive. Industry expressed concern with the amount of time and effort compliance would likely require, especially in light of the lack of alignment with the California program.

Finally, many in industry questioned the legality of the program. To many, it seemed to reflect all the attributes of a final rule, but none of the procedural protections that accompany a rulemaking as part of the process in issuing the program.

THE LAWSUIT

In October 2018, two trade associations, the Household and Commercial Cleaning Products Association (HCPA) and the American Cleaning Institute (ACI), filed a lawsuit in state court challenging the disclosure program. They sought declaratory relief and a judgment invalidating the disclosure program on the basis that the program was a rule for which NYDEC did not comply with its State Administrative Procedure Act (SAPA) rulemaking procedures. The groups also argued that the program was established in violation of Article IV Section 8 of the New York State Constitution, was issued in excess of NYDEC's statutory authority, and was arbitrary and irrational.

The court agreed, finding the disclosure program violated the SAPA and the state constitution. The court held that the program was a "rule" as argued by the groups and not "guidance" for which adherence to SAPA wasn't required, as argued by NYDEC. The court found that "since there is no opt out provision whereby petitioners may choose to deviate from the program, the Disclosure Program is not mere guidance." The program, the court concluded, was thus "null and void and the matter is remitted back to DEC with the directive to comply with SAPA."

DISCUSSION

The court's decision is a decisive victory for the petitioners. Although NYDEC has the option to appeal the decision or ask the legislature to pass a law authorizing the disclosure program as written, many hope instead that NYDEC takes to heart the court's concerns about the abuse of process and works with stakeholders to develop a workable and effective program. This path would present an important opportunity to align NYDEC's program with California's. Implementing a national model for ingredient communications will ultimately benefit industry stakeholders interested in ensuring compliance and better inform consumers about the information communicated when provided in a consistent manner.

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TURN UP PROCESS SAFETY PERFORMANCE

Implementing an effective operational discipline program can help

By James A. Klein, ABSG Consulting Inc.

EVEN HIGHLY trained people make mistakes. Some errors have minor consequences — but others potentially can lead to catastrophic incidents, especially in a high-hazard chemical process. An effective process safety management (PSM) program anticipates that people will make mistakes. As Figure 1 [1] depicts, such a program includes the three crucial elements: process safety systems that describe how to do work safely and correctly; a focus on safety culture and leadership; and an operational discipline (OD) program to help ensure correct execution of system requirements and cultural priorities every time.

OD is essential to achieve excellent process safety performance. Excellent performance means well-designed process safety systems that function day-to-day as intended and the prevention or effective mitigation of incidents that could result in fatalities, serious injuries, business interruption and environmental harm. Of course, poorly designed or implemented process safety systems and a weak organizational safety culture can significantly undermine the value of an OD program.

The U.S. Occupational Safety and Health Administration's PSM regulation is over 25 years old and many companies in the United States and elsewhere have implemented PSM systems. For several years, companies also have focused on safety culture and leadership to help achieve their process safety goals. OD efforts — the commitment by everyone in an organization to always follow the systems and procedures that have been developed — often receive less attention but are crucial for reducing human error. If a company isn't satisfied with its process safety performance, a new or renewed effort on OD may represent one of the best opportunities for improvement.

HUMAN ERROR AND OD

In an incident investigated by the U.S. Chemical Safety Board (CSB) [2], an operator opened the bottom valve of an operating polymerization reactor, apparently bypassing an active pressure interlock, instead of opening the bottom valve of a nearby reactor that was being cleaned. A large release of flammable material from the reactor ignited; the resulting explosion led to five fatalities and major damage to the facility. The CSB concluded, among other findings, that the facility "did not adequately address the potential for human error." Of course, human error often is a major contributor to incidents [3, 4] as shown by industry investigations of incidents and near-misses.

There are many causes of human error. Some common ones include [1]:

- human fallibility, capability, complacency and commitment;
- training issues, including procedure quality and training effectiveness;
- workplace environment, including accessibility of information and distractions;
- familiarity with the work being done and the time since it was last done;
- fitness-for-duty considerations, such as alcohol, drugs, stress and fatigue;
- urgency for completing a task quickly; and
- lack of risk recognition or sense of vulnerability.

The reality is that a company should anticipate human error and provide appropriate systems and safeguards to ensure errors don't lead to serious injuries and other consequences, especially if work tasks include higher-risk activities involving significant process hazards. OD addresses human behavior in following required systems and procedures correctly, every time, to consistently achieve safer and more reliable operations. Developing an OD program [5–9] intended to support day-to-day commitment by all company personnel — in combination with well-designed process safety systems

Figure 1. Three elements contribute to an effective process safety program. *Source: Ref. 1.*

and a strong safety culture — can help both to minimize the potential for human error and confirm that process safety (and other) program requirements are rigorously followed.

A strong OD program can provide benefits in a variety of areas [1], including:

- *Environmental, health and safety* — prevention or reduction of workplace injuries, occupational exposures, process incidents, environmental releases, and associated costs;
- *Operations* — decrease in unscheduled shutdowns, poor process utilization, inefficient use of staff, incident-related downtime, and associated costs; and

- *Quality* — reduction in off-specification product, rework and waste, lower yields, poor quality, customer complaints, and associated costs.

The safety triangle (Figure 2) illustrates qualitatively that significant consequences, such as serious injuries or catastrophic incidents (at the top of the triangle) often (but not always) are the result of, or predicted by, a larger number of smaller near-miss events or unsafe acts and behaviors (at the bottom of the triangle). Focusing on minimizing or eliminating potential problems frequently can help prevent the more-serious events. An effective OD program works to reduce undesirable actions at the bottom of the triangle by encouraging and supporting correct actions in following program systems and procedures. This is especially important for higher-risk activities involving significant process (or other) hazards, where the base of the triangle may be very narrow — meaning that even one mistake or unsafe action can lead directly to a serious injury or other consequence. Ultimately, OD programs aim to help reduce the frequency and associated risks of human error.

PROGRAM CHARACTERISTICS

A program must focus on both organizational and personal OD [1,6,7]. Organizational OD involves developing the programs and work environment to support strong OD as well as providing resources for OD improvement efforts. Organizational OD efforts closely relate to good safety culture and leadership practices, and supplement associated management systems to promote and achieve program goals. Personal OD characteristics target worker activities at all levels of the organization to ensure workers know what they need to do and perform their work correctly and safely every time.

Good OD performance doesn't happen on its own. It requires continued management attention [7] — to demonstrate personal attention and dedication; provide appropriate resources, as needed; implement and use effective systems; monitor and evaluate actual performance; and develop and support effective processes to facilitate employee understanding, engagement and follow-through.

Organizational OD possesses four characteristics [1]:

- *Leadership focus*. Leaders emphasize and provide a positive work environment, managing processes and resources for effective programs and employee engagement. Leaders are personally involved and passionate for safety and model the behaviors they expect from everyone in their organization.
- *Employee engagement*. Employees at all levels of the organization understand and value the importance of safe work activities and contribute to organizational programs and activities.
- *Procedure principles.* Correct ways of doing work are defined and work is completed as planned, following reviewed and authorized systems and procedures.
- *Housekeeping and workplace standards.* Standards are established for maintaining safe equipment, tools and facilities. Employees are proud of their work environment and consistently maintain high levels of housekeeping.

While related to safety culture, these characteristics serve to emphasize the OD aspects of effective programs. Leadership focus provides the foundation of any OD program — without it, priority and support for OD improvement can't exist. Leadership also must promote strong employee engagement; too many uninvolved or uninterested employees will limit an organization's ability to achieve robust performance. An important part of leadership focus, therefore, is providing the culture and work environment to engage employees at all levels of the organization, involving them as active participants in safety programs and in achieving strong performance. The most visible results of leadership focus and employee engagement are employees following approved systems and procedures, operating equipment within safe operating limits, and maintaining equipment and work areas in safe operating condition.

Personal OD has three characteristics [6]:

- *Knowledge*. The employee understands how to do the work task correctly and safely.

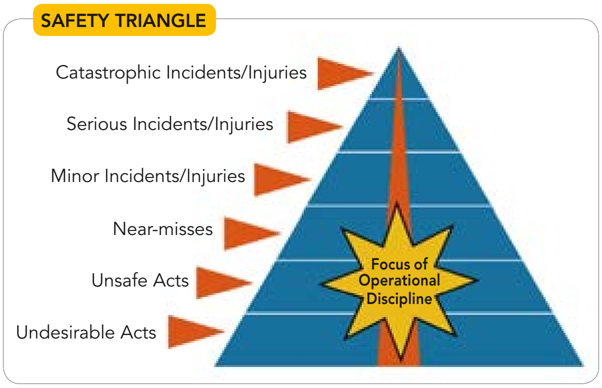
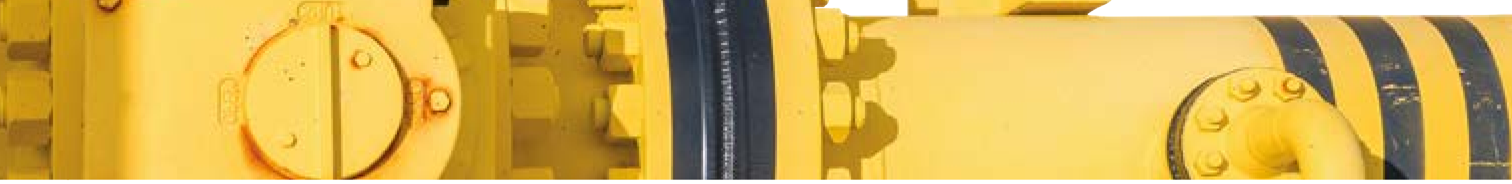


Figure 2. Minimizing lapses lower in the triangle often can help forestall more-serious events. *Source: Ref. 1.*



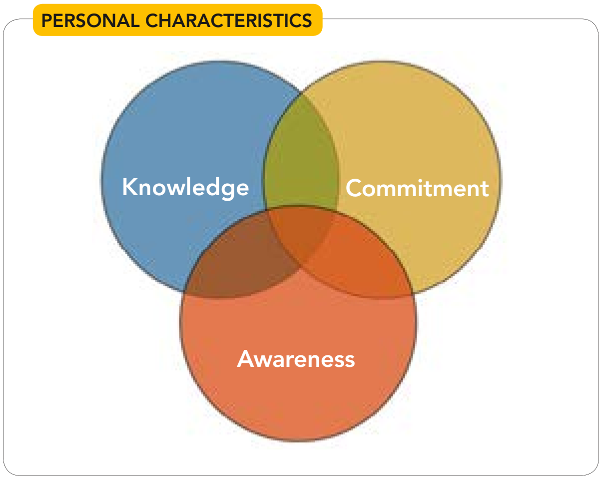


Figure 3. A deficit in any one area can undermine OD performance. *Source: Ref. 6.*

- *Commitment.* The person commits to doing the tasks the right way, every time.
- *Awareness.* The individual anticipates potential problems and recognizes unusual situations.

As Figure 3 highlights, all three personal characteristics are essential for achieving high levels of OD performance; a deficit in one area can increase the risk of an error. The goal is to have a prepared, skilled and suitable work effort that can effectively and safely deal with the existing work environment rather than an unquestioning focus on strict adherence to procedure when circumstances differ or change. Of course, procedures and training should cover possible deviations and the correct ways to respond to them to help mitigate any potential negative consequences. Efforts on personal OD necessarily relate to other major programs for reducing human error, including human factors analysis, behavior-based safety, human performance technology and human reliability assessment.

ELEMENTS OF AN EFFECTIVE PROGRAM

OD issues and problems typically are specific to an organization and local site, often varying in priority widely within the same organization or facility, based on different safety cultures, leadership, work activities, hazards, geographic locations and other factors. While common issues may exist within a larger organization — for example, no current focus on OD — improvement activities, which should not be prescriptive, must be evaluated locally to help identify and prioritize improvement opportunities and goals. For example, one site may have poorly developed procedures while another site may lack housekeeping standards. Both factors can affect OD performance but improvement requires different approaches. Effective OD programs, depending on the size of the organization or site, should consider one umbrella goal, for example, implementing an OD improvement program — but the details of specific activities for achieving better OD should be developed, prioritized and pursued based on specific local conditions and issues, as appropriate.

Figure 4 [1] shows a recommended approach for developing an effective OD program. The primary steps include:

- *Focusing on OD improvement.* Without specific management attention, organizationally and locally, OD is unlikely to improve in a sustained way.
- *Raising OD awareness.* Introduce all employees to what OD is and why it's important. You can do this by discussing OD with employees in special workshops or meetings, safety meetings, shift meetings, etc.; reinforcement day-to-day in the workplace by management attention and practices is important. Solicit employee input on OD to help raise awareness and identify specific issues, causes and possible solutions for further evaluation.
- *Evaluating OD performance.* Assess current OD performance to establish a starting point and identify potential OD improvement opportunities, based on review of performance metrics, incident data, audit results, quality data and, potentially, targeted surveys.
- *Prioritizing OD improvements.* Focus on key areas for enhancing performance and opportunities that can produce tangible results quickly. Engage site employees for input, establish specific goals and timing milestones, and provide resources. Given the many competing priorities for resources, it's generally better to limit the

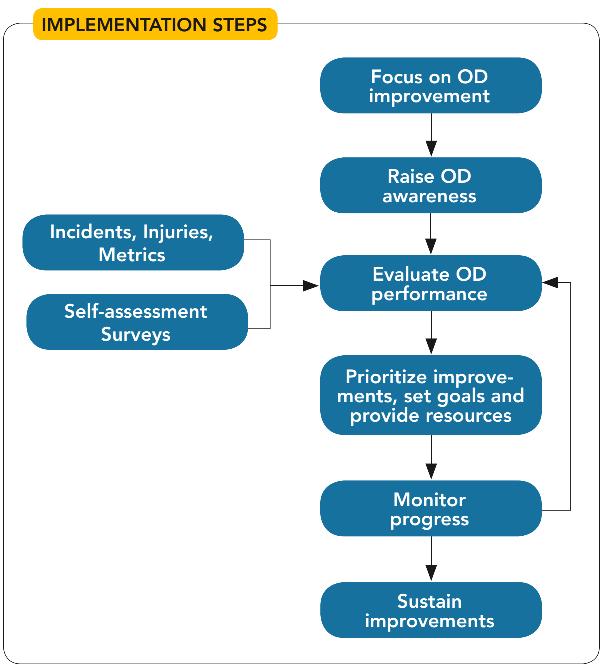
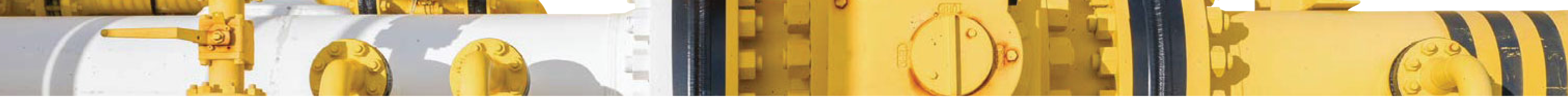


Figure 4. Following this approach can foster the development of an effective OD program. *Source: Ref. 1.*



initial number of projects to help ensure success. Then, identify and add new projects as current ones finish.

- *Monitoring progress*. Establish metrics to check progress toward improvement goals and schedule periodic management reviews to support successful project completion. Also, pay attention to the greater work environment and, when appropriate, modify project goals based on new information/conditions. Recognize progress and successful project completion and continue to engage employees to support and provide input on progress.
- *Sustaining improvements*. As projects are successfully completed, there always will be additional improvement opportunities. Periodically repeat the previous steps, as needed, to identify, prioritize and implement new projects. Ensure that gains made are supported and preserved.

Making significant progress on improving OD takes time. A mix of projects to achieve quick and relatively easy improvements as well as longer-term more-substantial progress is ideal to establish value for the OD effort and build momentum. For example, simpler projects, such as developing checklists for higher-risk activities, take less time than needed for larger projects, such as significantly revising operating procedures or adding evaluation of OD in incident investigations or audits.

Improving OD is a continuous process. It involves a repeating cycle of identifying, completing and sustaining opportunities and then pinpointing new opportunities to pursue. You always must assess changes to technology, operations, hazards, etc.; these may provide additional needs for OD program efforts.

A variety of similar approaches are available for spurring organizational change. Here, as an example, are the best practices for leadership efforts to implement and sustain effective OD programs in the FLAME model [1]:

- *Focus*. Develop a vision to enable appropriate focus on OD, effectively communicate it to develop awareness and engage site personnel, and provide daily reinforcement through leadership attention and priorities.
- *Leadership*. Leaders act as role models committed to continuous improvement and excellent OD performance through use of effective, consistent leadership practices.
- *Accountability*. Organization, team and individual goals include a focus on OD with clear expectations on performance, feedback and recognition, as appropriate.
- *Measurement*. Metrics, audits and other tools are defined to periodically assess site activities, performance and progress toward goals.
- *Engagement*. Leaders provide a work environment that fosters the engagement and support of site personnel, based on good communication processes, employee input and involvement, and interdependent behaviors. Site personnel know they are important to success and that their contributions are valued.

It may make sense to assign an OD leader to give additional focus and accountability on achieving an effective program, especially for larger companies or facilities. Ultimately, the OD program should provide:

- Tools to document and support effective work practices, such as procedures, checklists, fitness-for-duty programs, management systems, etc.
- Training, both initially and via periodic refreshers, to confirm that workers understand how to complete their work correctly and safely; build value and commitment for following established procedures and systems every time; and support workers in anticipating and planning for potential work problems.
- Time for building capability and experience; completing work in a timely manner; and maintaining awareness of the work environment.

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A VALUABLE PROGRAM

People make mistakes, sometimes with potentially catastrophic consequences. Effective process safety programs — built on foundations of safety culture and leadership, management systems, and operational discipline — anticipate and manage the likelihood of human error. As Jim Collins stated in "Good to Great" [10], "Sustained great results depend upon building a culture of self-disciplined people who take disciplined action." If your metrics tell you that improved process safety performance is desirable to meet company goals, then an effective OD effort as part of your process safety program may provide the greatest opportunity for improving performance. ●

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Obtain the Optimal Pilot Plant

Follow some practical pointers for getting a well-designed cost-effective unit | By Matt Benz, EPIC Systems

AN INVESTMENT in a pilot plant often is an important step for successfully scaling up a product. The pilot plant can provide critical technical knowledge of how to build a large-scale plant. Indeed, a properly engineered pilot plant delivers important insights. Discovering faulty assumptions and errors on a small scale can avoid financial, safety and technical risks in subsequent larger units.

A pilot plant essentially is an evolution of your product to increased scale. A pilot plant's primary objective is to demonstrate chemical and physical stability of a new production technique. Modern modeling software offers a quick and iterative way to find optimal design parameters — but models contain many assumptions that often have vast unknown effects on chemical processes and carry inherent risk.

How can you ensure your pilot plant is optimally designed to deliver the correct insights? This article describes proven pilot-plant design and optimization techniques that increase your opportunities for successful scale-up.

START RIGHT

Laboratory-scale data are a small piece of the information puzzle required to design a successful pilot plant. You'll need a variety of other essential details (some perhaps not fully known):

Commercial information. This often is an afterthought but is extremely important to a project's success. This category includes goals that establish budget, timeline, expected lifecycle operating cost and desired return-on-investment for the project. The spend and timeline targets

will affect everything from the operating ranges you can use to the suppliers available.

Additional commercial aspects of a project include environmental permitting requirements and site selection.

It's important to identify required environmental permits and apply for them early in the project. Obtaining the correct permit approval often takes longer than building the pilot unit.

Early site selection also is critical because a pilot plant must be designed for its destination. Are all the utilities (steam, water, nitrogen, etc.) required by your process available on site? What are the dimensions of the available space your unit must fit into? Do needed heating/ventilation/air-conditioning and electrical services already exist? Do you know seismic zoning or wind loads?

When possible, select a site where you can use existing infrastructure and with available chemical plant operators and maintenance personnel. This will save you money during design and operation.

GROUPED PROCESS CONNECTIONS

Figure 1. Such an arrangement simplifies initial hookups and, if required, later moving the skid to another location.

Technical information. Establish a clearly defined basis of design first. It's important to ensure all stakeholders agree on the production goals before you begin designing the details. Disagreement on the pilot plant's goals, desired rate of production, finished product specifications or raw materials to use can delay or even derail the project.

Once stakeholders agree on those basic inputs and outputs, key information to gather includes:

- desired operating ranges (pressure and temperature) for each phase (e.g., heating, separation, cooling, etc.);
- order of component addition;
- all process steps with technical details including any required separating or blending of products for final use;
- mixing, heating and cooling times; and
- distillation or drying rates (if required).

A lab-scale unit can provide certain key information, particularly data on chemical composition at different points in the production process. These details are important to the pilot plant design and define the product evaluation and validation steps.

Additional information. Usually scale-up isn't performed in-house. Most often, you must enlist an outside engineering firm. Consider the areas that your in-house team lacks sufficient knowledge and fill in the gaps with outside resources.

One common in-house deficiency is a thorough grasp of the Process Safety Management of Highly Hazardous Chemicals Standard (29 CFR 1910.119). Understanding the requirement isn't easy; you need experts with field experience in this area to avoid expensive mistakes.

Your outside engineering firm will require a variety of information:

- What automation and controls are needed?
- Will you require any "add-ons" like clean-in-place (CIP) or effluent neutralization systems, etc.?
- How do you plan to handle waste byproducts?
- What method of packaging and shipping do you want?
- Where will you get seasoned operators to run the pilot plant?

The earlier you can start planning for these operational considerations, the more accurate your design will be.

TACKLING DESIGN AND COSTS

Even though you're building a physical pilot plant, the process steps begin with modeling. Modeling software is the perfect zero-to-infinity knob for rapidly dialing into target specifications. Process modeling of your desired product inputs and outputs quickly will determine if

scaling to the selected size is feasible — and doable at a reasonable expense.

After determining the optimal mass and energy balances via simulation, selecting equipment is the next major step. Think one move ahead. Strategize on the next-size pilot plant and the data necessary to create a confident design for that scale. The goal is to use large-enough equipment for key processing steps to get valid data without over-engineering that results in high costs.

Follow a 10:1 rule when sizing your system. If you're making 1,000 gal/d, you should aim to select equipment that allows for 10,000 gallons. Going beyond that scale doesn't give you reliable data on heat transfer and reaction kinetics.

Once you have a working design and model, the next step is to value-engineer your pilot unit to address factors you can control. While you can't change the corrosive nature of a required chemical, you likely can achieve cost savings by taking steps in other areas, e.g.:

- *Re-evaluate output requirements*. Throughput goals are a balancing act between expense and data validity. Select a production output that provides the right flow. Create a model for the next level that isn't excessive. A 1,000:1 difference is too big to offer much confidence whereas a 2:1 ratio won't give you the proper scientific data.
- *Cut non-critical instrumentation and sampling points.* Not all data will lead to design decisions. Re-evaluate which instrumentation and sampling points are providing important data and which are just "nice-to-have." A single flow meter can cost several thousand dollars and every sampling point requires extra design, equipment, etc.
- *Reduce access points.* An initial pilot plant design usually provides access to too many areas. For example, do you require stairs or a permanent platform on the side of a reactor for an instrument you check once per month? The cost of a ladder is much lower than that of a platform.
- *Exclude known processes.* A pilot plant is engineered and fabricated to test unknowns, not to model a complete process. If a portion of your production facility involves well-understood technology, then leave it out. This can include having bulk tanks of CO_2 instead of scrubbing flue gas, not purifying your final product or testing packaging methods. Similarly, you likely can cut a downstream process that doesn't feed another unit operation in the main process technology sequence.

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- *Take advantage of modular construction.* The iron triangle rule of project management states that scope, schedule and budget drive a project. Off-site modular construction of a pilot plant is a great method to reduce your project timeline without compromising scope or schedule, especially on a project that needs on-site improvements or permitting. Your pilot plant can be designed, built and fully tested off-site. This parallel-path project schedule can shave months off a project timeline.
- *Re-examine materials of construction (MOC) requirements.* Highly corrosive products and other materials may require expensive MOCs to run safely. While you must ensure your skid is safe, you might be able to reduce costs by reviewing exactly what MOCs you need where. If, for example, part of the process just delivers benign ingredients to a tank, maybe you can downgrade materials for that section of piping. The best way to confidently make this call is to coupon test at lab scale.

In addition, logistics is important to project success. You must optimize constructability and equipment installation sequencing to minimize interference for later equipment and instrumentation additions. Two-dimension and three-dimension skid models can identify how equipment is layered and simulate additions to the skid to form a sequence plan.

LOWERING OPERATING COSTS

Pilot plant costs don't end when the system is installed at your facility. Changes to the utilities and raw materials required for operation and daily pilot plant procedures can significantly influence overall expenditures.

Even though a pilot plant often is a temporary installation, it still can markedly affect your overall manufacturing site. To optimize your operational expenses, consider the following:

- *Design with installation and operation in mind.* A pilot plant skid's physical layout can substantially impact installation, maintenance and repair time. For example, placing all process connections at one

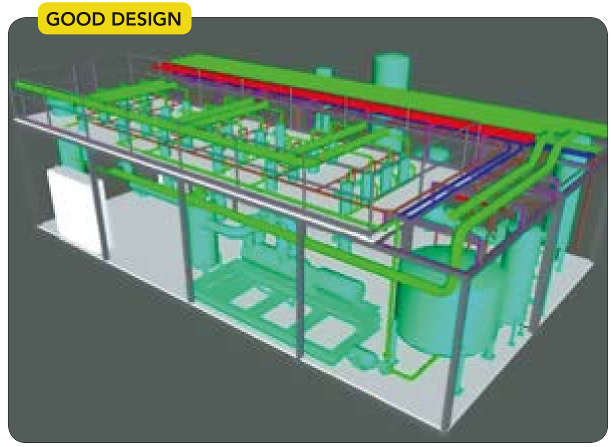

Figure 2. Running piping in streamlined racks, installing equipment on the skid's outer edge, and providing a center aisle enhance accessibility for maintenance.

location on the skid can simplify utility hookup on site arrival or when moving the skid to a different location (Figure 1). Ensuring easy access to all equipment and installing piping into streamlined racks (that run along the tops or sides of skids) aids accessibility for maintenance personnel. You can improve this process by arranging equipment on the outer edges of the skid and leaving room for a center aisle when possible (Figure 2).

- *Select an appropriate site.* Locate your pilot plant near utility hookups whenever possible. It's beneficial if required draw materials for your process already exist. Check your permits and draw capacity. The pilot plant might alter an existing permit or require draw beyond the capacity of existing utilities and raw material supplies.
- *Resist the automation temptation*. For a temporary process setup like a pilot plant, manual operation usually is most cost effective. The expense of automating functions within the pilot plant might outweigh the benefits. Control valves are the perfect example of excessive automation that often bloats the cost in a pilot system. If specific valves on the pilot plant are open most of the time, you don't need a programmable logic controller to turn them. A plant operator with a valve checklist is an inexpensive alternative.
- *Manually add ingredients.* An operator with a shovel often is a cost-effective alternative to expensive automated solids-handling equipment. A pilot plant usually requires a much lower volume of ingredient additions than a full-size plant. You may include automated equipment if your process highly depends on sequenc-

ing precise ingredient additions or you want to test the automation for larger-scale production.

- *Rethink packaging.* Can you eliminate bulk product storage and manual packaging? Switching chemical totes with a forklift every few hours is significantly cheaper than packaging automation. Packaging usually isn't a critical process to test at pilot scale because most packaging technologies (and costs) are well known.

When considering ways to lower operating costs, avoid sacrificing the robustness of your overall system. People tend to be less consistent than automated equipment and potentially could introduce a new source of process upsets, increased transient states or required startups and shutdowns.

THE SECRET SAUCE

The last major area to consider is project management. Poor project management rather than a design flaw often causes a project's failure. From scheduling mishaps to sub-contractor miscommunication, many steps can go wrong once your pilot plant leaves the design desk.

There's a considerable advantage to having an outside pilot plant design/build expert manage your project from concept to completion. Risk management plans, scheduling tools and equipment specifications are a few examples of highly refined tools your design/build partner will feature.

Look for a partner with knowledge of both plant operations and design/build/engineering experience in your size project. The process systems company should have a deep understanding of the fundamental relationships and dependencies that exist between the major phases of projects and the design/build/equipment tradeoffs for your type of project.

When you find that great partner, get out of its way! Trying to split management between your team and the outside project manager takes the liability of the project outcome away from the firm. Many operating compa-

nies think it's more cost effective to order their own equipment. However, this is a great way to unwittingly hold back an engineering design team, order the wrong equipment, weaken technical efforts or delay fabrication. These problems cost more time and money in the long run and can add frustration for both you and the firm.

Find a partner you trust and lean on it to avoid mistakes, prove your process and deliver a successful pilot plant.

LINING UP A GOOD PARTNER

Working with an experienced engineering and fabrication firm allows you to avoid costly pitfalls during many stages of your pilot plant project. But how do you find the right firm? Any company can look good in its sales brochures or on its website. Three strategies can help you sift through the marketing and sales noise to find an outfit you can count on:

1. Request case studies, photos, testimonials and references.

To get more than a surface-level impression of the company you may engage, ask for proof of a firm's work with pilot plants and the industries it has served. Request a reference list or reach out to others who have used the outfit before; dig deeper than the typical "Would you use this process equipment design firm again?" Focus on questions that highlight potential strengths and weaknesses, such as:

- What went right (and wrong) with its project? How did the company handle unforeseen challenges?
- How would you rate the quality and value of the final system?
- How did the project manager and craftspeople act during the project? What were the firm's greatest area of expertise and least experienced area?
- What differentiates the company from others you've worked with?

As you go through the case study materials, consider some key internal questions:

- Can you see similar traits to your teams in the clients the firm serves?
- Does the firm's expertise and problem-solving capabilities translate to the sorts of challenges you experience in your plant environment?

- Can you see a consistent project management approach demonstrated in its work?

Photos and videos provided by the firm can give you valuable information. Has it worked in plant environments similar to your own? Do the images give you a sense of finished system quality? Do they emphasize the company's safety practices and job approach? Diving into past work may require a phone call, not just reviewing photos and written materials.

2. Bring in technical and commercial stakeholders.

Involve both your engineering team and your commercial stakeholders to evaluate quotes and capabilities. A successful project for you means satisfying many groups when it comes to finance, production and engineering. Having these stakeholders participate in the vendor selection process is critical for building early buy-in and ensuring you select a vendor that can meet everyone's needs. Forwarding a presentation isn't the recommended method for this. In-person meetings allow for dynamic interaction where stakeholders can ask questions and dig deeper for clarifying information, enabling them to better gauge true capabilities.

3. Visit the contenders.

If possible, travel to the sites of your top candidates. You want to see each's facility but you also should get to know the company's leadership and learn how the firm operates. Are you just another project or are you important to them? A company's values, culture and internal processes can be just as relevant as its technical capabilities. A clean shop filled with empowered, passionate employees often can provide a much better service experience than a top-down autocratic outfit.

While this vetting process might seem expensive, it represents a small investment of time and money compared to what you'll spend on the pilot plant. The right design/build partner makes the difference in whether your project is on time, on budget and ultimately successful. Select a partner that can genuinely tell you the stories behind how it solves challenges with pilot plants — the kinds of challenges relevant to your operation. ●

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Pursue the Right Path to Industry 4.0

Avoid wrong turns that can lead the journey astray

By Peter Guilfoyle, Northwest Analytics

MANUFACTURING CONTINUES to evolve and has progressed through four stages thus far. It started with the implementation of steam power to mechanization. The second stage comprised mass production and the introduction of the assembly line powered by electricity. The third stage added computers and automation into the mix and, in the fourth stage, cyber-physical systems emerged to enable the computerization of manufacturing. This stage currently is evolving before our eyes and commonly is referred to as Industry 4.0.

"Industrie 4.0," coined by the German government in a national strategy to promote the computerization of manufacturing, exemplifies the fourth industrial revolution on the way to an internet of things, data and services. Decentralized intelligence helps innovate intelligent object networking and independent process management, with the interaction of the real and virtual worlds representing a crucial new aspect of the production process.

The principle concept embodies connecting machines and systems to create intelligent networks along the value chain that control each other — for example, machines that predict failures and trigger maintenance processes autonomously or self-organized logistics that react to changes in production. Industry 4.0 technologies include many of today's buzz-words like big data, advanced analytics, virtual reality, the cloud, the internet of things (IoT) and machine-to-machine (M2M) communication. In the past decade, these technologies have swept across the globe, as manufacturers worldwide recognize the value of Industry 4.0.

It certainly sounds great: a vision of the future with efficient, self-automated manufacturing processes that monitor themselves so they never go wrong.

A DEVELOPING PROBLEM

It's difficult to find fault with this formidable vision but a problem is brewing in implementing the principles of this industrial revolution. The potential for Industry 4.0 is so vast that a lot of companies rushing to adopt the technology haven't paused to first figure out what root goals they are trying to achieve and problems they are striving to solve.

If these two issues aren't addressed before embarking on the path to Industry 4.0, the route to follow is unclear; indeed, many companies are losing their way. The key technologies required for digital transformation cause radical changes in the business processes of any company. Those changes require discussion and understanding before they are undertaken.

For example, key stakeholders in the business must consider the company's culture and how to help employees (at all levels) deal with change. This involves overcoming a general reluctance to change that's typical of the human makeup as well as training employees to ensure they are qualified to use the new technologies. In addition, corporate leadership must address staff concerns about continued employment after digitalization is achieved by providing reassurances as appropriate and deciding if people can be redeployed in the new system (as often is the case).

Adopting Industry 4.0 involves a commitment and adequate resource allocation by the information technology (IT) department to ensure necessary connections are made and maintained, and to avoid any IT snags that could cause expensive production outages. Modern information and communication technologies like cyber-physical systems, big data analytics and cloud computing will foster early detection of defects and production failures, thus enabling their prevention and thereby providing productivity, quality and agility benefits that have significant competitive value. However, as more databases move onto — or connect with — the cloud, security issues commonly are cited as a barrier to fully embracing the new technology. It's undeniably important to adequately protect all databases.

Some software technologies necessitate the moving or duplicating of historian data or other data sources. This creates its own problems, both in terms of external data security and internal validation of the data. If a validated database is duplicated, does it need to be re-validated? These additional drains on IT and other resources demand consideration and discussion; sometimes an alternative approach is available that avoids these issues but still allows the company to move forward with digitization.

New technology must be reliable and stable for critical processes and operations and must meet any regulations applicable to the particular industry sector.

Ideally, a company can justify the economic benefits of this considerable investment and estimate an expected return on investment (ROI) for each stage and investments prioritized accordingly. In addition, it should ensure that all changes are based on strategic plans to place the company at an advantage or, at the very least, preserve current favorable market position.

WHERE TO BEGIN

Like any journey, the path to Industry 4.0 should start with a map. From both strategic and technological perspectives, a company adopting these technologies must visualize every step on the route towards a digital enterprise. Success in the digital transformation process largely depends on a firm's ability to prepare that plan in the most accurate way.

Dow is a great example of a major chemical company on its journey to Industry 4.0. Crucially, that journey started with an extensive effort to take better advantage of its data (see: "Data Initiative Improves Insights," http://bit.ly/2FGOTop) as well as embark on a review of processes and unmet needs. Dow looked at how best to maximize existing strengths, expertise and technology in moving forward to the next stage of its evolution.

For example, one plant suffered repeated upsets that resulted in unscheduled downtime. The site's management realized that learning how to listen to signals the plant was sending to operators and responding better to those signals was key to addressing the problem. A team identified parameters of importance. This wasn't an easy task. The amount of data was substantial — staff was spending eight hours per week gathering, analyzing and visualizing the data. However, these data were scattered in different databases, making it difficult to understand what was important. Analytics helped the team realize what the data meant and which parameters were crucial. The software provides operators with a simple green/red dashboard so they can quickly and easily see which parameters require attention and respond before product quality suffers or a shutdown results. Moreover, the analytics cut the time for gathering and analyzing the data to zero, freeing the production staff to focus on other things. The ROI was rapid.

In summary, in looking for a solution to issues that were impacting the bottom line through lost manufacturing

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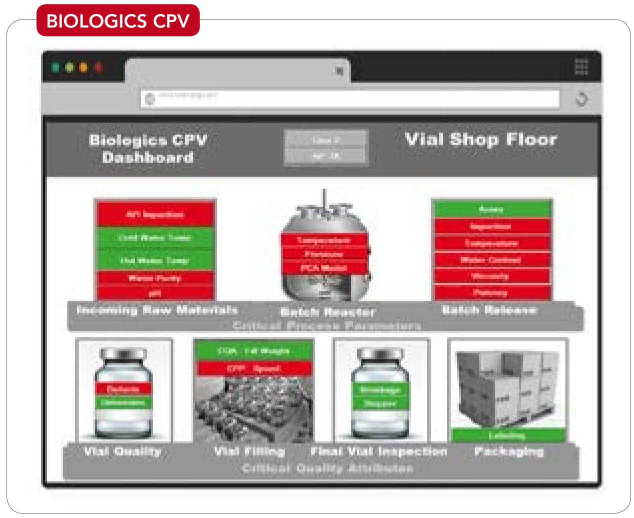

Figure 1. Dashboard provides a single red/green view of the entire manufacturing process.

time and the need for reprocessing, Dow set a goal to achieve a better data-driven understanding of parameters changing during the manufacturing process and the real-time effects of those changes — realizing such insights would lead to more-consistent more-efficient production. The success of this project reflects careful planning regarding the implementation and applicability of the new technology, setting the company on its path to Industry 4.0 in a useful and productive way.

CONTINUOUS PROCESS VERIFICATION

The adoption of continuous process verification (CPV) by the pharmaceutical industry presents another ideal application for Industry 4.0 technology (see: "Control Systems: Take the Smart Road to CPV," http://bit.ly/2k5EuxQ). To meet regulatory guidance from the U. S. Food & Drug Administration and the European Medicines Agency, a pharmaceutical plant must continuously monitor hundreds — sometimes thousands — of variables to verify they remain within the parameters established and validated for its process. Industry 4.0 technology provides four key ways in which digitization can support CPV:

1. *Analytics*. Statistical process control techniques develop the data collection plan and statistical methods and procedures used in measuring and evaluating process stability and capability.
2. *Risk-based real-time approach*. This verifies a process produces material that meets all critical quality attributes and control strategy requirements.
3. *In-line, on-line or at-line controls*. These monitor process performance and product quality.
4. *Quality attributes*. Checking of feeds, in-process materials and finished products confirms they meet specifications.

Other benefits of digitization that apply especially to the pharmaceutical industry are the continual assurance of process

control and the ability of data analytics to quickly detect any deviations from expected parameter limits (Figure 1). Such automatic monitoring and control gives a company continuous data for validation against regulatory guidelines, helping it comply with the rigorous associated requirements.

FIVE KEY STEPS

Our world is becoming increasingly digitized. This can be a good thing — improving efficiency, enhancing quality and helping a company meet ever-increasing data-related regulatory requirements. However, before embarking on the journey to Industry 4.0, a manufacturer should pause to consider the objectives of the exercise and set clear goals that will guide it on the way to successfully implementing — and sustaining — novel technologies. There's no shortage of technologies. The crucial decision is choosing the one that's going to provide the greatest positive impact on your company in the area that you most need it.

With this in mind, the five stepping stones to success on the path to digitization are:

1. *Start with the problem*. What challenge are you trying to address?
2. *Pick an appropriate team*. Which employees have the technical expertise to identify parameters of importance and how is your IT group going to help access key data sources?
3. *Analyze the "people aspect" of the problem*. Do you have the talent you need to achieve success?
4. *Determine the best technologies*. Besides being fit for purpose, do they maximize using existing technologies and data sources, provide a platform compatible with current equipment and offer scalability for the future?
5. *Deploy effectively*. Can you identify a pilot project fo refining implementation and building confidence so you then can speed rollout to other sites?

By following these five steps, you can avoid common mistakes in implementing Industry 4.0, and set your company on the right path to a valuable and industrious new era of manufacturing. ●

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Monitoring Moving Equipment Isn't Standing Still

Getting valuable real-time diagnostic data is becoming easier and less costly | By Seán Ottewell, Editor at Large

DEVELOPMENTS IN sensors, coupled with the Industrial Internet of Things (IIoT), are enabling fast and economical monitoring of equipment such as motors, drives and pumps. Moreover, such advances are fostering the emergence of edge processing — i.e., analyzing and interpreting data right where they are gathered.

While operating companies can't eliminate risk of equipment issues, affordable Internet of Things monitoring can provide "cheap insurance," stresses Jonas Spoorendonk, digital portfolio manager, motors and generators, ABB, Ladenburg, Germany.

"A customer does exactly what it did before, but in an easier and more affordable way. Reliability is improved and both maintenance and safety optimized," he says.

As an example, Spoorendonk points to the success of a smart sensor condition-monitoring pilot completed in July at Transcontinental Advanced Coatings (TAC), Wrexham, U.K. That company, which also has a facility in Matthews, N.C., makes precision coated papers, films and specialty substrates for use with digital imaging technologies.

POWERTRAIN MONITORING

Figure 1. There's an increasing focus on more-cohesive checking of assets that belong together. *Source: ABB.*

TAC's pilot project aimed at enhancing the existing monthly manual maintenance regime on a critical oxidizer process that cleans air before its release to the atmosphere.

ABB Ability smart sensors fitted to the motors and mounted bearings of the oxidizer's two fans collect and analyze performance data. Exceeding pre-defined limits for parameters such as temperature and vibration sets off system alarms.

Based on the success of the pilot, TAC is launching a second phase of the project; it will use multiple smart sensors to remotely monitor the motors and bearings throughout a process, together with up to four Bluetooth gateways connecting with ABB's secure server. Ultimately, the company will roll out the technology across its global platform.

"If you look at our offerings until quite recently — and those of everybody else — we've been looking at individual assets such as electric motors. The big thing now, however, is the digital powertrain, i.e., monitoring assets that belong together [Figure 1]. Transcontinental has a classic radial fan set-up. There we monitored three assets: the motor and the two bearings of the fan. We also monitored the ambient temperature of the room in which the fans were installed. Altogether, that's a good example of one powertrain," he explains. "Readers should understand that there can be many different powertrains with users choosing which assets form part of theirs," he adds.

The natural evolution of this approach is the use of artificial intelligence (AI) machine learning to provide more insights into a powertrain's workings and to identify correlations and anomalies, Spoorendonk believes.

DRIVING CHANGE

Drives will play a key role, believes Steve Meyer, Georgetown, Texas-based regional sales manager, Danfoss Drives, North America, because they can provide important information about the pumps or other equipment connected to them. Danfoss already offers a drive sensor (Figure 2); it will get additional IIoT features this fall.

"We see drive intelligence on the move, enhanced by the ability to embed more powerful processors at low incremental cost. The question then becomes, what opportunities will more processor power enable? Today, the trend is towards increasing the functionality of drives to eliminate the need for PLCs [programmable logic controllers]. Soon increased data processing capability and connectivity will make it possible for a drive to work as an edge server," he says.

Industry is re-inventing itself to take advantage of smart manufacturing methods, a process that will require at least the next ten years to implement, he reckons. "Already users can buy low-cost sensors with powerful embedded processors capable of carrying out edge analytics. The local analytics can be focused on machine condition monitoring at the point of use. At the same time, this data can then be served up to a plant server or to the cloud. Then, true AI processing can be used to look at every aspect of a plant operation."

Investing in an IIoT-focused approach promises two compelling benefits, notes Meyer.

First, it can significantly reduce maintenance costs. "The advanced analytics lead from traditional scheduled maintenance to intelligent, predictive maintenance. So, if you think of a chemical plant as a large asset with a $50-million/yr maintenance budget, industry studies suggest that it is possible to halve this by investing in an IIoT strategy. That's $25 million/yr saved on the maintenance side alone."

Second, the same investment becomes a bridge to making data available from local sensors to a server running broader AI programs. "The goal here is to optimize the overall process. If you get a 3% next gain in production at a $1-billion plant, that can increase its value by $30,000,000," he says.

Having intelligent drives with built-in IIoT capabilities act as edge servers for overall AI plant analysis is a low-cost, low-risk strategy along the way to IIoT adoption, he believes. "Effectively the whole IIoT solution is therefore embedded into what we regard as an existing control system. You can do predictive analytics, edge analytics and process optimization — the whole shooting match."

EDGING FORWARD

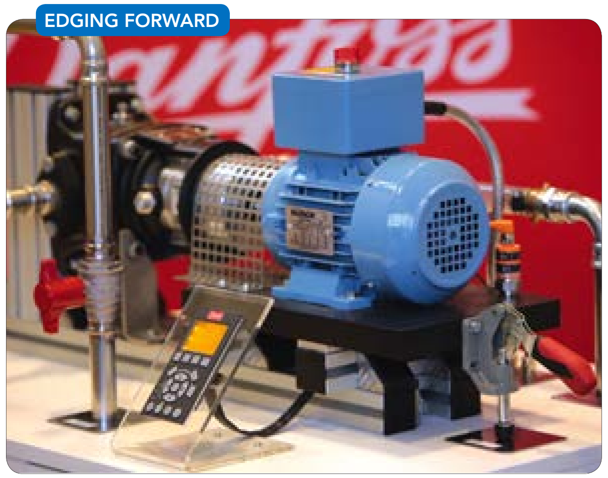

Figure 2. Drives soon may function as edge servers. *Source: Danfoss.*

DATA DIVIDENDS

For its part, Nidec Motor Corp., St. Louis, is focusing on its stand-alone Forecyte remote monitoring platform. This uses battery-powered wireless sensors to measure equipment vibration and temperature, enabling users to predict imminent equipment failure and to better operate and maintain equipment. Nidec is developing sensors for other inputs such as current, pressure and flow.

Forecyte gathers continuous real-time data — with the collection interval customizable for each individual sensor — and visualizes equipment health. The data sent wirelessly to a gateway then go through either ethernet, wi-fi or cellular networks to a cloud portal for aggregation, storage, analysis and visualization using a web interface.

"The best use is generating advance warnings so customers can plan when they will carry out maintenance rather than waiting for an unplanned downtime which might last days. We've even seen the benefits of this in our own plants," says Pranesh Rao, Nidec's director of new products – electronics and software.

As an example, he cites last year's very first installation of Nidec's vibration/temperature sensor at a company that uses very long conveyor belts. The gearbox in one of the two motors driving the main conveyor belt was prone to failure. Past breakdowns had caused two-day shutdowns, each resulting in more than $150,000 in lost production.

"It took just two days for the sensor using its temperature inputs to notice that one gearbox was consistently running 25°C hotter than the other. It turned out that this gearbox took more of the load at start-up — it wasn't being shared equally," he explains.

The problem could have been solved with variable speed drives or some other way of load sharing but, as Rao points out, this would have been expensive.

Instead, because the data collected by the sensor gave the company at least a week's warning of a potential failure, it could order a spare gearbox in advance and plan for its installation (which only took two hours) once the original failed. This, in turn, eliminated the huge costs incurred by two days of process downtime.

"The margins are so thin for many companies these days that they are happy to pursue this sort of 'reactive' strategy. It's simply a huge benefit for them to be forewarned and have the replacement part ready for installation," notes Rao.

Nidec's easily scalable vibration sensors detect 60–70% of the most common problems, Rao estimates. A company shouldn't necessarily strive to capture the other 30–40%, he says. "It can be done, but does it make sense in every application? We have seen customers get great benefits even with limited sensing power which is simple to use, deploy and cost-effective."

Indeed, don't go overboard with onboard data collection, Rao cautions.

First, it often is more-cost-effective to collect only basic data necessary to warn of a pending problem and then, at that point, to do more-detailed analysis with the substantially more expensive equipment traditionally used in route-based monitoring.

Second, a similar caveat applies to edge processing as advances occur in such diagnostic intelligence capabilities. "Here too, collecting and processing only what you need allows the edge intelligence to be deployed more cost-effectively," Rao notes.

"It's really very important to understand that there is a lot of value to be gained by doing very simple things — getting the low hanging fruit. In years to come you might get a specific time and date for an equipment failure — but not yet, despite what some vendors say," he emphasizes.

MAKING SUCCESS SIMPLE

Simplicity is key at this stage of the technology take-up — especially for the traditionally slow-adopting chemical industry, agrees Dan Kernan, executive director product management and technology, ITT Goulds Pumps, Seneca Falls, N.Y.

"That's why we made the i-ALERT equipment health monitor so simple. It's battery powered, can be glued to a pump or motor and uses edge capabilities to detect waveform variations in them. This data is then extracted to the free mobile app and it's all up and running for $300–400," he explains.

The returns often are rapid and straightforward. For example, one customer's monthly maintenance walk rounds have been cut by 30–50%, freeing up engineering staff for other duties, he notes.

Another chemical company was struggling with a pump

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PUMP MONITOR

Figure 3. Compact device provides a simple way to monitor pump condition. *Source: ITT Goulds Pumps.*

that failed every 6–12 months. An i-ALERT monitor (Figure 3) found two events in its two weeks of operation. The culprit turned out to be a storage tank with a low-level alarm set so low that it was damaging the pumps. Raising the low-level alarm setting solved the problem.

"Remember that you have this insight 24/7. Also, these examples illustrate how much low hanging fruit is out there," adds Kernan.

ITT Goulds Pumps now is in the trial phase of integrating more devices plantwide — moving into the multiple hundreds.

"We are finding that customers are now wanting to integrate all this information in one location, most usually the data historian," he says.

Many are using the company's i-ALERT Gateway to achieve this. Launched in April, the gateway configures all sensors in range, allowing users to remotely and continuously monitor rotating equipment to identify and troubleshoot problems before they become serious.

However, many chemical companies are struggling to determine the most important data within the massive amount gathered, believes Kernan. "I'm seeing lots of new jobs with 'digital transformation' in the title and hearing much talk of data lakes and data warehouses while they come up to speed," he notes.

Once a company overcomes this triage challenge, it then can look at the process itself because this is just as important as machine health data in identifying root causes.

"I see AI and machine learning combining data and making recommendations. Perhaps we will see the situation where AI rather than operators makes the decision to manipulate process variables."

However, for now, speed and simplicity are key to leveraging the low-hanging fruit, he concludes. "That's the most important activity in the coming years. Later on, more integration will start to happen." ●

HAZARDOUS PROCESS GETS IMPORTANT IMPROVEMENT

New safety instrumented system reduces risk and eases future expansion

By Peter Skipp, Rockwell Automation

WITH A production history that dates back to 1899, PPG's plant in Barberton, Ohio, is no stranger to change. Its products have evolved from raw materials for glass-making to today's range of specialty chemicals. The site's operations also have completely transformed from manual processes to more-automated ones tied into a distributed control system (DCS).

One of the most recent changes in the plant was in how workers evaluate and mitigate safety risks. In 2016, the company adopted the layers of protection analysis (LOPA) risk-assessment method to give workers a better understanding of the effectiveness of plant safeguards. The methodology also has proven useful in identifying areas where the site can further strengthen those safeguards.

SAFETY RISKS UNCOVERED

The chloroformate unit is one of the Barberton plant's smallest process units but one of its highest safety risks.

Workers at the plant have performed process hazard assessments (PHAs) on the unit for decades in accordance with the U.S. Occupational Safety and Health Administration's Process Safety Management Standard (29CFR1910.119). With the adoption of LOPA, workers had to evaluate the safeguards identified in those PHAs to quantify and validate their effectiveness.

For example, LOPA helped workers pinpoint scenarios with the highest risk. These scenarios required redundant pressure transmitters for one of the inputs to meet the safety integrity level (SIL) rating.

"We started by evaluating our current interlocks and looking at the scenarios they might be protecting," notes Matt Kinsinger, senior process control engineer, PPG Industries. "Then we re-evaluated anything that we had already ranked as a high risk in the PHAs to make sure it had adequate protection. This helped us identify opportunities where the existing control system, instruments and control devices could be improved to meet our acceptable risk level."

Next, Kinsinger and his team developed requirements for a new safety instrumented system (SIS) in accordance with the ISA-84/IEC-61511 standard. The new SIS would need to not only help reduce risk on the process unit but also address other key plant requirements, including:

- *Usability*. The SIS should provide an easy-to-use operator interface easily integrated with existing DCS interfaces.
- *Scalability*. It should support new or modified plant equipment.
- *Expandability*. The system should readily accommodate expansion or additional requirements for higher levels of protection based on future analysis or PHAs.

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MAKING A CHOICE

The team reviewed SIS offerings from two vendors whose technologies were already used in the plant. It wound up selecting the AADvance system from Rockwell Automation in the spring of 2017. This flexible and scalable system suits operations ranging from those with a small number of inputs and outputs (I/Os) to large systems, and can meet multiple SIL levels in an application. It also provides easy, standard communication to the plant's existing Allen-Bradley ControlLogix controller.

"The AADvance system hit all our boxes for an SIS," Kinsinger says. "The price was great. It met our initial requirements. And it could easily be expanded or scaled-up, as needed."

Once the order was placed, the team had a short timeline of four months to develop the new system and implement it during a planned outage.

To start, Rockwell Automation assigned a project manager and project engineer to support the upgrade. The project manager coordinated the team's meetings, communication and documentation to keep the project moving and verify milestones were met. The project engineer worked directly with Kinsinger and his team to develop a system that met all its needs.

For the factory-acceptance test (FAT), Kinsinger traveled to the Rockwell Automation Houston facility with a spare controller that was modified to include the SIS communication. The Rockwell Automation team performed a detailed FAT, including simulating every safety instrumented function (SIF), I/O point, and bypass and reset condition.

The SIS then was shipped to the Barberton plant where PPG personnel performed a site-acceptance test (SAT) without any outside support. This provided a validation of the system as required in the ISA-84/IEC-61511 standard.

Implementation of the system at the plant involved the physical installation of additional valves and relays to be controlled by the SIS. The team also put in a few extra transmitters and rewired some existing field instruments to the SIS instead of the DCS. Planning for the physical installation of the valves and instruments, combined with the piping modifications required, quickly became the most challenging portion of the project, recounts Kinsinger.

CLOSING THE GAP

Kinsinger and his team hit the target of installing the AADvance system and going live according to the scheduled timeline.

The new SIS provides the protection required to meet the plant's acceptable risk level for the chloroformates process unit. It also offers flexibility to grow or evolve with the plant. This is important because the process already is at capacity and probably will need expansion. Also, continual re-evaluation of process hazards in the plant means changes to the SIS are very likely.

"We performed what we felt was a comprehensive review of the current system," Kinsinger explains. "But we also wanted room for any additional items to be added to the SIS or requirements for higher levels of protection based on future PHAs." ●

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Explosion Reveals a Broader Problem

Operators and managers lack adequate understanding of process

THIS MONTH'S
PUZZLER

Our ethylene oxide (EtO) batch reactor (view figure online at http://bit.ly/2kRuzfF) suffered an explosion one Saturday morning. The reactor was filled with glycerol before EtO feeding began. A steam-heated exchanger raised the temperature of the reactor to 240°F. The pressure spiked suddenly when the EtO addition started; the operator had been taught that meant the EtO wasn't reacting. The reactor had been cleaned the night before with water and caustic.

The shift supervisor authorized the operator to raise the trip point to 400°F and to continue to heat the reactor. The supervisor, who had experience in a similar process where the temperature sensors became fouled and insulated, didn't trust the temperature reading. Besides, the night foreman had steamed the purge nitrogen in the insulated reactor a half hour before glycerol was added; this isn't part of the cleaning procedure, just something operators have done for years.

Recent changes in the control system faceplate weren't fully understood yet. The operator, confused by the labels for the cooling and heating block valves (that feed the temperature control valve), decided to take a walk outside. The faceplate didn't indicate the pump was circulating through the heat exchanger and catalyst bed all along, which the operator confirmed in the field. However, instead of finding the cooling water valve open and the steam valve closed as expected, both valves were closed. The supervisor ordered the operator to open the steam block valve; the reactor relief valve blew but not before two flanges on the reactor split, damaging the reactor and sending parts of the top reactor pipe flying.

After the accident, the new supervisor blamed the operator for opening the valve. An inspection of the reactor also showed suspicious holes near the top of the reactor in the dip tubes for the caustic, glycerol and EtO.

The superintendent, who wasn't aware the reactor contained an abandoned refrigeration coil, blamed it for the incident, saying a hole allowed caustic to collect in the coil and that the caustic leaked out and led to a pressure spike when the EtO reacted with it. The superintendent asked a retired operator who knew about the coil and the dip tubes why the caustic never caused this problem before. That person responded that in the past the reactor was flushed by hot water before being purged and dried. Cutback in inert gas usage and limits on water consumption led to recent changes in the cleaning sequence.

What do you think the root cause of the incident was? Could we have prevented this accident?

DELVE DEEPER

The accident occurred because the reactor was heated instead of cooled. Superficially, the accident was caused by poor understanding of the new controls. However, the real root cause is much broader; you won't get at that cause until you better understand the relationship between people and process.

What's apparent here is the importance of having fresh eyes review the accident as soon as possible and then documenting everything. This minimizes the chance of people in power sanitizing the narrative, which may hurt efforts to fix the problem. Improving safety and operations requires employees involved to understand what they did, both right and wrong. However, don't focus on assigning blame and meting out punishment; remember, you'll probably need to rely on the people who got you into the mess to forestall future problems. So, instead, concentrate on identifying the root cause and appropriate steps to avoid the incident happening again.

It's clear to these old eyes that management doesn't know the process as well as the operators. However, the operators don't understand the chemistry and simply are following procedures without comprehending why they do them. I've found that involving management in equipment teardowns and inspections and in preparing operating instructions and procedures is an excellent way for them to understand an operation. Also, I suggest they play a role in putting together and prioritizing maintenance lists.

Another problem is poor coordination between shifts, as indicated by the night foreman's activities. The best approach I've found for handling this problem is structured shift change meetings at the beginning and end of every shift. Document these so something can be learned from them. By structure, I mean by topic: safety, production, quality, maintenance and other topics as required. However, allow the meeting moderator to table any discussion that goes more than a few minutes.

The project group doesn't get off the hook for this accident. New equipment can either simplify operations or complicate them with additional problems. Use a senior operator to review distributed control system faceplates for ease of use.

Don't let operators off easy during training for new or changed processes. Working through a faceplate helps but walking operators outside the control room to identify each step in a new process also is critical. In addition, explain what's happening in each step and what can go wrong — an alarm trip summary table helps; add flow charts for complicated troubleshooting. Create a checklist for new and old processes and require operators to tick off each entry.

Ensure everything is labeled and flow arrows are added. Review process and instrumentation drawings and process flow diagrams to verify the operator can walk through them.

Don't let the senior operators walk out of training; clearly they're just doing things from rote, not from an understanding of the process — you've got to get these senior people involved and asking questions.

Management also requires some changes. Don't let supervisors give permission for raising temperature limits. Until supervisors understand the process, they shouldn't be allowed to increase limits.

Dirk Willard, consultant
Wooster, Ohio

DECEMBER'S PUZZLER

Our 25-year-old vacuum scrubber system (Figure 1) had worked flawless for two years; now, it's responsible for a toxic release. We increased the vent volume about 20% last year. At the time, the safety and environmental engineer complained bitterly that the capacity already was overtaxed, noting that we had added more demand over the years and the material balance wasn't well understood. Still, the system worked fine, although operators complained of fumes.

Our maintenance manager looked at the equipment and found the following:

- The blower had been rebuilt several times; its capacity was increased once, five years ago.
- The pH probes were abandoned — the system is on the roof and the probes fouled often — and replaced by a titrator; the lab services the titrator because maintenance and operations forgot to keep up on reagents.
- The dike floor has cracked and heaved; equipment additions mean the dike now is slightly undersized (58,000-gal required versus 56,000-gal available).
- The mist eliminator was eliminated years ago because maintenance was annoyed by its fouling.

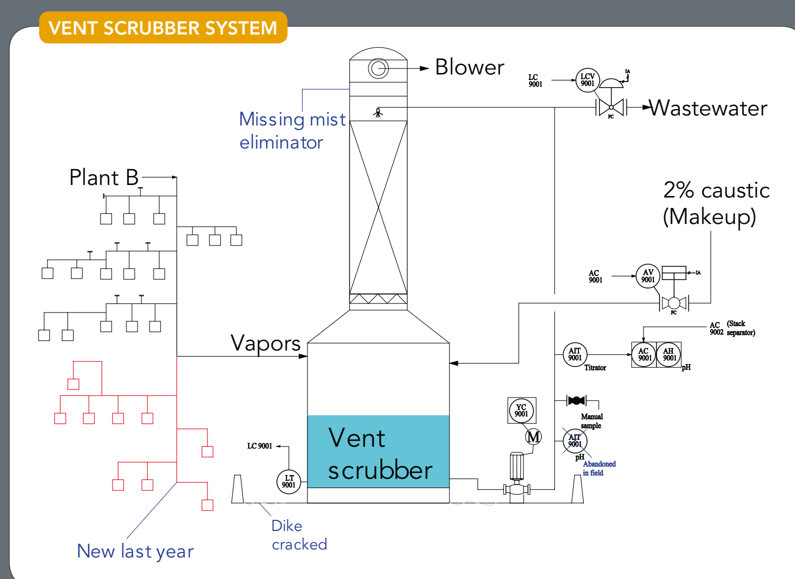

Figure 1. After a toxic release, plant is grappling with an upgrade project.

The project group says it will cost a fortune to replace the system and repair the secondary containment because this system is integral to plant operations. In addition, there's a dispute over containment volume: operations says we should count the blower containment, which is elevated above the scrubber area and drains into it but the safety engineer disagrees. The project group proposes putting a roof over the area to eliminate stormwater concerns. The maintenance engineer says that's impossible because the diluted caustic in the mixing shack is cooled by an airfoil cooler.

How should we proceed with this project? Do you see any other concerns?

Send us your comments, suggestions or solutions for this question by November 15, 2019. We'll include as many of them as possible in the December 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.

Properly Protect Your Compressor

Preventing damage from entrained liquid demands care

Even if the drum works perfectly, some liquid can go downstream.

MOST COMPRESSORS have suction drums or knockout pots upstream for protection against liquid slugs entering the compressor feed. The droplet size being removed rarely is explicitly stated. The equivalent size normally is buried in a sizing coefficient relating drum diameter to the vapor rate for the drum. Depending upon the sizing criteria used, most drums are designed to remove liquid droplets whose diameter exceeds some size between 100μ and 150μ.

A client had hydrogenation reactor effluent going to a separator drum. The overhead gas from the separator was hydrogen; it went directly to the suction line of a dedicated reciprocating compressor.

Inspection after a shutdown showed significant solid deposits in the compressor suction line. Laboratory work identified the deposits as solidified reactor effluent. The drum feed was a liquid/vapor mixture at normal operating conditions of 260°F but the liquid solidified around 150°F.

The concern was that liquid was entraining — such entrainment could damage the compressor. Unfortunately, simply monitoring compressor vibration may not suffice when evaluating entrainment. In multiple incidents, liquid entrainment has resulted in compressor operation with very low vibration levels; the compressor operated successfully for an extended period but then catastrophically failed.

You should monitor compressor vibration and take appropriate corrective action when vibration levels are high. However, if you suspect entrainment, remember that low vibration levels are a poor indicator that entrainment isn't causing damage.

The concern about entrainment prompted the plant to consider adding a knockout drum downstream of the separator. This is common practice in hydrogenation reactor systems. Indeed, roughly 80% of hydrogenation reactors with operating conditions similar to those at this plant have an effluent separator for bulk vapor/liquid separation followed by an additional knockout pot to protect the compressor suction. The knockout pot normally has a trip that shuts down the compressor on high liquid level.

The knockout pot only gets a small quantity of liquid in its feed. The pot holds a liquid level but removal of liquid only happens sporadically, i.e., the liquid out of the pot is a NNF (normally no flow) stream. If the pot requires frequent draining, this indicates the upstream separator is undersized or having problems.

Of the about 20% of hydrogenation reactors that don't use such a setup, about half directly feed the recycle compressor from the separator drum without using a knockout pot. The other half have two knockout pots in series downstream of the separator — despite the fact that, generally, if a single knockout pot doesn't remove enough small liquid droplets, a second knockout pot of the same size won't do any better. Other combinations, such as a knockout pot and coalescer or filter, are possible but rare.

The plant had purchased a used vessel to separate the reactor effluent; it was supposed to be oversized for this service. In fact, the standard GPSA method showed that liquid droplets smaller than 51μ would settle in this drum. The drum had a vapor velocity far lower than a typical good-practice drum needs in this service. The vessel amply should have done the job of liquid removal.

Heat loss through the pipe was the major reason for the deposit buildup. A brief inspection showed pipe temperature was low enough to cause any liquid that wetted the pipe surface to solidify. The fix to prevent solidification is simple, insulate the lines better.

Even if the drum works perfectly, some liquid can go downstream. Over time, enough small droplets, <51μ in this case, can coat the line and cause significant deposits to accumulate gradually. However, because droplet sizes and total quantities reaching the compressor are small, this liquid shouldn't result in compressor damage.

The other possible culprit was the inlet line to the separator because it can affect separator performance. Expectations for what a good inlet line looks like have changed over the years. Separator guidelines in the 4th edition of the GPSA Engineering Data Book don't even discuss the inlet line but the current, 14th edition includes specific advice for the inlet piping to the vessel.

The plant's repurposed vessel had a particularly bad inlet piping configuration. The pipe enters the vessel vertically and points toward the vapor outlet. Although the distance between the two is large and inlet velocities are low, this isn't a good practice and one always to avoid. While insulating the line to the compressor will prevent solid deposits forming, liquid entrainment may be occurring. The data on this aren't clear.

The ideal solution requires both insulation and modifications to the separator drum inlet piping.

ANDREW SLOLEY, Contributing Editor
ASloley@putman.net

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The Vaneaxial adjustable pitch direct drive fan is designed for high-flow, high-pressure applications. The fan's inline, compact design suits applications confined by space. The fan reaches a volume of 120,000 cfm and the adjustable fan blade pitch helps improve efficiency and throughput. Full and half solidity wheels enhance the fan's flexibility, making it easier to select a fan for specific application requirements. The industrial-grade coating resists corrosion in harsh, outdoor applications. The wheels are located on the discharge side of the fan to pull clean, ambient air through the beltwell and inner bearing tube. The fan can withstand high-moisture environments where gas stream temperatures reach 375°F.

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www.nyb.com

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Acrison, Inc.
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Brooks Instrument
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EXAIR Corporation
800-903-9247
www.exair.com/108/303htlv.htm

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Siemens Digital Industries
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www.mixers.com

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from 500 to 150,000 cfm, the Series 6000 tray scrubber utilizes special tray designs in single or multiple stages to achieve maximum gas absorption using once-through water at extremely low rates to absorb and concentrate product in one easy step, without the need for recirculation pumps. This once-through water flow pattern also enables recovery of higher-vapor-pressure concentrated solutions for reuse in the process. For applications where fine mists are formed during absorption a final coalescing filter is used to reduce overall emissions to extremely low, nearly non-detectable levels to easily meet environmental standards.

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REMBE Inc.
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www.rembe.us

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Endress+Hauser
317-535-2108
www.us.endress.com/SMT77

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Hawk Measurement Systems
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www.hawkmeasure.com

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Emerson
314-553-2000
Emerson.com/Rosemount5300

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IDEC Corporation
800-262-4332
http://hmi.idec.com

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Det-Tronics
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det-tronics.com

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www.trendminer.com

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*GUI (Graphical User Interface)

Myron L
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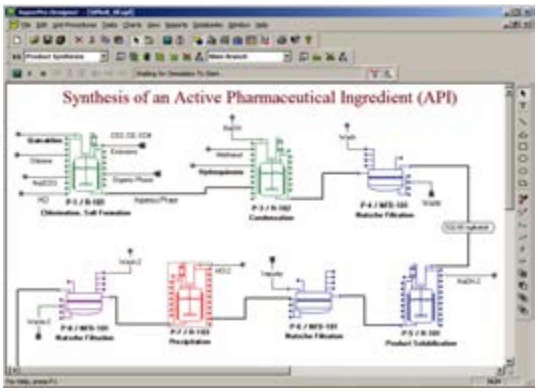

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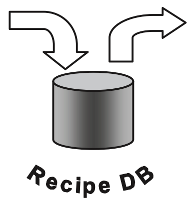

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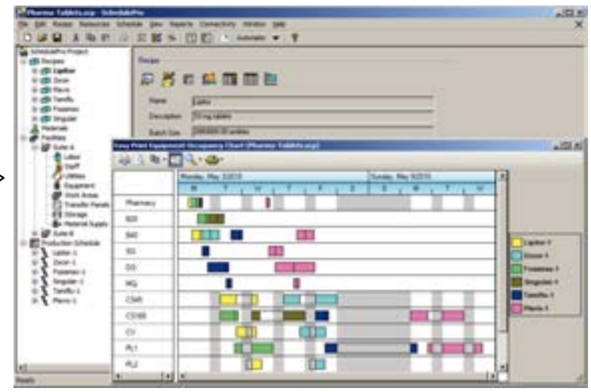

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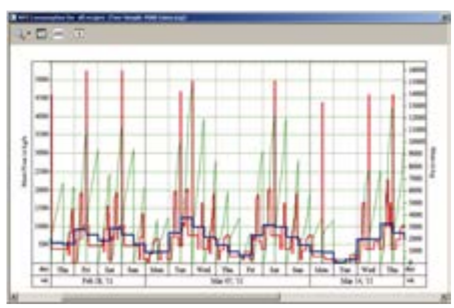

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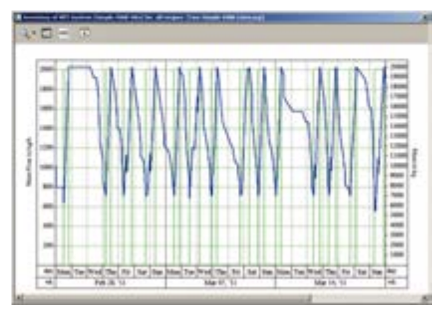

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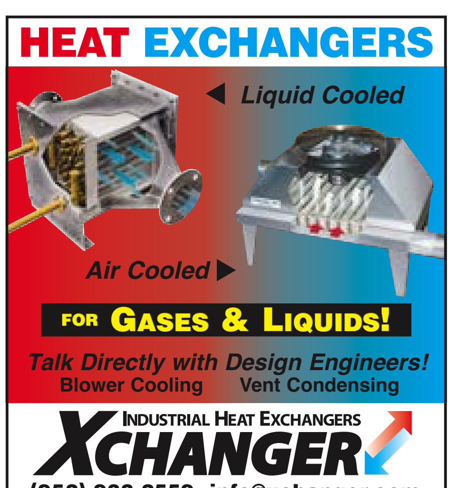

Report Targets CO_2 as a Resource

Several hurdles still exist to developing a carbon reuse economy

Progress depends on industrial renewal.

VTT, FINLAND'S Espoo-based technical research center, has published a paper on how carbon dioxide can be turned into a resource with a favorable impact on climate.

The report, "The carbon reuse economy — Transforming CO_2 from a pollutant into a resource" covers topics such as drivers of change, product options in the carbon reuse economy, pathways to a carbon reuse economy, and how to overcome barriers to change.

"It can be envisioned that, in the future, there will be more low-carbon electricity and almost unlimited amount of atmospheric carbon dioxide available. The biggest barrier to using carbon dioxide is mainly the high production costs related to the supply of low-carbon energy in a world used to low-cost oil. Political decisionmakers would now need to make bold decisions relating to low-carbon energy in any case," says Antii Arasto, VTT technology manager and one of the report's authors.

The paper identifies three main drivers for a carbon reuse economy. The first relates to carbon reuse's potential to displace fossil resources for energy, fuels, chemicals and materials production.

The second is the need to reduce CO_2 emissions in the atmosphere, for example, by expanding the regional raw material resource bases and secure energy supply (i.e., the energy needed to sustain societal activities).

Third, is the potential for new business based on the sustainable supply of carbon for value-added products.

The report discusses several possible process pathways to produce fuels from CO_2 and low-carbon hydrogen. For example, modular decentralized production of hydrocarbon fuels from CO_2 and hydrogen Fischer-Tropsch (FT) synthesis also can be applied to captured CO_2 and electrolytic hydrogen as feedstocks.

"However, FT has traditionally required plants with large production volumes to be profitable. A new concept based on a modular production unit using micro-reactor technology and efficient solid catalysts enables profitable production of hydrocarbons suitable for transportation fuels on a smaller scale," the authors note.

Such a unit can be located next to industrial CO_2 emission sources and production sites with surplus hydrogen. These decentralized units can produce hydrocarbons for drop-in transportation fuels (electrofuels) in oil refineries, they say.

VTT has demonstrated this approach with its sea-container-based modular pilot plant that moves from site to site to take advantage of available CO_2 streams (See, "Pilot Bolsters 'Green' Hydrocarbon Route," http://bit.ly/2kphASr).

However, there are still numerous hurdles; the authors highlight seven of the most important, along with recommendations to tackle them. One is the cost of low-carbon energy, which largely determines the cost of carbon capture and utilization (CCU) products.

"Previous assessments have shown that CCU concepts become feasible after low-carbon electricity becomes continuously available at a cost below €20–30/MWh ($22–33/MWh)," the authors state. The price of low-carbon electricity is expected to drop due to increasing investments and governmental actions and meet the target level by 2030.

Another is the tendency to transform industrial and energy systems towards more distributed production. This means small distributed point sources emit CO_2, which increases the costs of CCU plants, for example in terms of unit costs of captured CO_2. To overcome this, the authors suggest utilizing high shares of significant industrial point sources and direct air capture.

Then there are sustainability concerns. Lifecycle assessment methodologies are still being established for different applications of carbon reuse. So, questions such as whether fossil CO_2 could be used as raw material alongside biogenic and atmospheric CO_2 are only now being debated. Reaching consensus on sustainable practices will take time and possibly delay technology scale-up. The authors believe standardized lifecycle assessment methodologies driven by global intergovernmental organizations could resolve the problem.

Progress also depends on industrial renewal. "Decarbonization of the industrial and transport sectors will be an enormous task and will take decades to accomplish," they declare. For example, fossil raw materials are not only used for producing energy and fuels but also as raw materials in chemical and steel industries. Total renewal of heavy industry and transport is needed to meet climate change mitigation targets.

The authors conclude that the most important actions to take relate to business and the political environment: "Commercialization of the carbon reuse economy requires low carbon energy investments and policies to promote these investments. Moreover, the commercialization of lower-value products can be accelerated by legislative actions."

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