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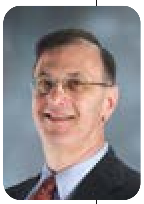
1501 E. Woodfield Road, Suite 400N
Schaumburg, IL 60173
Phone: (630) 467-1300
Fax: (630) 467-1120
www.chemicalprocessing.com
E-mail: chemicalprocessing@putman.net

IChemE Celebrates Centennial

Group remains a major force in the chemical engineering profession



HISTORIANS TRACE the origins of chemical engineering back to a series of twelve lectures given by George E. Davis at the Manchester School of Technology, Manchester, U.K., in 1887. These presentations led to his writing "A Handbook of Chemical Engineering," a two-volume work that first appeared in 1901, and to him often being called the first chemical engineer.

Before that, Davis was a force behind the founding of the U.K.'s Society of the Chemical Industry (SCI) in 1881. He reportedly wanted it named the Society of Chemical Engineers. The SCI did form "The Chemical Engineering Group" (TCEG) in 1918. Some practicing engineers, believing a separate qualifying body for chemical engineers still was necessary, spurred TCEG to work toward developing such an organization. These efforts culminated in the inaugural meeting of the Institution of Chemical Engineers (IChemE) on May 2, 1922, in London, with formal incorporation taking place in December of that year.

IChemE's membership now numbers more than 30,000, representing 100 countries. The U.K. still accounts for two-third of members; the second highest proportion comes from Malaysia, with Australia third.

The group, to mark the milestone, has launched a website called ChemEng Evolution, www.chemengevolution.org/, that covers both the history and future of the profession. While duly celebrating its past, IChemE is focusing more on addressing current challenges. It cites digitalization, major hazard management, and responsible production as priority topics where chemical engineers' unique skills can play a leading role.

To get the message out to a wider audience, it has partnered with ITN Productions Industry News to develop a program called "Serving Society" that includes several films on the role of chemical engineers and how the profession is helping address key societal challenges. For more details and videos, go to https://bit.ly/3Dnwmx1.

For the those in the profession and related industries, IChemE is running a webinar series on what the future may hold in a number of key areas. Webinars so far have looked at topics such as sustainability and the environment, and education. The May 11th webinar explores how the mix of energy sources likely will evolve as the quest to achieve net-zero carbon emissions progresses. (For details on how some chemical companies are reducing such emissions, see April's cover story "Net Zero Efforts Add Up," https://bit.ly/37kcWxr.) On June 8th, the webinar will focus on how new safe processes can contribute to a sustainable world, while July 13th's session will look at how chemical engineers can bolster the sustainability of food and water supplies. For more details on the IChemE centenary webinars, see: https://bit.ly/35kNuqy.

Digitalization, major hazard management, as well as responsible production are priority topics.

Process safety and loss prevention long have been a focus of the group. Indeed, in July 1979, its Northern Branch organized the initial "Major Loss Prevention in the Process Industries" conference. Today, the IChemE Safety Centre, https://bit.ly/37ifRqa, plays a major role in worldwide efforts to improve plant safety. (Its director, Trish Kerin, co-hosts the regular *CP* podcast "Process Safety with Trish & Traci," https://bit.ly/CP_Podcasts.)

While IChemE has had a distinguished history, it certainly is not resting on its laurels. ●

MARK ROSENZWEIG, Editor in Chief
mrosenzweig@putman.net

Don't Stint on Separator Selection

Choosing solid/liquid separation equipment demands care

The equipment is inexpensive and, thus, often gets inadequate attention.

YOU'VE MADE your slurry or paste from crystallization. Now, the next hurdle is separating the desired product from the mixture. Often, we focus on the particles but the product also could be the liquid. What separation device should you use? Here, a chemist may provide some insights, as I counseled in my column "Talk to a Chemist," http://bit.ly/30puZcK, by investigating alternatives to the process design by looking at other physical properties that might suggest different separation options. However, laboratory results rarely enable easy and direct scale-up to industrial-size equipment.

We may need more data, such as settling characteristics, cohesiveness of the solids, detailed filtration rate (filter or G-force), and desired quality of the product (either liquid or particulate solid), as I outlined in my column "Should You Use a Filter or Centrifuge?" https://bit.ly/3JM0m86. It would be a shame to waste all the energy that went into making these crystals. Equipment for solid/liquid separation often is the most inexpensive part of a process and, thus, frequently gets the least amount of time devoted to its selection. However, inadequate attention can lead to a costly mistake.

The two columns I've cited address the question of how you should go about selecting a filter or centrifuge but not why. I did hint you must consider the human factor (the operators); however, that's a political problem. In this column, let's look at some of the technical factors involved in the choice: cost, process complexity, and the next step in the production sequence.

Cost sounds simple but involves issues that often get downplayed or ignored. It must include labor, environmental impact, lost production due to upsets, and reliability. If you select a filter or a filtering centrifuge, what do you do with the worn-out cloths or media? Are they hazardous? Are spills possible and how would you handle them? Remember that removing solvent in a filter or centrifuge is much cheaper than passing the material to a dryer. This can justify more-complex and -costly equipment for the separation step.

Process complexity can be an advantage or a problem. One of the biggest mistakes I've seen in solid/liquid separation is trying to accomplish the task in a single piece of equipment to keep things simple. We had a peeler centrifuge that occasionally overflowed when it would get a batch of heavily loaded solids. Normally, the loading to the centrifuge was low and the timed feed worked fine. However, piping layouts allowed for settling at low production times. The solution was to add a hydrocyclone to make the feed to the centrifuge more uniform. A secondary advantage of adding this inexpensive device was to increase utilization of the centrifuge.

Solid/liquid separation is unique compared to other technologies because the form of the material leaving the step can significantly impact downstream equipment's operational and capital cost. Centrifuges prefer high solids loading, while filters are more forgiving. When the product is the solvent, then filters are the best choice. However, you often need secondary filtration to reach product quality requirements. Most solid/liquid separations yield a paste or cake that would go to a dryer in the form of clumps. However, these clumps frequently require dispersion to improve drying and flowability. An alternative is the use of extrusion. This not only removes the solvent mechanically but also heating of the solids can dry the product to produce pellets or ribbons.

EXPLORE ISSUES POSED BY SOLIDS

Check out previous Solid Advice columns online at www.ChemicalProcessing.com/voices/solid-advice/.

One of the challenges faced in solid/liquid separation is handling the slurry from the crystallizer as well as the wet cake from the separation. Intermediate storage of slurries is fairly straightforward but is not without problems. A classic example is feeding a centrifuge with a wide particle-size distribution. We had a batch operation where the centrifuge feed tank relied on an impeller to keep the solids suspended during production of batches of wet cake. As the feed tank was drawn down, the time needed to make a wet cake batch increased and the product became finer. While the impeller kept the solids suspended, it only mixed the lower part of the feed tank. The solution: recirculate slurry to the top of the tank with the centrifuge feed pump.

My next topic is drying the wet solids. ●

TOM BLACKWOOD, Contributing Editor
TBlackwood@putman.net

Polish Your Project Estimates

Keep in mind a number of key points including the value of some padding

Dynamic accounting isn't as difficult as it sounds.

I BOOSTED my estimate for a knockout drum by 10% because I had no way to anticipate the effect of inflation and supply chain delays. Yet, the actual cost exceeded that number — even the extra 10% added by corporate. This wasn't too much of a surprise; the project was held up for a year and required design changes because production restricted downtime due to the pandemic. That said, estimating is tough even in "regular" times. (I've covered several aspects in previous columns, e.g., "Sensibly Estimate Project Time and Cost," https://bit.ly/3JMiK0t, "Come Up with Better Cost Estimates," https://bit.ly/3Ntu6c7, and "Pad Your Cost Estimate," https://bit.ly/3zrwU2u.) Let's look at some facets to consider.

First, corporate budgets generally include a contingency. For instance, if you estimate a project to cost $100,000, given a 20% contingency, the project is budgeted at $120,000. So, if your site has a budget of $5,000,000, you only really have about $4,100,000 to allocate before the contingency. Actually, it's probably more like $3,000,000–$3,500,000, to leave room for other projects that inevitably will come up.

Obviously, better estimates could free up some money that could go to improving the site. Unfortunately, a lot of this "extra" cash usually funds capacity improvements; infrastructure, routine maintenance, such as the drum project, and even reliability enhancements fight for scraps.

Against this, though, cost estimates aren't crystal balls and, so, some padding invariably makes sense. Estimates come in low for many reasons (let's ignore factors like inflation caused by war or a pandemic): exhaustion because engineers are spread too thin to consider risks thoroughly; scope creep or even explosion once stakeholders get their hands on project money; insufficient or poor information; errors in drawings or design; materials of construction chosen based on textbooks rather than corrosion coupons; and, well, I could go on for pages. For external effects like inflation, it's best to apply an annual index, then correct and beg forgiveness if you're wrong.

There's another angle to consider: a labor surplus. If you assign an engineer to one job, another to a second, and so on, what do you do when this work is finished? As a contract engineer, I've often run into the situation where I could complete the work faster than the, say, six months assigned for a project. I guess the people in corporate planning weren't managing hours any better than they were managing budgets.

Let's consider approaches for managing budgets more effectively without either leaving money on the table or incurring substantial cost overruns. First is dynamic accounting; second is the use of "Cinderella" projects; and third is having a parking lot.

Dynamic accounting isn't as difficult as it sounds. In its simplest form, someone is responsible for keeping a spreadsheet with two trend-line curves for each project that come together as the work progresses. The leading curve tracks projected costs based on a percentage of the cost of each component (say, a fabricated tank) or estimates of overruns converted to a percentage. The trailing curve is money actually spent based on invoices paid. To keep the system honest requires working directly with contractors.

A "Cinderella" project is one paid for with leftover funds. Such money usually no longer is available when the next budget year begins. Dynamic accounting can ensure there are enough funds for the work. Scheduling is another matter; time available must suffice for the work to be completed or adequately allow for delays.

This is where parking lot projects are necessary. Maybe you don't have money for the whole project but only for detailed engineering or tie-points or equipment fabrication. Of course, if equipment is built, you must include warehousing and storage costs. Note that rotating equipment requires preparation, e.g., greasing, before storage and then taking apart and cleaning if idle for a long time; this has its own cost. Engineering also may need ongoing attention. For instance, you may want to maintain contact with key people involved in a design so they can be brought in as consultants once money for a project is found.

If managed carefully, you shouldn't have to contend with too much in lost opportunity costs. If the level is too high, sloppy management usually is to blame. Perhaps your competitors will do a better job and put you out of business. ●

DIRK WILLARD, Contributing Editor
dwillard@putman.net

Bacteria Break Down Carbon Waste

Gas fermentation process converts carbon dioxide into commodity chemicals

RESEARCHERS FROM Northwestern University, Evanston, Ill., and LanzaTech, Skokie, Ill., say they have developed a gas fermentation process that uses engineered bacteria to successfully convert carbon dioxide (CO_2) into acetone and isopropanol (IPA), while avoiding the traditional use of fossil fuels.

ENGINEERED BACTERIA

Figure 1. Gas fermentation approach using engineered bacteria could help achieve a circular economy. *Source: Justin Muir.*

"Manufacturing of these chemicals using conventional processes result in emissions of ~2 kg CO_2/kg product along with accumulation of other toxic waste. Up to now, no sustainable, green chemistry alternative exists. We have developed a process that enables carbon-negative manufacturing of these chemicals, effectively pulling CO_2 out of the atmosphere and locking ~1.5 kg of CO_2 into the product per kg produced. So, as we move to larger scale, the process is carbon negative and this is significant," explains Michael Jewett, co-senior author of the study and a professor at Northwestern's McCormick School of Engineering.

The team started with *Clostridium autoethanogenum*, an anaerobic bacterium engineered at LanzaTech. Using synthetic biology tools, they next reprogrammed the bacterium to ferment CO_2 to make acetone and IPA.

After performing lifecycle analysis, the team reported in the journal *Nature Biotechnology* that the carbon-negative platform could reduce CO_2 by 160% compared to conventional processes.

Most commercial biomanufacturing processes are in the 1–5 g/L/h range, so, their current ~3g/L/h productivity for acetone and IPA already is commercially relevant, says Jewett.

The researchers note the approach is readily adaptable and could potentially help create streamlined processes for generating a wider range of commodity chemicals.

"We can adapt the organism by providing new enzymes that allow for the synthesis of new chemicals. We anticipate, as in this case, that we'll also have to reprogram native metabolism to facilitate high yielding production," Jewett elaborates.

The engineered strains also seem immune to poisoning by constituents commonly found in industrial emissions, syngas and other likely feed streams.

"This is one of the special features of this organism. It is tolerant to these contaminants. The process also is tolerant to fluctuations in the feedstock compositions, which is important for industrial-scale production and process stability," notes Jewett.

Their next step is to demonstrate the process beyond pilot scale.

"Our vision for commercialization is to transform established ethanol-producing gas fermentation facilities into product-flexible production plants. By swapping the ethanol-producing microbe currently deployed in our commercial gas fermentation facilities with a new microbe programmed for acetone or propanol production, or one of a number of other commodity chemical products, we can instantly increase the range of products that an individual facility can make. This product flexibility will enable plant operators to make market-based decisions on which products to focus on at any time," explains Jewett.

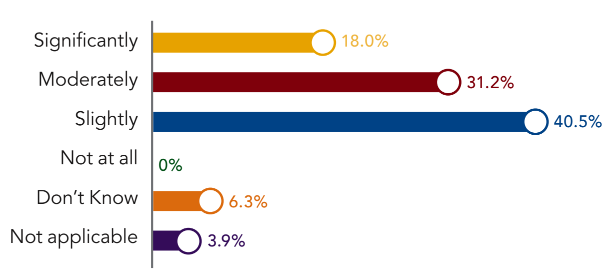
LanzaTech's two commercial plants have, to date, converted emissions from heavy industry into over 30M gallons of ethanol and avoided over 150,000 tons of CO_2, says the firm.

For the initial industrial/commercial application of the engineered strains, the team believes it could tackle several possible waste streams.

"At a high level, we can use this process to convert industrial, agricultural and urban waste gases into important chemicals," notes Jewett. For instance, LanzaTech already has developed technology to capture a steel mill's waste gas (a mix of mostly CO, CO_2, and hydrogen gas), which would otherwise be vented into the atmosphere.

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

How much have supply chain issues affected your site recently?



Nearly 90% of respondents saw at least some impact.

"Acetone and IPA are important commodity chemicals with established markets of >$10 billion. Both molecules are industrial solvents as well as platform chemicals for the production of materials such as acrylic glass (polymethyl methacrylate) and polypropylene. A key feature of these molecules is that they can be separated using similar technology as ethanol, which allows us to use the same plant infrastructure at LanzaTech and switch between products (e.g., from ethanol to acetone or IPA) by simply changing the microbe. This is a paradigm shift to the chemical industry, where a plant is typically purpose-built for a certain product and production cannot be easily changed. We believe this approach is significant towards a circular economy," declares Jewett.

"What's so exciting is that we believe that the framework developed here will provide a blueprint for development of further carbon-negative chemical production processes. More broadly, our work highlights how synthetic biology has the potential to be a central pillar of a global strategy for enabling people and the planet to flourish in partnership," Jewett concludes.

Polycarbonate Recycling Gets a Boost

AN UNEXPECTED discovery points the way to breaking down polycarbonate under mild conditions and promises a potentially cost-neutral process for upcycling the common waste, believe researchers at the University of Bath, Bath, U.K.

Based in Bath's Centre for Sustainable and Circular Technologies (CSCT), the researchers were investigating a number of ZnII complexes bearing half-salan ligands in the mild and selective chemical upcycling of various commercial polyesters and polycarbonates.

When they tested $Zn(2)_2$ and Zn(2)Et complexes in methanol at room temperature, the researchers were surprised to see commercial poly(bisphenol A carbonate) (BPA-PC) beads broken down into their chemical constituents in 12–18 minutes.

The resulting bisphenol A (BPA) and dimethyl carbonate (DMC) molecules are high quality, with the latter reportedly ideal as a green solvent and building block for synthesis of industrial chemicals. The ability to recover BPA prevents leakage of a potentially damaging environmental pollutant, too.

CSCT researcher Jack Payne describes the results as remarkable. It is the first example of a discrete metal-mediated poly(BPA-PC) methanolysis reaction being appreciably active at room temperature, he stresses.

"This was extremely surprising since state-of-the-art systems prior to this relied on elevated temperatures (≥70°C), high catalyst loadings (≥5 mol%) and/or prolonged reaction times — especially for those that had reported activity at room temperature. Given the lack of discrete metal-based catalytic examples in the field, we expected our systems to be competitive with organocatalytic examples, but to complete polycarbonate consumption within 20 minutes at room temperature exceeded our expectations ten-fold," he declares.

The CSCT team now is focusing on optimizing the catalyst, mainly by trying to fine-tune the ligand that binds the zinc.

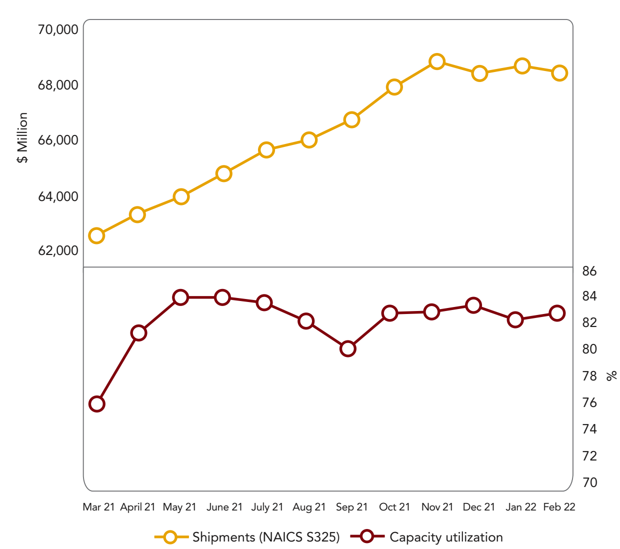
"Once we have a clearer understanding of the catalyst design features that promote such high activity, we will then explore applicability to other reactions and polymer classes," Payne notes.

At the same time, the CSCT is collaborating with Bath's chemical engineering department in a project to demonstrate proof-of-concept scale-up work.

"The major challenges here have been catalyst scale-up and stability since we need the catalyst to be stable in air. Looking on to pilot and commercial scale, catalyst recovery will be a primary challenge to address since our system is homogenous. One possible solution to this is to immobilize the catalyst on a support to allow easy separation from the product(s)/solvent," he explains.

Since being described in a recent issue of *ChemSusChem*, the work has attracted significant interest from industry, says Payne; the CSCT is in the preliminary stages of exploring possible collaborations with several companies.

ECONOMIC SNAPSHOT



Shipments slipped somewhat while capacity utilization edged up. *Source: American Chemistry Council.*

Better Calculate the Cost of Steam

Consider several factors when reckoning heat, power and steam costs

Simple marginal steam costs are useful for quick scoping calculations.

ESTIMATING THE value of energy savings is essential in the screening of projects (see March 2021's column, "Screen Your Energy Projects," https://bit.ly/3mmevhh), and simplified calculations often are the first step. One important, but often misunderstood example of this is the use of simplified "marginal costs" for steam, i.e., the incremental cost of providing or eliminating one unit of steam production (often expressed in $/klb).

Most large chemical plants and oil refineries use steam turbines in a simple form of cogeneration (see "Double Up on Cogeneration," in our May 2020 isssue, https://bit.ly/3fcqABC). High-pressure (HP) steam enters a turbine. Passage through the turbine reduces it to low-pressure (LP) steam. Some of the thermal energy in the steam is converted into mechanical energy, which can be used either to drive process equipment (a pump or a compressor), or to generate electricity. The power delivered by turbines offsets electricity that would otherwise come from the grid. This decreases the site's electric bill, which lowers the effective cost of the LP steam. Typically, some steam also passes through a pressure reducing valve (PRV) in parallel with the turbine, and desuperheating water is added for temperature control (Figure 1).

The following simplified example, based on the material balance in the figure, considers only the two largest cost components — fuel burned in the boiler ($5.00/MMBtu), and imported electricity ($0.05/kWh). We produce HP steam (600 psig, 645°F) from boiler feedwater at 225°F. We need LP steam at 150 psig, 418°F. We created the material balance using additional data from steam tables, based on 2 klb of HP steam, split equally between a steam turbine and a PRV. The boiler fires 1,316 Btu of fuel/lb of HP steam produced. The steam turbine/generator produces 25 kWh of electricity per klb of steam. The desuperheater requires 0.083 klb of water per klb of incoming steam.

MARGINAL COSTS AND CREDITS

HP Steam	$6.58/klb	Fuel cost only
Power Credit	$1.25/klb	Value of power from turbine
LP Steam from Turbine	$5.33/klb	HP steam – power credit
LP Steam from PRV/ Desuperheater	$6.08/klb	Average cost per klb is reduced because of increased flow

Table 1. Not factoring in desuperheating water can lead to significant errors when calculating the value of steam savings.

STEAM TURBINE COGENERATION

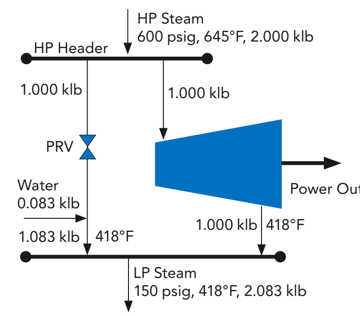


Figure 1. Steam passes through a pressure reducing valve in parallel with the turbine to offset electricity imported from the grid.

Based on this information, Table 1 shows marginal costs and credits.

The LP steam from the turbine is cheaper than the HP steam due to the power credit. However, the marginal cost of the LP steam from the PRV/desuperheater route is also less than the cost of the HP steam — in this case because of the additional flow due to the desuperheating water. This fact often is missed; it can lead to significant errors when calculating the value of steam savings.

Simple marginal steam costs are useful for quick scoping calculations. However, you can include other factors for more accurate calculations — e.g., makeup water and chemicals, energy for pumping and boiler fans, steam consumption for deaeration, heat losses from piping and equipment, and mechanical and electrical losses in steam turbines and generators.

More detailed calculations, with rigorous heat and material balances and all significant cost components, are best carried out with modeling tools (see "Homemade Spreadsheets Aren't Enough," from August 2019, https://bit.ly/3qrnE9J). Additional factors to consider depend on whether the steam turbine is coupled directly to plant equipment or to a generator to produce electricity. ●

ADDITIONAL INFORMATION:

Alan Rossiter & Beth Jones, "Energy Management and Efficiency for the Process Industries," AIChE/ John Wiley & Sons, Inc., Hoboken, New Jersey, 2015, Chapter 17.

ALAN ROSSITER, Energy Columnist
arossiter@putman.net

California Eyes Proposition 65 Modifications

Agency wants to make additional revisions to proposed changes to "short-form" warnings

Prop 65 compliance continues to be a hot button issue.

ON APRIL 5, 2022, the California Office of Environmental Health Hazard Assessment (OEHHA) issued a notice recommending additional revisions to its proposal to modify Proposition 65 (Prop 65) Article 6 "clear and reasonable warnings" regulations for "short-form" warnings (Notice). OEHHA first proposed to change the short-form warning requirements on January 8, 2021. This column explains the significance of this development.

Prop 65 regulations provide an option for a "short-form" warning as an alternative to the general requirements for consumer product exposure warnings. This option requires the hazard symbol, the word "warning" in capital letters and bold print and a reference to OEHHA's website. There is no limit regarding when the short-form warning can be used (e.g., limited label space). Importantly, the short-form warning doesn't require a company to name a listed chemical within the label's text.

OEHHA's January 2021 proposal sought to limit when the short-form warning could be used. This includes restricting use to labels smaller than a certain size (i.e., 5 $in.^2$ or less) and eliminating the short-form warning option for Internet and catalog warnings. If the criteria could be satisfied, OEHHA further suggested editing the short-form warning language, including the requirement to list a Prop 65 substance.

Following OEHHA's review of comments, the agency suggested additional changes. OEHHA has proposed to increase the label size requirement to 12 in^2. OEHHA rescinded its initial proposal to prohibit using the short-form warning online and in catalogs. Regarding the short-form warning language, OEHHA recommended two additional modifications:

1. Instead of only permitting the word "WARNING" in capital letters and bold print, include two other options: "CA WARNING" or "CALIFORNIA WARNING." OEHHA states this is to "allow businesses to make clear that the warning is being given pursuant to California law."

2. A warning option that OEHHA states "more directly addresses exposure to carcinogens or reproductive toxicants."

In its April 5, 2022 Notice, OEHHA suggested further alterations to its short-form warning regulations. These include:

- Label Size: Eliminate any size or package shape conditions for when the short-form warning can be used. These changes mean the short-form warning can be "used on product labels of any size, regardless of package size and shape." Apparently, OEHHA has difficulty determining compliance with the provision because of the lack of specificity in how to determine whether the package shape and label could or could not accommodate the full-length warning.
- Font Size: Remove the requirement that the font type size be the same as the largest type size providing consumer information. OEHHA suggested this change because recent federal requirements would in some cases result in oversized short-form warnings, and provide a disincentive to adding Proposition 65 warnings to labels.
- Effective Date: Change the date the regulation becomes operative to two years from the effective date rather than the one year previously sought. The additional time provided is a direct response to concerns raised by industry that the one-year time period was insufficient to implement the changes.
- "Expose" Language: Change the warning language from "exposes you to" to "can expose you to" so the language conforms with the general content language in the general consumer warning in Section 25603.

OEHHA also wants to correct the regulatory text regarding the warning to state "[name of chemical]" instead of "[name of one or more chemicals known to]."

The short-form warning is very popular. These suggested modifications are improvements to OEHHA's initial proposals. The label size changes and one-year compliance period are important issues about which industry raised significant concerns. The short-form warning language, if adopted, will continue to invite substantial changes in requiring the inclusion of a Prop 65 listed substance, but the elimination of size restrictions and font requirements, as well as permitting short-form warnings online and in catalogs when the label also uses the short-form warning, means the short-form warning option remains viable.

Prop 65 compliance continues to be a hot button issue for any entity doing business in California. Tracking these often-changing requirements is essential to avoid assertions of non-compliance by the state and citizen enforcers.

LYNN L. BERGESON, Regulatory Editor
lbergeson@putman.net

COLLABORATION PROMISES A WINNING HAND

Joint efforts by companies and governments confront carbon challenges

By Seán Ottewell, Editor at Large

AS INDUSTRY and society as a whole place increasing emphasis on carbon neutrality, i.e., net-zero carbon emissions, the successful development and deployment of carbon capture and utilization (CCU), carbon capture and storage (CCS), and carbon capture, utilization and storage (CCUS) technologies will underpin the complex projects necessary to reach that goal. Many of these projects involve extensive collaboration by companies and governments, as initiatives that include BASF, Air Liquide, Neste, Perstorp and others show. (Last month's cover story "Net Zero Efforts Add Up," https://bit.ly/3KXhYi7, looked at carbon-reduction projects of some individual chemical makers.)

One of the world's most ambitious projects involves the coming together of BASF, Ludwigshafen, Germany; Air Liquide, Paris; the European Union (E.U.); and both the Belgian federal government and that of the country's Flemish region.

Together, the two companies are committed to developing the world's largest cross-border CCS value chain at the industrial cluster in the port of Antwerp, Belgium.

Known as the Kairos@C project, it aims to optimize and integrate carbon dioxide capture and purification at five different production plants — two for hydrogen, two for ethylene oxide, and one for ammonia — at BASF's Antwerp complex (Figure 1).

The project has been made possible by €357 million (≈$390 million) in funding from the €1.1 billion (≈$1.2 billion) E.U. Innovation Fund; it is one of seven large-scale projects selected at the end of last year from more than 300 applications.

To remove the CO_2 from these plants, the companies plan to combine Air Liquide's Cryocap CO_2 capture technology with BASF's

BELGIAN COMPLEX

Figure 1. Carbon-capture-and-purification project will cover five different production units at Antwerp complex. *Source: BASF.*

Sorbead water-resistant silica-gel adsorbent material. This will be the first time the two companies have worked together with these two technologies, according to a BASF spokesman, who would not divulge any technical details on how they will be integrated.

"The challenge is especially the scale. The technology is known, but it hasn't ever been applied at this scale," he adds, noting that Kairos@C targets reducing CO_2 emissions by 1.5 million mt/y.

Start-up currently is planned for the third quarter of 2025. However, this depends both on the Karios@C technologies being in place, and on the necessary compression, liquefaction and export terminal facilities being ready, too, the spokesman explains.

This infrastructure is being built under the framework of Antwerp@C, a consortium that includes founding members Air Liquide and BASF, along with Borealis, ExxonMobil, Fluxys, INEOS, Total, and the Port of Antwerp.

Together, they aim to remove 18.65 million mt/y of greenhouse-gas emissions from the Antwerp complex by 2030.

Antwerp@C already has secured Connecting Europe Facility funding. A feasibility study concluded that a central pipeline "backbone" linking industrial zones on both sides of the River Sheldt with shared processing units, a shared CO_2 liquefaction unit, interim storage facilities and cross-border transport of the gas, both by ship and by pipeline, is possible.

"The FEED [front-end engineering design] of this backbone and of the liquefaction terminal is currently being executed," notes the spokesman.

OTHER EUROPEAN PROJECTS

Another beneficiary of the E.U. Innovation Fund is Neste, Espoo, Finland. The company has been awarded just over €88 million (≈$96 million) for a green hydrogen and CO_2 CCS project at its Porvoo refinery (Figure 2).

Known as Sustainable Hydrogen and Recovery of Carbon (SHARC) project, it will reduce emissions from the plant by moving it from grey hydrogen toward green hydrogen through the introduction of electrolysis facilities, and blue hydrogen by application of CCS. (Because hydrogen is essential in the making of transportation fuels, this green and blue hydrogen will decrease the carbon intensity of the fuels produced.) SHARC also will scale the production of green hydrogen to help make it a viable transportation fuel itself.

The first ten years of the project's operation should capture four million mt of CO_2.

The novel water-electrolysis technology applied by SHARC has a capacity of 50 MW, according to the company's funding application. This, combined with CCS, will maximize the benefits to the environment and the development of a strong supply chain from the refinery, by ship to storage site, and will lay the foundation for a European hub for renewable hydrogen and CO_2 utilization.

"Neste hosted a grant signing ceremony on April 4 and the project is currently in the feasibility phase. The target is to start up in the mid-2020s," says Outi Ervasti, Neste vice president, renewable hydrogen.

While Neste has experience on the use of carbon capture technologies, they will be implemented on a larger scale than ever before by SHARC, she adds. In addition, the company has yet to finalize the details for implementing the novel electrolysis technology.

Neste also is evaluating other in-house projects as potential candidates for future E.U. Innovation Fund applications, she says.

FINNISH REFINERY

Figure 2. E. U. funding will support a green hydrogen and CO_2 CCS project at Porvoo site. *Source: Neste.*

Meanwhile Perstorp, Malmö, Sweden, submitted a modified application to the E.U. Innovation Fund on March 3, the deadline for second bids.

Together with energy company Fortum, Espoo, Finland, and decarbonization specialist Uniper, Dusseldorf, Germany, Perstorp has applied for €97 million (≈$106 million) toward Project Air.

The plan is to create the first-of-its-kind, large-scale, commercial, sustainable methanol plant that uses a CCU process for converting CO_2, residue streams, renewable hydrogen and biomethane to methanol. The renewable hydrogen will come from a new electrolysis plant that will be the world's largest hydrogen electrolysis unit installed for production in the chemical sector, the company says.

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The facility, planned for Stenungsund, Sweden, would cost over €236 million (≈$257 million) if it goes ahead. It could be up-and-running by 2026 and reduce CO_2 emissions by 400,000 mt/y, equivalent to approximately 1% of those of Sweden overall.

NORTH AMERICAN VENTURE

Meanwhile, Svante, Vancouver, B.C., and Kewit Energy Group, Omaha, Neb., have signed a memorandum of understanding to establish a strategic alliance to pursue industrial carbon capture projects in both Canada and the United States.

Known as KSI Alliance, the aim is to offer a one-stop-shop common business development and construction approach from pre-construction services phase to engineering, procurement and construction project delivery.

The projects will employ Svante's solid sorbent technology to capture CO_2 directly from industrial post-combustion diluted flue gases. This will provide a non-intrusive end-of-the-pipe way to produce pipeline-grade pure CO_2 for safe storage.

In another development, Svante has announced the successful scale-up of a new sorbent material used in carbon capture processes. Its CALF-20 metal organic framework (MOF) material captures up to 95% of CO_2 emitted from industrial sources, using rapid solid adsorption and low temperature steam.

Working with BASF, Svante says it has successfully scaled up manufacture of the MOF to industrial scale using a low temperature process.

In addition, Svante has developed a high-volume and low-cost roll-to-roll process for coating the sorbent onto a laminate sheet. This "sorbent on a roll" then is stacked into a high-performance filter. The company did not respond to queries about whether this filter now is in industrial use.

Meanwhile, various efforts by individual companies and universities on CO_2 storage and conversion are underway.

UNDERGROUND STORAGE

Many CCS technologies focus on compressing CO_2 into a liquid and injecting it underground. However, this strategy poses significant engineering challenges and environmental concerns, with CCS also attracting criticism for being too expensive and energy-intensive for widespread use.

A case in point is the Moomba CCS project of natural-gas producer Santos, Adelaide, Australia. The plan is to store 1.7 million mt/y in depleted natural-gas reservoirs in the onshore Cooper Basin in South Australia.

Santos says that carbon capture would serve to reduce emissions from the gas extraction process. Longer-term, the company also hopes to use the technology in the manufacture of blue hydrogen, which extracts hydrogen from natural gas and captures and stores the waste CO_2 produced in the process.

According to the *Financial Times*, Santos has secured a network of depleted gas reservoirs that can hold 100 million mt of CO_2, opening up a potentially lucrative line in carbon credits worth as much as A$25 million/y (≈$19 million/y). On the other hand, critics point out that similar CCS schemes in Australia have under-performed and that the strategy would allow Santos to prolong gas production and the associated release of CO_2.

Meanwhile, researchers from the Department of Chemical and Biomolecular Engineering at the University of Singapore, Singapore, have come up with an innovative strategy to store CO_2 underground. They propose storing the gas in the form of hydrates under ocean floor sediments; natural pressure created by the weight of the seawater above would keep the hydrates in place. The conditions there, typically 2–6°C and 100 atm, enable the CO_2 hydrates to store nearly 200 times their own volume of the gas.

The researchers say not only is this approach viable but also the existence in nature of huge volumes of methane hydrates in ocean-floor locations around the world offers an encouraging analogy about the stability and safety of CO_2 hydrate storage.

Working under lead researcher professor Praveen Linga, they designed a pressurized vessel and lined it with silica sand to imitate ocean sediments. The CO_2 hydrates used remained stable over the 30 days of the experiment.

The researchers now plan to scale-up the reactor capacity and lengthen the reaction time to six months.

"There are multiple challenges here, including sustaining the system under such pressure while avoiding mechanical and process failures, and keeping the pressure, temperature and other sensors calibrated," explains Linga.

"Long term tests would extend our understanding the behavior of CO_2 hydrates in simulated oceanic sediments and allow us to get essential data about the evolution of CO_2 gas — if any — that takes place during the stability experiments," he adds.

Such data are essential for designing computational models to predict the stability of hydrates for thousands of years, notes Linga. "The experimental data we [obtain] during stability tests will incorporate factors such as type of sediments, effect of salinity, temperature/pressure conditions, CO_2 evolution, and other parameters like potential natural hazards like earthquakes, tsunami and man-made hazards like global warming," Linga says (Figure 3.).

HYDRATE STORAGE

Figure 3. Undersea storage of CO_2 hydrates must consider their stability, including when subjected to earthquakes and tsunamis. *Source: National University of Singapore.*

SOLID PROGRESS

Another appealing option is to convert the carbon in CO_2 into solid carbon. A team at the Royal Melbourne Institute of Technology, Melbourne, Australia, claim to have made a significant breakthrough here using a bubble column containing liquid metal heated to 100–120°C.

The CO_2 is injected into the liquid metal. As gas bubbles move through the liquid metal, they undergo a split-second reaction that forms flakes of solid carbon.

"It's the extraordinary speed of the chemical reaction we have achieved that makes our technology commercially viable, where so many alternative approaches have struggled," stresses co-lead researcher Ken Chiang.

Unlike earlier work that used liquid metals as a catalyst, the new reaction is much more efficient, faster and simpler to scale-up and integrate into industrial processes, the team notes.

A provisional patent application has been filed for the technology and researchers have signed an A$2.6-million (≈$2-million) agreement with environmental technology company ABR, Newcastle, Australia, which is commercializing technologies to decarbonize manufacturing industries there.

The next stage in the research is scaling-up the proof-of-concept to a modularized prototype the size of a shipping container, in collaboration with ABR.

The two also are eyeing the Australian government's A$1-billion (≈$750-million) fund for the development of new low-emissions technologies that cites CCS as a priority area. ●

EFFECTIVELY TROUBLESHOOT PILOT PLANT EQUIPMENT

Proper preparation and verification are key elements for success

By Richard Palluzi, pilot plant and laboratory consultant

TROUBLESHOOTING IS tedious and time-consuming. Fortunately, it is a skill anyone can learn and enhance by understanding some simple basic principles. Here, we will focus on those most useful for a pilot plant.

Haste always makes a troubleshooter less effective. When a problem arises, people get agitated; so spending some time to assess the situation is far from easy. Operators want you to start doing something immediately. A more effective approach is to take a moment before you touch anything to carefully examine the system. Note the position of all the key valves. Look at the pressures and temperatures. Check what is and is not operating. Often, this will reveal the problem very quickly and clearly. I once solved a problem defying the combined efforts of a much more senior group by noticing a feed valve had been inadvertently closed.

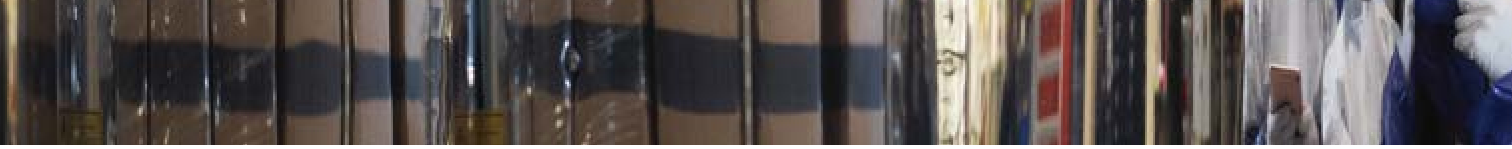
It's often necessary to ask the operator to give you a moment to think. An alternative is to patiently wait for the operator to explain what's happening, partially listening while also pondering the problem. One way I have found to address an operator's concern and still function effectively is to think out loud. This shows you are contemplating the issue while keeping the person involved. However, it does not always work because some operators insist on arguing or commenting on each point or trying to get you to stop and move in the direction they believe best. A polite but pointed comment that you are not as familiar with the problem as the operator and need a few moments to come up to speed often helps. Sometimes you might have to resort to declaring: "Could you please stop and let me think for a minute."

Write down the existing conditions and equipment status, including the positions of all key valves, before you do anything. Jot down notes as you make changes and ensure these notes are clear and legible enough to understand what you did, when you did it, what abbreviations mean, etc. This may sound like wasteful added work but, after doing five or six things, it is very easy to be uncertain if, e.g., the last test was with the valve on manual or automatic, nitrogen was or was not flowing, the initial pressure on the tank was 10 psig, et al. I can't tell you how many times I have had to use this information to unravel a confused operator (or myself).

START SENSIBLY

Don't blindly accept everything the operator or person discovering the problem says. People will leave out key items because they think they are unrelated, are embarrassed to tell you something they did, are reluctant to admit they have no idea what the pressure gauge was reading or if the feed valve was on, or simply don't remember correctly, e.g., thinking they put a valve on manual when, in fact, they didn't. Occasionally, even in the best organizations, operators may sense they created the problem and, thus, won't give you all the background for fear of making their culpability apparent. After wasting an hour finding out the operator simply forgot to set something properly or did something in the wrong sequence, it is very hard not to let some annoyance show. However, I suggest pointing out the error in a way that doesn't blame the operator: "It's like the cooling pump wasn't on when you started. Is there any chance that might have happened?" A reply of something vague like "I guess that is possible" often allows saving face and solving the problem.

Be suspicious of the person who has "solved" the problem and just wants you to fix something. I've wasted much too much time getting a pump changed out, a controller pulled for repair, and a regulator replaced only to find the pump wasn't working because of an unsatisfied interlock, the controller because of an incorrectly set pressure balance, and the regulator because the gas cylinder was empty. I often try to address these "solutions" by discussing how the solver is positive this is the problem. While often not received well, good operators rarely mind explaining their thought processes



while weaker operators frequently can be helped to understand that, perhaps, they are not 100% certain. In either case, this allows a more-grounded discussion to start; the time spent usually is well worth the time saved on an incorrect solution. Similarity to a past problem can badly mislead even experienced operators. They may not recognize the current erratic flow (±50%) differs a lot from the previous erratic flow (±10%) caused by a pump seal leak.

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Train yourself to start from the beginning or end of a system and work your way to the other end. This often seems counterintuitive because most people want to start in the middle. They feel they easily can identify if the issue is behind or ahead of their starting point; sadly, they are wrong. Starting at one end or the other of the system avoids false moves and, ultimately, saves time. Is the breaker on or does the equipment have power? Either is an unambiguous starting point for further checking. That a particular component is not energized may be much less so. Moreover, complex systems often have numerous paths, making the ability to figure out which direction to go suspect at best.

Never assume the most complex or troublesome component is the culprit. We all tend to think the flow has stopped because that finicky valve has hung up again or that difficult-to-access filter clogged once more. That may be the case but the cause just as likely is something entirely different like a closed feed valve. Problem-prone components exert a magnetic pull on troubleshooting efforts that often hinders a more logical and, ultimately, faster approach, as I personally can attest. Learn to avoid the pull.

Recognize that everyone has a "hunch" where the problem may reside. While these sometimes are correct based on past experience or simply a good intuitive sense, I have seen hours wasted checking an issue that a quick analysis would show could not explain the problem. Making matters worse, if you don't trust a component, you tend to keep circling back to it, often needlessly. This is where the next step helps.

DEVELOP A PLAN

Do this before you do anything else. Too often, troubleshooters rush to perform tests that won't prove anything. Taking the time to draw a simple flow chart to show where the results of each step will lead is invaluable and well worth the effort to develop. It frequently will make clear that a certain path will reveal very little or that you must do an additional step first to ensure you can reach a valid conclusion later. Sometimes you get lost in the process and forget what the step can or cannot show. Talking through the steps with a knowledgeable individual often helps you to avoid faulty logic or skipping over another, more viable path.

For particularly troublesome problems, review with someone what you have seen and done. That person might ask you an eye-opening question or challenge an unfounded assumption. If no one is available, writing down a summary sometimes can work. Many times, the effort to organize your thoughts and explain the problem will help you solve it or at least identify the next steps.

When you have done everything you can think of and nothing has fixed the problem, resist the urge to do it all over again. Instead, take a step back and try to identify what you have not looked at. While it is possible you incorrectly checked something, you are more likely just not focusing on the right area. I often have found the problem by simply asking: "What have we not looked at so far?" The key you lost always is in the last place you look.

Doubt everything you are told no matter how much you trust and respect the person. All too often the tank is empty, the cylinder not connected, the power not on, or there's some other incredibly obvious issue that someone failed to note. I have stood near too many valves I swear I opened and too many switches I swear I closed to not recognize how easy it is to get confused or fail to scrutinize something closely enough.

Look carefully at the system and pay attention to any nagging points. Why do you keep staring at that pump? Why is your attention always drawn to that feed system? Often your subconscious is noting something is not right and, if you look at it a bit longer, you will realize the issue.

Never do more than one thing at a time. Keep a close eye on everyone involved so that you are not starting something while some else has stopped it. Having someone double-check all five valves are in the right position or double-checking that you correctly traced that feed line to its source often saves incredible amounts of time and effort.

Make sure you understand the status of everything involved before the problem started to develop. Once, after pushing an operator to remember if anything was different right before a heater stopped working, the person finally remembered that an electrician had borrowed a ladder a few minutes

before the problem arose; it turned out the electrician had locked out the wrong circuit by mistake, cutting all the power to our panel.

Conversely, be willing to let go of something that you cannot logically link to the problem. The lights might have flickered in the control room just before the problem started but, if the distributed control system is working properly, that may well have nothing to do with the problem.

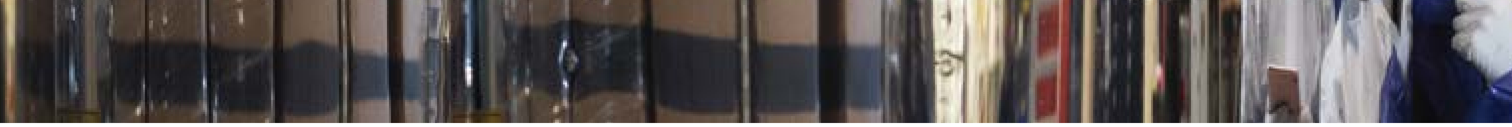
Always remember the proposed issue cannot violate basic physics and chemistry. Closing a valve can't increase the flow. Of course, you must be very diligent in making sure you have all the right information. If the valve was reverse acting, then perhaps you are opening, not closing it.

GET PROPER DOCUMENTATION

Never trust any drawings without verifying their correctness. This isn't the first thing I do every time — however, I always try to confirm how the equipment is piped and wired. It is too easy for a drawing to be wrong. Good management-of-change systems have reduced but far from eliminated this problem. Some operators resist this step, loudly arguing they know their units; cajole them into letting you check anyway. My favorite tactic is to agree with them but note I always would have a lingering doubt until I verified the installation.

Always gather all available documentation on intermittent problems. Insist that people write down observable facts at the time the problem arises, not afterwards when mistakes are too easy to make. Stress to operators that it is better to admit they forgot to note a value output than to just put in a "normal" value. Make sure the operators know to stick to verifiable facts, not opinions. "The seal started leaking sometime just before the problem" is valid if the drip pan always is dry and the operator saw it a few hours before. It is not so valid if the drip pan usually contains liquid and the operator's opinion is that the amount of liquid was more than usual. I once spent a week trying to find why a 30-psig rupture disk kept bursting when the system never had more than 5 psig on it. Only after reviewing the documentation did we discover the disk burst whenever someone turned on a gas chromatograph. As ridiculous as that seemed, it allowed us to find the incorrect line that fed 60-psig helium into our system.

Always ask the people involved about anything odd they notice, particularly the recurrence of anything when the problem appears. I finally pinned down why a gas



monitor intermittently shut down a unit despite there being no releases when an operator casually noted it always seemed to happen when an operator was cleaning another reactor. (The monitor was much more sensitive to the cleaning solution.)

When you appear to have fixed the problem, try to find a way to prove you are right. If you can show the problem appears when a regulator is set too low but disappears when it is set properly, you usually can be sure you found the true culprit. However, often ancillary things you do during troubleshooting fix the problem and you don't realize it. I once swapped out a metering pump twice before grasping the issue was vapor build-up not the pump. Each time we changed the pump, we carefully bled the lines, fixing the problem until vapor built up again. Obviously, this isn't practical in every situation but, if, for example, the replacement component looks fine, a fast offline test may raise suspicions that you have not found the real problem and, so, may not have fixed it.

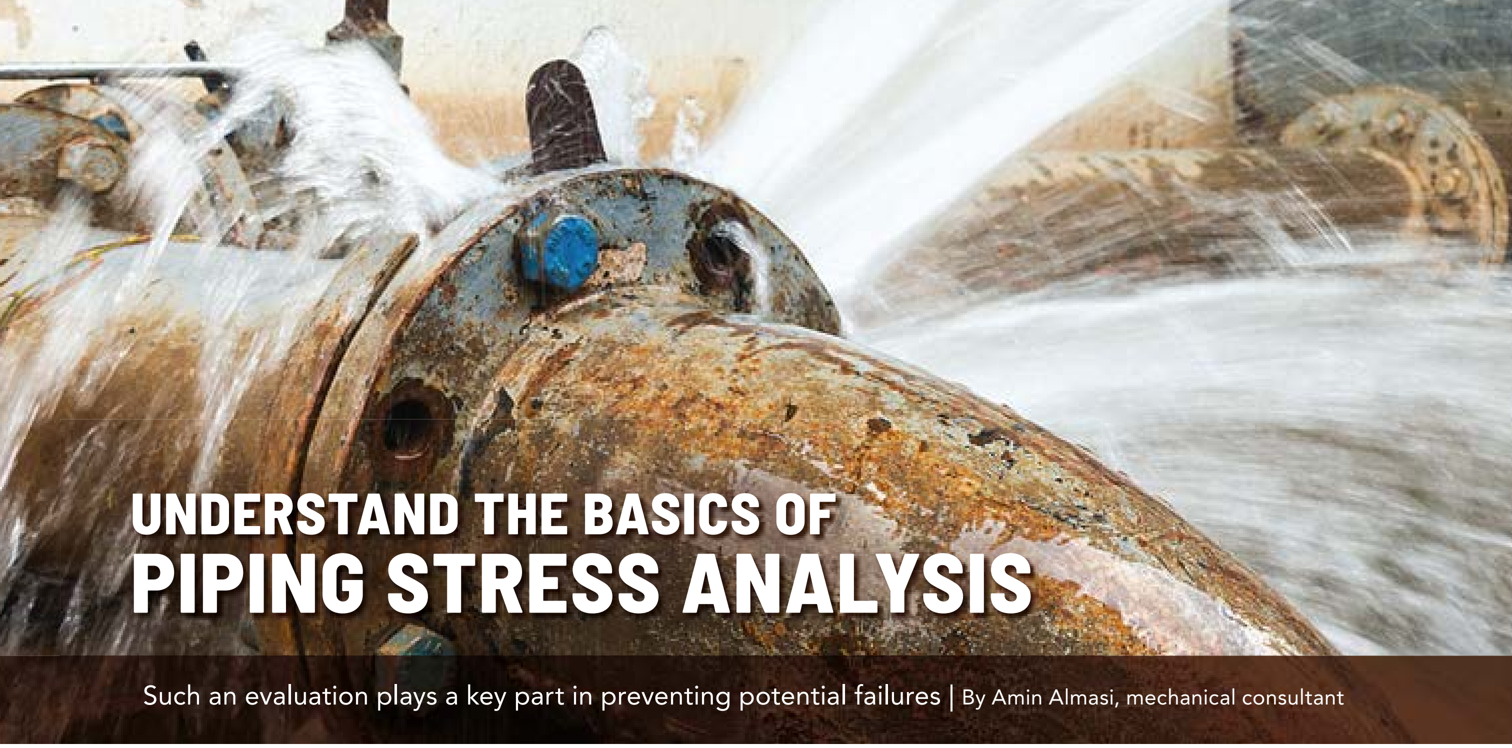
A larger troubleshooting team is not always better. Involving numerous people in the process often simply slows it down (everyone needs to have his or her say), creates the potential for confusion (too many people doing different things at once), and rarely solves the problem faster. A better approach usually is to step aside when you appear to have hit a dead end and let someone else have a try. A fresh set of eyes or a new approach, without you breathing down the person's neck, often can solve the problem.

Stepping away from the problem for a time sometimes also can help. I am always amazed at how many problems are solved faster the next morning than the previous evening.

Sometimes, problems fix themselves. (Actually they don't, but you somehow fixed them without realizing it.) Sometimes, you don't understand why doing a particular thing solves the issue. Both cases are rare and worthy of further investigation. To this day, I share such stories in the hope someone smarter than me will explain why the problem disappeared. Be careful in assuming the problem truly has been fixed or gone away in these cases. Often, such situations are hiding a very subtle or intermittent problem.

Even if you fastidiously follow all these guidelines, troubleshooting will take time and effort and, often, be incredibly challenging. However, on average, it should go a bit faster and easier. ●

RICHARD PALLUZI is principal of Richard P Palluzi LLC, Basking Ridge, N.J., and serves as pilot plants guru for *Chemical Processing*'s online Ask the Experts Forum, https://bit.ly/CP_PilotPlants. Email him at rpalluzi@verizon.net.



UNDERSTAND THE BASICS OF PIPING STRESS ANALYSIS

Such an evaluation plays a key part in preventing potential failures | By Amin Almasi, mechanical consultant

PIPING SYSTEMS constitute a major part of modern chemical plants, by some estimates accounting for 20–35% of the total cost of facilities. Unfortunately, piping systems have caused many reliability and safety incidents. So, their reliability, integrity and safety demand rigorous evaluation.

Piping stress analysis is a critical tool to prevent premature failure of piping and piping components and ensure piping stresses and all related loads remain within allowable limits. It enables the timely checking and verification of important parameters such as stresses, loading, leakage, safety of related and connected equifigurepment (nozzles), and piping deflection. Here, we'll review the basics of piping stress analysis and also present a case study.

Piping configuration, nozzle loads, spans and supports all impart stresses on the system. It is essential to confirm that different parts and components can withstand the stresses (internal pressure, thermal stresses, etc.) posed by regular, transient and abnormal operations as well as maintenance, e.g., pressure testing. In addition, the analysis should consider occasional and intermittent events such as vibration, fluid hammer, flow-induced vibration, high wind, earthquakes and more.

FLEXIBILITY ANALYSIS

Piping stress analysis involves different tasks and checks. A key one is flexibility analysis. This evaluates the ability of piping to deform elastically. A piping system should be flexible enough to handle potential thermal expansion/contraction or movement of supports or piping endpoints, thus preventing failure of piping and supports due to excessive stresses. Deciding upon the necessary flexibility requires consideration of:

1. *Maximum allowable limit of stress in various parts and components.* The many reported failures in welds, pipes, fittings, elbows, etc., underscore this as a major concern. An important factor is operating temperature because both high and low temperature reduce the allowable stress. Another factor in high-pressure systems (particularly for large-diameter piping) is hoop stress, which usually is high and can account for a substantial portion of the overall stress and leave a low margin for stresses due to bending, torsion, axial deflection, etc. For instance, a high bending load on a flange set may cause a leak. The pressure rating limits of valves, flanges and other equipment require checking.

2. *Maximum allowable forces and moments the piping system can impose on any connected nozzle.* Often called the nozzle load limits, they can be a significant limiting factor, particularly on delicate equipment where allowable nozzle loads could be very low.

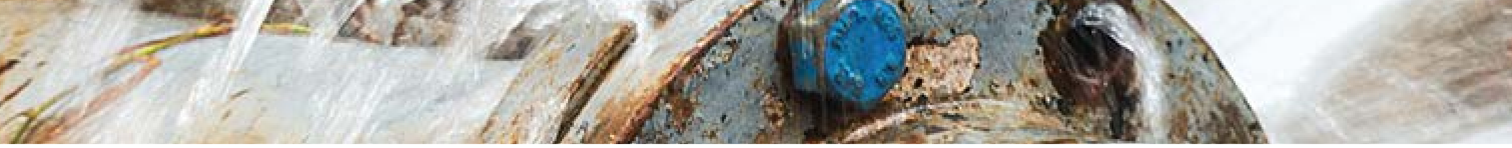
3. *Maximum allowable load that can be applied on supports.* Different factors such as the support itself or supporting structure can set this limit.

4. *Displacements existing within the piping system.* An example is the gap with nearby piping systems.

A systematic procedure is needed to check all these limits for every section and subsystem of the entire piping system. Support location is very important because wrong support placement may lead to failure of that section and then of the whole associated piping system. So, first the maximum permissible span is calculated by considering all loading conditions. This often is a set of estimated spans that later are confirmed via a thorough stress and modal analysis. Support locations and types then are inserted and adjusted until all flexibility requirements (stress, displacement, reaction loads, nozzle loads, etc.) and other requirements (such as modal, dynamic, etc.) are satisfied.

CONCERNS AND CHALLENGES

Piping stress analysis poses a number of key concerns. The first relates to code stress and allowable stress. Different



codes and standards offer disparate methods to calculate code stress and allowable stress.

Other major concerns are issues around stress intensification factor (SIF), flexibility factor, branch connections and, generally, any complex fittings or components in piping. The geometry of fittings (such as branch connections, bends, reducers, etc.) can significantly influence the flexibility of a piping system. They change cross-sectional shape under the action of bending moments and other loadings and, thus, provide greater flexibility than the same length of straight pipe. This action also increases the stress levels in the fittings. The SIF and flexibility factor can account for these phenomena. However, some challenges can arise. For instance, larger-diameter branch connections sometimes lead to inefficient distribution of piping loads, owing to the lack of consideration of the inherent flexibility of a branch component.

The software for piping stress analysis is relatively straightforward. However, mistakes too often occur because of lapses in the critical preliminary tasks of interpreting process data and providing appropriate inputs such as temperature, pressure, operating conditions, etc. Changes in piping material specification, tie-in locations, and revisions in applicable codes or standards need adequate attention. Excursions, e.g., low temperature (for instance, due to depressurization, repressurization or the like), high temperature and elevated pressure, as well as transient cases and extreme operating conditions require great care. It is essential to exercise good judgement in defining the operating conditions of isolated sections, transition parts and those items not subject to defined process conditions in each operating case. Usually, a piping system can encounter multiple potential scenarios. Indeed, it is not uncommon to specify eight or nine operating cases for some piping systems. This leads to a far greater number of loading cases — often 100 or more — because they combine elements of different scenarios.

Verification of results is another important step, especially with software that involves manual specification of input and load cases. The thermal movement, deformations, stresses, forces and other output results require careful checking to ensure no input or numerical error has occurred.

In addition, as already mentioned, each piping system can encounter a variety of operating cases. Usually, the operating or loading case that is the critical one is not known; a complete set of simulations is needed to find it. A further complication is that process conditions and materials may differ in connected piping items and parts. In other words, even in a single operating scenario, connected parts may confront markedly different operating conditions. For instance, in a cold operating case, two connected piping components might experience different temperatures and pressures. Moreover, the components might be fabricated from different materials. Because a system generally contains many different parts and components such as pipes, fittings, valves, flanges and equipment, the overall situation gets very complicated or even confusing. Such interactions between different parts fabricated from different materials operating under different process conditions in different scenarios make piping stress analysis more challenging and complex.

Another challenge is that different sets of limits and allowable parameters need checking. Confirmation of stresses, nozzle loads, support loads, displacements and other parameters is crucial as is verification that those key parameters are within specified limits in all possible combinations.

The next source of complication is when a parameter, such as stress, load, etc., exceeds the specified limit in a loading case. The formulated modification to solve the issue should not cause any difficulties in other operating cases, and all key parameters (stresses, loads, etc.) in all those combinations and scenarios still should stay within specified limits.

SUPPORTS AND HIGH STRESSES

The details of supports such as support types, their load limits, their characters and options can significantly affect the piping layout and piping stress analysis. Weak supports with low load limits can cause serious problems because support loads can easily exceed the limits, necessitating re-configuration. Proper support may require a variety of kinds of support to cover different locations and types of piping.

The general strategy is to use an optimum stiff support scheme to keep movements as well as modal and natural frequencies under control. Piping can be subjected to a wide range

Figure 1. This piping, shown during construction, requires careful stress analysis to ensure it can cope with attached equipment.

of dynamic excitations from rotating machines, flow-induced vibration, pressure transients and other causes. Therefore, it makes sense to adopt a conservative support approach (or relatively stiff scheme); this typically involves the use of gripping and clamping supports, such as U-bolts, clamps, guides with optimum gaps and the like, to keep the piping under control. If more flexibility is needed, then converting one or two guides or clamps to resting supports can provide some local freedom, e.g., to let piping move laterally in those supports.

When high stresses, support loads or nozzle loads are spotted, then changes become necessary. Solving the problems and optimizing the overall piping requires studying different options and configurations. This often is a matter of trial and error, although we'll cover some guidelines to cure each set of problems.

Different root causes can produce high stresses. However, a common problem is localized deformation leading to locally high stresses. This often arises where different piping systems with significantly different stiffness are connected in series. This leads to the flexible (less-stiff) piping section absorbing a large portion of thermal movements produced by the entire piping system — potentially resulting in overstressing of that section. Other situations also can prompt localized deformation. For instance, in a system of uniform piping size, a configuration in which the neutral axis or thrust line is situated close to the major portion of the line may result in a very small offset portion of the piping line absorbing most of the thermal movements.

In many piping systems, the thermal movements cause considerable stresses; absorbing thermal movements and relieving the piping from excessive stresses may call for one or more expansion loops. These can be Z-shape or U-shape loops provided in the run of piping. However, expansion loops require extra space, elbows, bends and additional supports (and steel structure) that could adversely affect both initial and operating cost. Therefore, it is necessary to optimize the geometry, the number of expansion loops and their supports. A favored approach is to reduce the number of loops in a single piping system or decrease the length of the loop itself, so long as stresses are within safe limits.

Elbows usually are the weakest part of an expansion loop; many plants have reported breaks in these elbows. So, design of expansion loops demands care. Many methods and software packages for expansion-loop dimensions rely on empirical models rather than engineering fundamentals. Proper piping stress analysis is needed for all expansion loops to calculate accurate movements, stresses and support loads.

A CASE STUDY

Let's now look at the stress analysis of a section of a critical 2-in. schedule-80 piping of class 1500# in a processing facility. The piping serves different operational purposes including depressurization of a crucial piece of fixed equipment. Eight different operating cases were considered. These included normal operation at a temperature of 31°C and pressure of 134 Barg; a cold case of -45°C such as when gas gets cooled due to Joule-Thomson effect during depressurization of the equipment; and a hot case of 66°C.

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(This includes links to more than 20 CP articles.)

This section of piping is 2.9 m in horizontal (x) direction with a class 1500# valve located at 0.36 m, 1 m in vertical upward (z) direction, and 0.96 m in lateral (y) direction where it connects to the fixed equipment with an elbow and small piece of pipe through a flange set and nozzle. Different charts and tables for allowable span of 2-in. schedule 80-piping gave allowable spans between 3.6 m and 4.7 m. An initial assessment indicated a support might be needed for this section of piping. This, at first, seemed correct because a relatively heavy valve was in the section. However, such charts and tables are known to be conservative and only are suitable for rough estimations. In addition, access and other issues made providing a support in that section difficult.

Accurate stress analysis always is the best way to see if a piping configuration is suitable and whether or not additional support is required. Using stress analysis software, the maximum stress was obtained around 100 Mpa at the elbow/pipe juncture near the nozzle equipment for the cold operation case (weight + cold temperature + pressure). Compared to an allowable stress of around 160 Mpa at the cold operating condition, the overall configuration was acceptable. Nozzle loads also were below the limits. The calculated first natural frequency was around 9.7 Hz for the dynamic movement in lateral direction (y). This exceeded the 9-Hz limit for this part of piping mandated by plant requirements. In addition, detailed studies proved there was no potential for resonance, flow-induced vibration and dynamic issues. The conclusion was the piping was acceptable — although some stringent guidelines would consider the stress, span and natural frequency as marginal — and an additional support was not required. The piping was fabricated in this way. It is operating successfully and without trouble. ●

AMIN ALMASI is a mechanical consultant based in Sydney, Australia. Email him at amin.almasi@ymail.com

UPGRADE YOUR SIS INSTRUMENTATION

Enhanced functionality increases plant safety and provides fast return on investment | By AnnCharlott Enberg, Emerson

RELIABLE SAFETY instrumented systems (SISs) that robustly protect personnel, assets and the surrounding environment are vital to the safe operation of chemical plants. Many facilities rely on legacy, often decades-old, SISs. Despite this, these systems continue to provide a dependable layer of protection in compliance with the International Electrotechnical Commission's IEC 61508 and IEC 61511 standards relating to functional safety. Some chemical makers adopt an attitude of "if it isn't broken, don't fix it" and do not consider upgrading to modern instrumentation. With tight operating budgets and limited resources, this seems perfectly reasonable — but it means these companies are missing out on the opportunity to enhance safety and lower lifecycle operating costs.

The reluctance to modernize commonly stems from the perceived cost and complexity of replacing old instrumentation with new units. However, to reduce complexity, the latest flow, level, pressure and temperature measurement devices suitable for integration into SISs have been designed to ease their installation and use. Crucially, they feature enhanced functionality that provides a range of significant benefits, such as smart diagnostics suites and remote proof-testing capabilities. This functionality helps increase plant and personnel safety, and decrease maintenance costs and downtime, which typically leads to a quick return on investment.

REMOVING RISKS TO PERSONNEL

Figure 1. Remotely performing partial proof testing eliminates the need for staff to climb tanks.

Let's look at some specific aspects of this enhanced functionality in modern SIS instrumentation and the important benefits achievable.

PROOF TESTING

SISs are designed to perform a safety instrumented function (SIF). This requires three elements: measurement sensors that monitor the process; logic solvers that evaluate the sensor input to assess whether the process is running safely; and final control elements (very often valves) that safely shut down the process when necessary.

An SIF should use the most-reliable components. Recognized standards (e.g., IEC 61508) define methodology for assessing device reliability. A third party generally performs these assessments, although manufacturers also are allowed to conduct self-assessments (IEC 61511). The methodology considers the design of the device to determine its inherent susceptibility to fail in the first place. Obviously, this is the most robust way to ensure reliability. The methodology then assesses potential failures considered "safe" and failures detected through diagnostics. Assessing any remaining potential failures requires periodic proof testing.

Proof testing verifies that, when a safety demand arises, equipment will work correctly, achieving its required safety integrity level (SIL) for the application. It involves testing each component individually as well as the complete safety loop. A safety loop's probability of failure on demand (PFD) increases over time. Performing a proof test resets the PFD to a lower value and ensures the safety loop provides the expected risk reduction. The PFD average of the safety loop determines the frequency of proof testing. A technical justification, such as the PFD calculation, can enable extending the interval between tests.

A plant can perform two types of proof test — comprehensive and partial —in compliance with the relevant industry standards, IEC 61511 and API 2350. Comprehensive proof tests involve testing the entire safety loop in a single procedure, to ensure all its parts are functioning correctly. This will return the PFD of the safety loop back to, or very close to, its original level. A partial proof test may include one or several parts of the safety loop and will bring the PFD of a device back to a percentage of the original level.

Performing a partial proof test can provide significant benefits. Such a test is quicker to complete, interferes less with operations and, crucially, justifies an extension of the time interval required between comprehensive tests while remaining within regulatory requirements. This extension may allow scheduling the comprehensive test during a planned shutdown, thus increasing plant availability and efficiency.

Proof testing traditionally occurs on location. However, the digital technology available in modern level-measurement devices enables performing partial proof testing remotely; the devices remain installed while simulated overfill conditions activate the detector and generate an alarm signal. Use of simulation makes moving fluid into and out of the tank to conduct the test unnecessary and avoids the risk of spills. It also eliminates the need for workers to climb tanks (Figure 1) or be exposed to tank contents, thereby increasing their safety and freeing them up to concentrate on other value-added tasks. The ability to perform partial proof testing remotely has become a key selection criterion when implementing level measurement technology as part of an SIS.

PLUGGED IMPULSE LINE

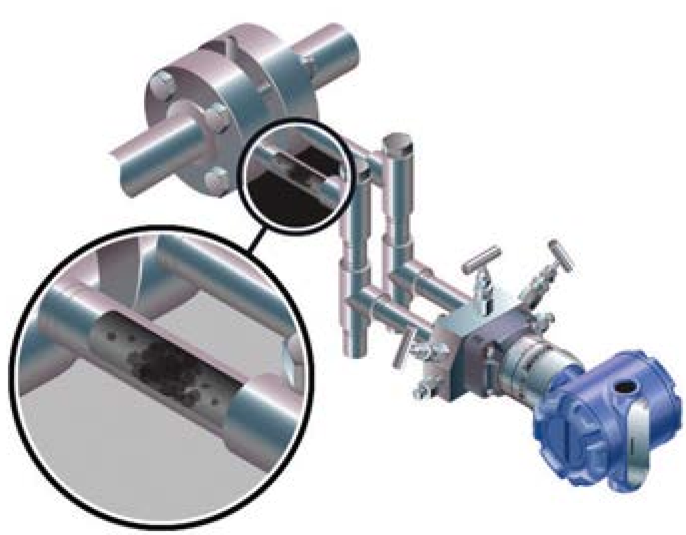

Figure 2. Small-diameter tubes or pipes used with pressure sensors can fill with solid material or freeze in cold environments.

DETECTING PLUGGED IMPULSE LINES

Advanced diagnostics in modern pressure transmitters can detect many abnormal conditions in processes, including plugged impulse lines, which are an all too common problem. These lines — small-diameter tubes or pipes used to transmit the pressure signal from the process to the transmitter — can become plugged with solids or frozen fluid in cold environments, which effectively blocks the signal and prevents measurement of a change in pressure (Figure 2). The transmitter will continue to provide the same pressure reading as before the blockage; by the time this misleading measurement has been discovered, the plugged impulse line already may have compromised safety.

To meet this challenge, a statistical processing technology has been developed that enables early detection of abnormal situations, including plugged impulse lines, in a process environment. The technology is based on the premise that virtually all dynamic processes have a unique noise or variation signature when operating normally and that deviations in these signatures may indicate a significant change in the process, process equipment or transmitter installation will occur or already has. For example, noise may come from equipment such as pumps or agitators, the differential pressure value may show natural variation caused by turbulent flow, or the signature may reflect a combination of both sources.

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The sensing of the unique signature begins by using a high-speed sensing device combined with software to compute statistical parameters that characterize and quantify the process noise or variation. This enables the device to detect significant changes in process noise or variation and then communicate an alarm notifying operators of an abnormal situation. Such early warning allows maintenance technicians to resolve the issue before it affects safety.

SIGNAL QUALITY METRICS

In some level-measurement applications, monitoring for changing surface conditions is critical. Unwanted foam, boiling or emulsions can lead to a spoiled batch, while surface changes that go unnoticed could result in overfilling. Because the materials involved can be hazardous, flammable and even explosive, an overfill potentially can put personnel at risk and cause significant damage to assets and the environment.

When batch processes require both level and surface-condition monitoring, plant personnel may rely on multiple measurement methods. This incurs additional maintenance and calls for more process connections. If a vessel is limited to only one process connection, staff may resort to manual or visual methods of monitoring surface conditions, which can be both time-consuming and unreliable.

To help monitor changing surface conditions, the latest radar transmitters include diagnostics based on signal quality metrics; signal quality values range from 0 to 10, with 10 representing a strong signal and no process noise. A significant change in the signal quality value might indicate changing surface conditions. For instance, if foam is present, the signal quality would drop in value. By sending level and signal quality to the control room as process variables, operators there can monitor these parameters over time. Crucially, this can enable the operators to quickly recognize an unwanted surface change, thus increasing safety by reducing the risk of tank overfills caused by these conditions. Such early detection also helps to maintain high-quality batches and avoid waste or rework, which would cut throughput and raise operational costs.

GROUND AND WIRING FAULT DETECTION

Magnetic flowmeters used in SISs must operate accurately over long periods of time. Flowmeter failure can prevent the SIS from performing as required and necessitate a process shutdown, thereby reducing throughput and profitability. However, issues sometimes can arise. The number one cause — primarily in new installations where the magnetic flowmeter is not referenced correctly to the process fluid — is improper grounding and wiring. This allows the electrodes to pick up electrical noise and, consequently, affects the signal-to-noise ratio and the stability of the transmitter output.

Modern devices feature a ground- and wiring-fault detection diagnostic. If the installation is not grounded or wired properly, the diagnostic will activate, delivering an alert to carefully review the grounding and wiring of the installation. It also can detect if the grounding is lost over time due to corrosion or another root cause.

The transmitter continuously monitors signal amplitudes over a wide range of frequencies. For the ground- and wiring-fault detection diagnostic, the transmitter specifically looks at the signal amplitude at 50 Hz and 60 Hz, the common AC cycle frequencies found throughout the world. A signal amplitude at either of these frequencies exceeding 5 mV indicates a ground or wiring issue exists and stray electrical signals are getting into the transmitter.

ADVANCED TEMPERATURE DIAGNOSTICS

As with magnetic flowmeters, unexpected failure of temperature measurement devices can prevent an SIS from operating as required. By alerting users to a de-

graded sensor or installation condition before measurement failure occurs, advanced temperature diagnostics can protect measurement quality and accuracy and help users safeguard their personnel, facilities and the environment.

These diagnostics monitor processes to identify, report and troubleshoot the impact of environmental influences, sensor failures, and intermittent or abnormal sensor conditions. Some transmitters feature the capability to provide temperature measurement redundancy, thereby increasing safety; the transmitter automatically sends a maintenance alert during primary sensor failure and switches the output to a secondary sensor without impacting the measurement signal.

Thermocouple loops often are installed in high-temperature processes where safety is essential and shutdowns can be extremely costly. Issues such as wire thinning, sensor degradation and corrosion can compromise these loops. A diagnostic that continuously evaluates thermocouple loop status can combat this. It monitors thermocouple loop resistance, detects degrading sensors before failure, and provides alerts when the resistance limit is exceeded, helping to increase process safety and prevent shutdowns.

ENHANCE YOUR LEGACY SIS

The advanced diagnostic information provided by modern measurement devices integrated into SISs reduces the risk of failure that could lead to a process shutdown or result in injury to personnel or damage to assets and the environment. Upgrading the instrumentation used within legacy SISs to take advantage of these diagnostic benefits not only increases the safety of personnel and assets but also can provide a quick return on investment by cutting maintenance costs and downtime.

ANNCHARLOTT ENBERG is Gothenburg, Sweden-based global functional safety manager for Emerson. Email her at AnnCharlott.Enberg@emerson.com.

Petrochemical Complex Reduces Utility Costs

Real-time energy management system saves fuel and cuts emissions

By Rita Trelewicz, KBC

A EUROPEAN petrochemical site wanted to reduce energy costs, increase energy efficiency, decrease emissions, and evaluate alternative processes as part of a digital transformation project. The facility encompasses two complexes. One is a polyolefin unit that includes world-scale polypropylene and polyethylene plants. The other is a petrochemical plant that produces additives, polyvinyl chloride, polymers, extracted butadiene and di-isobutylene.

The operating company contacted KBC. Based on successful projects performed at many similar sites, KBC initially proposed evaluating the facility's complex energy system networks to estimate the benefits of optimizing the networks in real-time. This evaluation justified implementing the energy management system. Once the company approved the plan, KBC completed the model building and configuration stage in approximately four months; the entire implementation project ran from September 2019 until October 2020. The project provided the desired results and achieved a payback period of less than one year.

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BETTER ENERGY MANAGEMENT

KBC recommended and commissioned its Visual MESA (VM) energy management system (Figure 1) to handle the production and distribution of the energy demanded by the process (e.g., steam, power, fuel gas, fuel oil, boiler feed water, and more) to simultaneously decrease costs and emissions, as well as to calculate and historize several energy-related key performance indicators (KPIs). The VM Energy Real Time Optimizer (VM-ERTO) application provided the operating company with multiple benefits including process-energy-demand monitoring, utilities-cost and real-time-emissions optimization, and what-if studies. Furthermore, the system used sensor data for equipment and plant status validation. Thus, the site always knew the operational conditions.

Implementing site-wide energy optimization involved four main stages.

1. *Definition and installation.* In this first stage of the project, KBC held several weekly meetings with the facility's engineering team. These discussions ensured the real-time digital-twin-based optimization model considered all operating constraints and accurately represented the site utility system. The engineers collected data and plant information including energy system diagrams, measurement tags and equipment datasheets. This enabled compiling a list of identified optimization variables and constraints, and evaluating the control system to determine how the identified optimization handles were related to the existing control strategies. Engineers were able to identify the optimization degrees of freedom accordingly.

Then, the VM-ERTO model was installed and connected to real data. It was built to automatically adapt to multiple operational scenarios and enable engineers to compare project alternatives. The team set the model to run automatically every 30 minutes. The model evaluated not only continuous variables but also discrete decision variables such as turbine/motors swaps and other equipment start/stop. By adjusting optimization limits, engineers explored current and future operational scenarios that satisfied energy system objectives.

2. *Modeling and configuration.* The second stage involved the creation of a detailed model of the fuels, steam, power, water, hydrogen and emissions. It was built and validated with real data. Because the system was implemented as open-loop advisory, improvements were made either on a daily or per-shift frequency. Operations staff received custom reports to understand the optimization actions, their impact and real-time monetary savings after implementing each recommendation. The system also monitored the fuels usage and calculated greenhouse gas (GHG) emissions. These usually decreased due to the optimization actions taken and helped the operating company achieve a more-sustainable operation. The energy efficiency improvement observed directly related to the carbon footprint reduction.

Certain coordinated actions in different plants and areas were key to decreasing energy costs and more efficiently managing energy usage. The increased use of a turbogenerator while avoiding steam letdowns sitewide improved overall efficiency and cut electricity demand. Selecting the appropriate turbine and motors helped reduce letdown and vents as well as excess low-pressure steam to the air preheaters. This resulted in lower site total steam demand.

The operating company always used low-pressure steam to run the air preheaters to increase boiler efficiency, which averages 91%. However, the real-time optimizer found that producing this steam at higher efficiency was more expensive than eliminating the steam for air preheating. To reduce the total steam demand for the site, the optimizer consistently recommended that the air pre-heaters only run when low-pressure steam was in excess.

3. *Training of users.* Stage three occurred before the roll-out. Engineers received one-week hands-on training to educate the team on how to navigate the VM-ERTO model, modify it, and access information for the carbon dioxide (CO_2) reduction roadmap assessment. In addition, advanced training took place to ensure the benefits were sustainable. This training taught attendees how to adjust constraints, build and maintain models, add new equipment or measurements, create custom reports and run case studies within the model. Also, the workflows were reviewed.

4. *Acceptance and commissioning.* At this stage, the engineering document that described the model and system was produced. This document helped the operating company maintain the energy management system. Stage four also involved presenting, analyzing and discussing the benefits with the objective of sustaining long-term benefits. After the system commissioning, rigorous screening of many potential project alternatives for CO_2-emission reductions occurred — as did analysis and prioritization of alternative decarbonization projects employing the same model that performed real-time optimization. The engineers reviewed the optimization outputs, economic impact, and the results.

By using the real-time model filled with historical data to evaluate various case studies, the company's engineers prioritized which projects to implement and the appropriate sequence to follow. This helped identify projects related to the site decarbonization program. Staff could estimate the real emission-reduction and operating-cost impact achievable when implementing the projects in the current utility system.

The KBC team adjusted the process units' steam consumption using historical data to a typical annual average for a representative base case. It also modified the VM-ERTO base case model to include four alternative projects: 1) changes in steam recovered in transfer line exchangers; 2) cracking furnaces' fuel gas consumption; 3) low- and medium-pressure dilution steam use; and 4) multiple-stage turbine-driven compressor power. The team reviewed and adjusted optimization limits with an eye to future operational scenarios and energy system objectives such as steam production and transfer between plants, gas and liquid fuels burning, and market constraints.

IMPRESSIVE RESULTS

The VM-ERTO ran automatically and continuously to reduce energy system operating costs and to calculate, validate and historize more than 100 utility-system KPIs. Some of the monitored KPIs included the efficiency of boilers, steam turbines and preheaters, and the performance of heat exchangers.

Specifically, the system recommended the manual implementation of the following optimization actions:

ENERGY MANAGEMENT SYSTEM

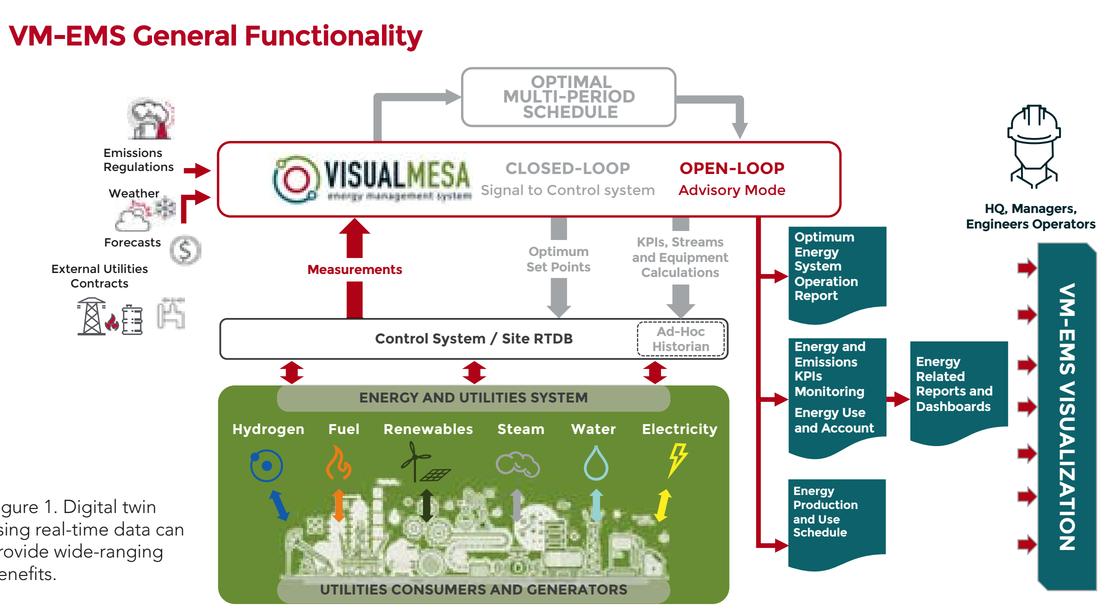

Figure 1. Digital twin using real-time data can provide wide-ranging benefits.

- liquid fuels to steam boilers;
- air inlet temperature to boilers;
- some manual steam letdowns and aerocondenser;
- medium-pressure extraction steam from large steam turbines driving compressors;
- medium-pressure steam extraction and load from a turbogenerator;
- hydrogen management across the network; and
- turbine/motor swaps.

These main optimization handles resulted in changes to the following variables through the control system:

- steam production and fuel gas consumption at boilers;
- steam letdowns and vents;
- import/export of medium-pressure steam to and from the power plant;
- turbocompressors' throughput and condensates;
- turbogenerator's throughput and condensates; and
- fuel gas and hydrogen to flare.

The site used a single real-time digital-twin model to collect all the information and automatically produce optimal actions. Customized reports enabled evaluation and comparison of how proposed changes impacted the energy system on emissions. Operators could easily access these actions via a web-based interface that also allowed everyone company-wide to view the shared information via the Intranet.

The energy manager and site engineers could track overall efficiency performance, cost and emissions in real time. Because the model auto-adapts based on current operating conditions, it continuously provided energy cost-savings even as demand or fuel prices varied.

The digital package optimized the operating company's energy usage across its entire site to reduce operating costs and meet emission reduction targets. Specifically, by using the VM-ERTO application, the site decreased energy costs by roughly 1.7% during normal conditions. When operating under abnormal situations, the facility reported additional savings of up to 7%. In addition, it lowered overall site fuel consumption by 1.5% and, consequently, GHG emissions by ≈1%. These findings suggest that using an energy digital twin is key for site-wide energy optimization at industrial complexes. It helps coordinate plant areas and leverage synergies to maximize profits. ●

RITA TRELEWICZ is a product marketing manager for KBC (a Yokogawa company), Houston. Email her at Rita.Trelewicz@kbc.global.

Conquer a Control Valve Crisis

Proper temperature regulation is crucial for product

INSPECT THE HEAT EXCHANGER

A number of operational changes could have caused the problem of burnt product. Consider the following possibilities:

Viscosity data show higher viscosity at higher temperature; this suggests some type of reaction leading to more-viscous product and resultant fouling problems. Since the exchanger was working okay until about three months ago, maybe feed composition has changed.

Because the exchanger is old, it might have developed tube leaks, allowing direct contact of the heating medium (steam) with the process liquid, causing thermal degradation. Sample the process liquid exiting the heat exchanger to check for leaks.

Rapid swings in the steam valve could result from controller response to unstable liquid flow through the tubes. Another possibility is that the temperature controller settings (gain, reset, rate) may be too high. Still another potential cause of the rapid swings of the control valve is too-tight valve stem packing. (This can cause delayed but rapid swings in valve position.)

The temperature of 150-psig fully or partially saturated steam is 366°F. Depending on your temperature requirement for the liquid exiting the exchanger, a high temperature gradient across the tube wall could be causing thermal degradation of the liquid film close to the tube wall. For a given process temperature, you can estimate temperature gradient across the tube wall and the temperature of the heating medium. This, in turn, will determine suitable pressure of the saturated steam. Of course, lower temperature (less than the 366°F of the 150-psig steam) will cut the capacity of the heat exchanger — but may allow you to limp along until the next outage.

Although wet steam has the same temperature as the saturated steam, excessive water (wet fraction) reduces heat transfer. Ensure any steam traps upstream of the heat exchanger are working okay. If there are no steam traps, manually drain the condensate. Of course, for your heat exchanger, the controlling heat-transfer coefficient is on the viscous liquid film; thus, condensate removal from steam may show only moderate improvement in heat transfer.

See if there are viscosity stabilizers you can use without affecting product quality. If successful, these chemicals (stabilizers) also could help reduce or dislodge the existing fouling deposits.

GC Shah, consultant
Houston

CONSIDER VALVE STICTION

The poser of this problem makes reference to the control valve swinging open more quickly than what was experienced in the past. This could be a sign of stiction in the valve operation. Opticontrols gives a good description of this problem. Here is the link: https://bit.ly/36sF6WG.

Douglas M. Price,
ChE Program Coordinator,
Youngstown State University, Youngstown, Ohio

THIS MONTH'S PUZZLER

Our plant's old heat exchanger is showing its years. It's a shell-and-tube exchanger with two passes for the tubes and one pass for the shell. A sticky product with a viscosity of 120 cP at 280°F and 80 cP at 150°F goes through the tubes. The density is 0.88 and 0.84, respectively, and the mass heat capacity is 0.82, and 0.9. I estimate a thermal conductivity of about 0.025 BTU/hr-ft-°F at about 100°F. Semi-saturated steam at 150 psig goes through the shell.

In the past three months, operators have noticed burnt product. Looking at the valve performance from trends, the steam valve seems to swing open more quickly and tries to throttle quickly down. Maintenance blames routine fouling. The next outage is due in six months. So, the manager says to run the product a little cooler going into the exchanger. The process engineer warns the pump can't handle that. The production manager complains the steam traps aren't being replaced when they stick open.

I'm not convinced by any of these arguments. The traps are working. While the pressure drop across the tubes is higher than before, we don't have a good flow meter on the product so there's no way to know what normal is.

What do you think is causing the problem? How should I approach my investigation? Is there a way to limp through until the next scheduled outage?

IT'S THE CONTROL VALVE

Sudden changes usually mean control issues: loop tuning; fouling of instrument; corrosion causing higher resistance in 24-V DC leads, etc.; or control valve problems.

Remember, a control valve is a mechanical device. Failures include: friction between the stem and stem packing — this actually could explain the wild swings as the spring resists to keep the valve closed and the air pressure builds to a point where it can force the stem to turn, causing an excess response that the control loop will fight; poor lubrication or dirt inside the actuator; and, of course, flashing and cavitation. You can inspect the actuator while the system is operating, provided the installation allows access.

You can diagnose mechanical friction by "bumping" the loop setpoint (SP), i.e., changing it a %, and watching for the desired response. The last two symptoms require an inspection of the wet parts of the valve. For additional information refer to: https://bit.ly/3Eoh77m. It is worth the trouble to witness the control valve in operation: a noisy valve points to flashing or cavitation — mixed-steam and condensate causing damage to the valve seat; as always, inspect the air supply and installation. Also, a good set-up has pipe supports on either side of the valve.

Now, let's consider how you can make product until you can afford to shut down. Given how viscosity raises the horsepower requirements of centrifugal pumps, I have to agree with the process engineer: lowering the

JULY'S **PUZZLER**

We use a conveyor belt dryer for drying our slurry to a fine powder that then falls through a chute to a bagger below (Figure 1). The product goes into either super sacks or 40-lb paper bags.

The problem is clumping; it is less of an issue in the winter, when static electricity is a problem, but always an issue in the summer. We've tried increasing the vacuum for the second conveyor and the air temperature for the first conveyor but, inevitably, we wind up slowing down the first conveyor as much as possible; it's on a variable frequency drive (VFD), which helps in the winter but less so in the summer. The second belt also is on a VFD.

We installed bangers on the product bin to break up clumps and a vibrating sifter that shakes out usable product that then is fed to the baggers; oversize material from the shaker goes to a recycle system. Dust is a real problem at the baggers with combustible Class-G dust collecting around our sifter and the baggers below.

Other problems include terrible corrosion of the carbon steel frame in the first section and moisture in the product bins below that feed the baggers. Besides the performance issues, operators are complaining about being too cold in the winter and about the humidity in the summer.

I'm at my wits end. What can be done to reduce waste in this system?

Send us your comments, suggestions or solutions for this question by June 10, 2022. We'll include as many of them as possible in the July 2022 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.

BELT DRYER

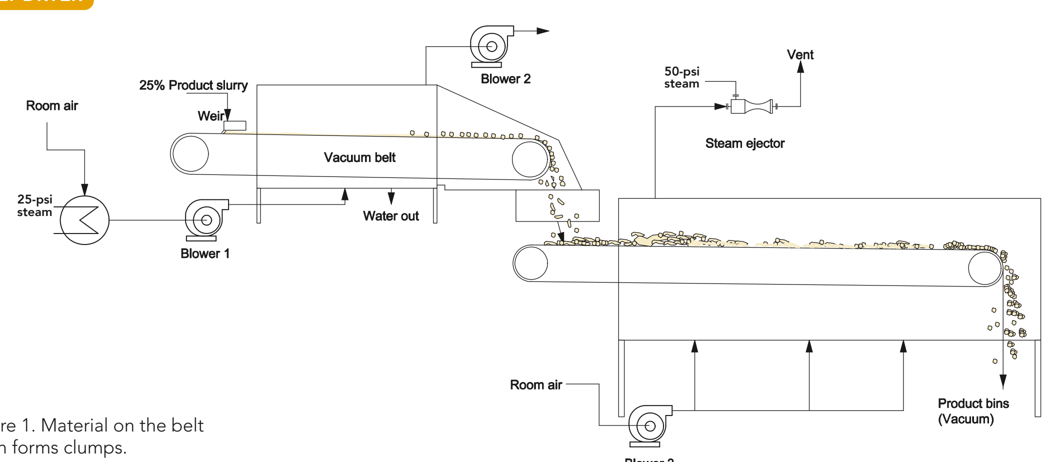

Figure 1. Material on the belt often forms clumps.

temperature won't help you. Besides, you may not want to chance how this will affect the system downstream from the heat exchanger; assessing this could involve a heat-and-energy balance of the entire process — upstream of the exchanger to the final product.

It's probably not the steam traps, although you should look at them first. If it is the traps, bypass them, and leave the valve at the end to the sewer partially closed to let the exchanger act as the trap. Of course, this means wasting a lot of steam if you recover the condensate. It also means getting a permit if there's a chance of a toxic chemical leak in your system: sample the stream before you assume it's safe to put down the sewer.

It never hurts to check the steam supply to the control valve. A broken steam trap upstream of the control valve causes all sorts of problems, such as cavitation and loop saturation. Check this when you inspect the exchanger steam trap. If this is the problem, then bleed out the steam/condensate upstream of the control valve immediately before and for a few minutes after start-up. Then, periodically bleed out the steam for the upstream trap, say, on an hourly basis, to avoid the temperature flux you witnessed.

A more-radical approach to get the desired performance out of a control valve is to manually control its air supply and raise the steam pressure upstream of the valve. If you can model this in a simulator, try it. However, don't put too much stock in mathematical models alone; they can navigate the way but some course corrections are to be expected. Remember temperature control in manual is tricky business.

Dirk Willard, consultant,
Wooster, Ohio

CHECK OUT PREVIOUS PUZZLERS

To see all the Puzzlers that have been published over the years, go to: www.ChemicalProcessing.com/voices/process-puzzler/.

Stop Slug Flow

The Froude number can offer important insights

The first step in evaluating two-phase flow is determining the flow regime.

A PLANT temporarily had reduced rates. This resulted in pipe shaking and vibration severe enough to raise concerns about equipment damage and safety. The suspected cause of the shaking was slug flow in a vertical line from a condenser (at grade) to a drum above it. Attention immediately turned to how to reduce the shaking and vibration.

Grappling with this required use of a dimensionless number, the Froude number, to help understand two-phase flow. In general, the Froude number is the ratio of inertial forces to gravitational forces acting on some characteristic mass — it represents the ratio of kinetic energy to potential energy in a flow system. The exact parameters used and equation of the Froude number depend upon the application, which can include bubbling in gas-fluidized beds, falling films, gravity waves in liquids, entrainment from surfaces, open-channel flow, resistance of floating objects in flow, two-phase flow, self-venting nozzle sizing and others. (For its use with gravity-flow systems, see my previous column: "Assess the Gravity of the Situation," https://bit.ly/37grbTn.)

Understanding two-phase flow is particularly difficult. Depending upon the flow direction (horizontal, vertical up, vertical down, sloped), different flow regimes exist. The flow regimes may include bubbling, slug, stratified, mist or others. The flow rates of each phase as well as physical properties determine the regime present. Multiple flow regimes may occur in the same pipe — for example in gas/liquid flow, if pressure drop reduces vapor density, the flow regime might change from slug to annular/mist.

The first step in evaluating two-phase flow is determining the flow regime. Calculation methods generally rely on a flow-regime or flow-pattern map for this. After calculating parameters based on system properties and flow rates, the flow regime is found by checking the map. The best known of these is the Lockhart-Martinelli flow map from 1949. It and its derivatives are the most-common flow maps used for horizontal liquid flow.

Options for alleviating the problem depend upon how far away the operation is from a transition point from slug flow to a more-stable flow pattern. Different correlations and flow maps often offer disparate answers. Here, five correlations gave three contrasting answers on expected flow regimes. Why is this?

Correlations proposed for the two-phase flow use maps based either on experimental results, theoretical calculations or a combination of these. Test data also show inconsistencies among work done on supposedly similar systems. Moreover, nearly all the experi-

GRIFFITH-WALLIS FLOW MAP

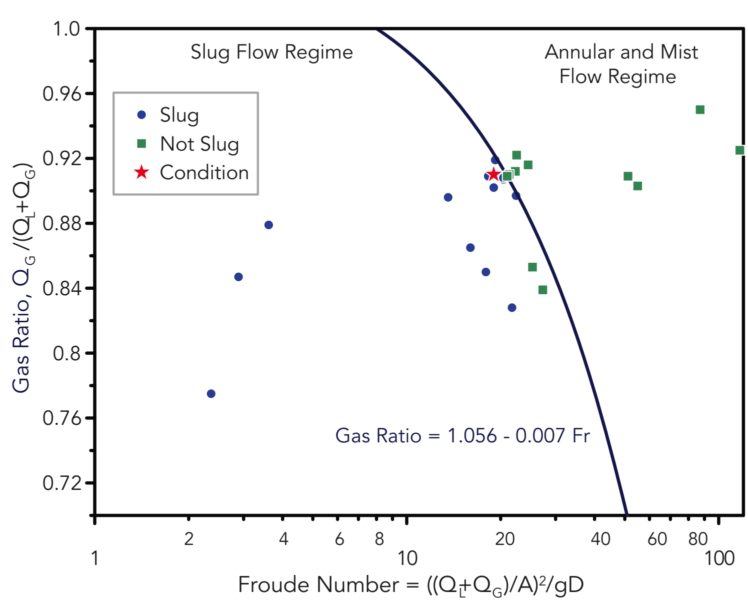

Figure 1. Location of operating point of problem system (shown by star) indicated a small amount of inert gas would stop slug flow.

mental data are based on 0.5–1.25-in. inside-diameter pipes with air/water or air/steam systems. Extrapolation to very different industrial systems can result in high uncertainty and extreme errors.

Figure 1 shows a section of the Griffith-Wallis flow map for a narrow gas-ratio range (~0.75–0.96) based on volumetric flow ratios versus Froude number. (As long as consistent units are used, both axes are dimensionless numbers.) The original correlation was based on a mix of data in small pipes (0.5–1.0 in.). However, data from commercial units (6–8-in. pipes) with hydrocarbons have been added. The data were a very good fit of gas ratio versus Froude number.

In the figure, a star shows the operating point of the problem system; it is very close to the transition line. Because higher-volume gas flows move the operating point up and to the right, injecting a small amount of inert gas into the system eliminated the slugging problem. This injection ended once normal operating rates were re-established.

This map seems a good fit here — but its applicability may not extrapolate to other conditions.

Numerous elements, including pressure drop, void volume, and slug size, play a role in two-phase flow that may be important in specific situations. In this case, understanding of flow regime sufficed to stop the slug flow.

The situation here highlights another important issue: for vertical upward gas/liquid flow, it's often better to round pipe sizes down rather than up because too large a line size may lead to slug flow. Sometimes, to avoid slug flow, using multiple parallel lines (with valves to remove some from service) may make sense.

ANDREW SLOLEY, Contributing Editor
ASloley@putman.net

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PUBLISHING HEADQUARTERS

1501 E. Woodfield Road,
Suite 400N
Schaumburg, IL 60173
Phone: 630-467-1300
Fax: 630-467-1109
www.chemicalprocessing.com

Brian Marz
Publisher
E-mail: bmarz@putman.net
Phone: 630-467-1300, x411

Carmela Kappel
Assistant to the Publisher
Phone: 630-467-1300, x314
Fax: 630-467-0197

SALES

FAITH ZUCKER
District Manager
Digital Sales Manager
Email: fzucker@putman.net
Phone: 216-316-8203

CLASSIFIEDS/AD-LITS

PEGGY HARRINGTON-MARZ
Inside Sales Manager
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REPRINTS

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Can Industry 4.0 Drive Sustainability Goals?

A study reviewed empirical data and surveyed companies from three countries

Their findings are a mixed bag.

INDUSTRY 4.0 needs more political clout if it is to realize its full potential, say the authors of a recent study published in *Sustainable Production and Consumption.*

The Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany, carried out the study to investigate the potential of Industry 4.0 to support the decarbonization and dematerialization objectives needed for industry to meet sustainable development goals (SDGs). It also generated empirical data to "reflect on the few and ambiguous assumptions about the effects of Industry 4.0 on environmental sustainability currently existing in the scientific literature." The IASS, a research and consultancy group, helps organizations and the United Nations (U.N.) meet their SDGs.

Lead author Grischa Beier and his co-workers started their study knowing little empirical evidence exists to substantiate the assumption that digitalization will make industrial production more sustainable. Beier has a background in mechanical and systems engineering and heads up the IASS research group on digitalization and impacts on sustainability.

Their literature search found a number of studies predicting Industry 4.0 will enhance energy and material efficiency while also accelerating the integration of renewable energy forms in industrial manufacturing. At the same time, however, they discovered a growing body of literature urging caution about assuming sustainability benefits are a foregone conclusion. Rather, they need to be actively integrated with the digitalization strategies of the respective companies.

Other research suggested if the adoption of digital technologies isn't steered in the right direction, it could make production more resource-dependent, as opposed to more environmentally sustainable and climate-friendly.

To test Industry 4.0's ability to support decarbonization and dematerialization, Beier's team surveyed company representatives in China, Brazil and Germany; all three countries regard digitalization as an important driver for economic development, and have government strategies in place to develop policies and investment needed for its success.

The team canvassed across a range of industrial sectors and company sizes. Their findings are a mixed bag.

For example, the majority of industry representatives contacted expect Industry 4.0 technologies will have a positive impact on their companies' environmental sustainability. Companies in Germany and Brazil with more than 5,000 employees have the most positive overall expectations.

On the other hand, actual experience with digitalization, in terms of resource efficiency and energy consumption, does not entirely support such optimism.

"Our findings suggest expectations are overly optimistic in companies that still have little actual experience with Industry 4.0 technologies. Companies that reported higher levels of Industry 4.0 implementation had more moderate expectations with respect to actual energy savings," explains Beier, adding that this validates other studies which found little evidence to support expectations of achieving significant savings across the board.

More positively, Industry 4.0 helps companies better align production with demand; firms with a high level of digitalization are well-positioned to improve their sustainability performance in other areas. In fact, the greater a company's digitalization, the better its ability is to align production with actual demand.

In addition, improved digitalization increases companies' willingness to align production schedules with the availability of renewable electricity. According to the researchers, these so-called demand response schemes are an important prerequisite for the stabilization and efficient use of future renewable energy systems.

While the authors acknowledge their results paint a mixed picture, they say it is clear the widespread uptake of Industry 4.0 offers opportunities to improve environmental sustainability. They believe their findings will most help those involved with implementing Industry 4.0 to better understand the trends that affect it. However, they caution implementation must be critically evaluated against the U.N. SDGs.

"The mere digitalization of production processes will not suffice to advance the transition towards a more sustainable economy. To take full advantage of the potentials of digitalization for corporate sustainability management, it must be flanked by supporting government regulations and incentives, including the establishment of binding targets for saving energy and materials," adds Beier.

Only then will a digitalized industrial production be able to serve people without harming the environment, he concludes. ●

SEÁN OTTEWELL, Editor at Large
sottewell@putman.net