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Survey Shows How

Job Satisfaction Stacks Up

Salary and satisfaction remain steady, even optimistic, amidst the pandemic's impact

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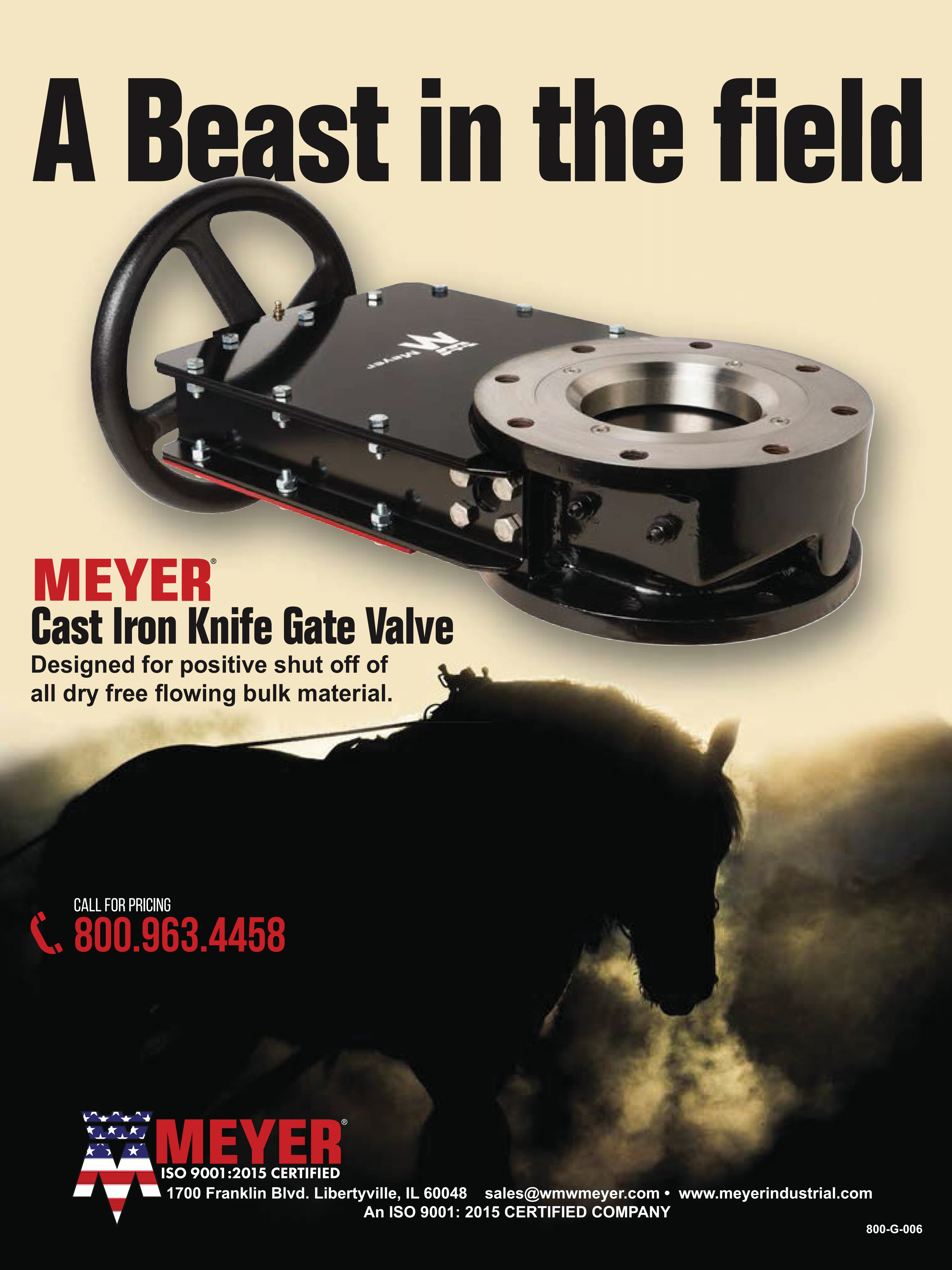
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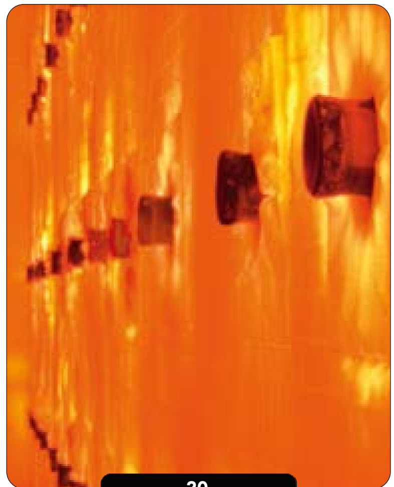

20

24

COVER STORY

14 Survey Shows How Job Satisfaction Stacks Up
The average annual salary reported this year showed a drop. However, the higher proportion of younger engineers in our sample likely is a major reason for this. Most survey participants feel confident in their job security and their compensation.

FEATURES

DESIGN AND OPTIMIZATION
20 Interest in Electricity Heats Up
Electricity now is attracting increasing attention as a means to heat process streams instead of using steam or other heat transfer fluids. Here's a look at what's sparking the interest as well as some significant current initiatives.

MAINTENANCE AND OPERATIONS
24 Veto Vibration in Rotating Equipment
Rotating equipment always has imperfections that cause some unbalance. In addition, vibrations can arise from misalignment, forces from working fluids, etc. Following some practical pointers can avoid or minimize problems.

INSTRUMENTATION AND CONTROL
27 Optimize Combustion Using a Digital Twin
Many processes rely on fired assets such as boilers, furnaces and heaters. Use of a digital twin can improve their operation. This article covers some common opportunities that a digital twin can assess without real-world risk.

MAKING IT WORK
31 How Good Are Techniques for Handling Abnormal Situations?
Both alarm management and safe park (upset automation) are viewed as ways to improve plant performance during an abnormal situation. A study with real operators provides perspective on the impact of both techniques.

COLUMNS

7 **From the Editor:** Add Industry Perspective to the CSB

8 **Solid Advice:** Start with the Right Equipment

9 **Field Notes:** See the Positive Side of Insecurity

12 **Energy Saver:** Drive Energy Efficiency with Decarbonization

13 **Compliance Advisor:** EPA Announces Blockbuster PFAS Actions

36 **Plant InSites:** Don't Skip Development Steps

42 **End Point:** Is a Circular Economy Really Sustainable?

DEPARTMENTS

10 **In Process:** Hybrid Catalyst Targets End-of-Life Plastics | Carbon Dioxide Conversion Gets New Option

34 **Process Puzzler:** Mind the Mettle of Packing Materials

37 **Equipment & Services**

39 **Ad-Lits & Classifieds**

41 **Ad Index**

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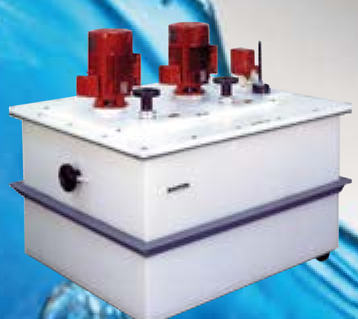
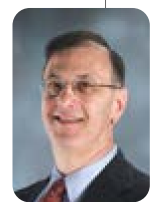


Add Industry Perspective to the CSB

The U.S. Chemical Safety Board needs a process safety expert on its board



No prospective member of the CSB board has process safety experience.

THE BIDEN Administration in late April nominated three people to serve on the board of the U.S. Chemical Safety and Hazard Investigation Board (CSB). Right now, the board only has a single member, chair Katherine Lemos, who has a background in aviation safety; she was nominated by President Trump in 2019 and confirmed by the Senate in 2020. If the Senate approves the three, the board still will remain one short of its full roster of five members.

Here's some background on the three nominees:

- Sylvia E. Johnson now works for the National Education Association, currently heading its legislative efforts for the safe reopening of schools. Before that, she served in the legislative affairs department of the United Auto Workers union, where she was involved in occupational safety and health issues. Her educational background includes a masters in biomedical engineering with a concentration in industrial hygiene.
- Steve Owens is an attorney specializing in environmental, health and safety issues at a law firm. He previously — from 2009–2011 — served as assistant administrator for the Office of Chemical Safety and Pollution Prevention at the U.S. Environmental Protection Agency. Prior to that, he was Director of the Arizona Department of Environmental Quality.
- Jennifer Sass is a senior scientist at the Natural Resources Defense Council, where she has worked since 2001. Her brief includes explaining the science behind toxic chemical regulation and advocating for regulations consistent with science, health policy and environmental law. She holds a post-doctoral certificate in human health and the environment.

The bolstering of the CSB board is long overdue. The nominees have a strong interest and background in human health and safety. They lack any experience in process safety, though.

CSB staff, not board members, investigate incidents, identify the causes and report lessons to be learned. However, the board sets direction and priorities, so an appreciation of process safety issues certainly would help the CSB best meet its mission.

This gap prompted the American Chemistry Council to issue a statement:

"Process safety experience is critical to an effective Chemical Safety Board. We are disappointed that the current slate of nominees lack sufficient experience and familiarity with industrial process safety practices or chemical manufacturing operations...

"The CSB has the important job of conducting complex investigations of major accidents and making recommendations, which is why it must be managed by qualified board members. We urge the Administration to work with industry and other stakeholders on advancing nominees with the requisite skills and experience to successfully carry out the CSB's valuable work."

I don't recommend withdrawing the current nominees. Instead, I urge the Biden Administration to fill the remaining slot on the board with someone intimately familiar with the chemical industry and its particular safety issues. Plenty of eminently qualified candidates exist. For starters, someone from the White House might want to look at authors of process-safety-related articles in *Chemical Processing* and presenters at the annual International Symposium of the Mary Kay O'Connor Process Safety Center at Texas A&M University. ●

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Start with the Right Equipment

Having good physical properties will improve selection

Sometimes simpler is better — but not always.

I'VE NEVER seen a piece of equipment that didn't do what it was supposed to do. That doesn't mean it did what its user thought it could do. In solids processing we often struggle with a piece of equipment because it was a poor selection or installed improperly or because we don't want to spend the money for modifications so it can do the job right. The most common example of this type of mistake is installing something that would work fine on another product but not on the one you want to make. Usually, insufficient physical property data are to blame.

A fluid bed is a wonderful device for drying solids — but it doesn't like sticky substances thrown at it. You can modify the dryer to handle sticky materials. However, this involves adding another component, such as a disperser or flash-dryer, to the system. An even better approach is to evaluate the sticky point (see "Surmount Sticky Situations," https://bit.ly/3yNc11i) during drying tests and maybe select a different dryer, such as a ball mill.

Physical property data are difficult and sometimes costly to obtain when working with solids. Knowing what to get for a particular technology isn't always obvious, as in the case of crystallizers ("Get a Solubility Curve," http://bit.ly/2JR2P5M). There are many elusive physical properties of solids other than stickiness. Most of these have simple ways to determine the property, or at least get a feel for where that property may cause a processing problem. A good example is de-aeration. A particulate solid that de-aerates slowly is a great choice for a fluid bed or pneumatic conveyor but doesn't work well on a belt conveyor. Mixing in some larger particles can be a disaster because those particles can drop to the bottom of a container or segregate from the mix.

We had an extruder that was fed three different sized particles — one was fine and de-aerated in about 20 minutes while the other two were much larger. At first, we thought about using a blender or maybe a hopper to feed the extruder. A couple of trials on a small-scale convinced us that the only solution was to have no blend or surge capacity because the larger particles segregated too rapidly. Our solution even saved on the cost of the added equipment. Sometimes simpler is better.

A plant in a foreign country had purchased a piece of used drying equipment that was performing poorly. In those days, before the Internet enabled remote troubleshooting, it was difficult to diagnose the problem without a visit. The installation seemed to have enough capacity and heat input. Upon arrival, I saw the problem. This screw-style dryer had a single feed for the heating fluid that was split between the heated screw and the jacket. The plant relied on a manually operated valve to adjust the ratio of heating fluid going to the jacket and the screw; most of the fluid went to the jacket. It turns out the drawings the plant sent me were from the previous owner; it had a controller on the jacket as well as for the screw. Sometimes simpler is not better.

EXPLORE ISSUES POSED BY SOLIDS

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

Find out the questions others have had about solids processing — and the answers to them — and pose your own questions by visiting www.ChemicalProcessing.com/experts/solids-processing/.

You must consider your workforce when selecting a new piece of equipment or even modifying a device. The expression "We have our ways" comes up all too often at project planning meetings. What's worse is hearing, "We know the problems of this device and how to respond. A new device would bring new problems." This latter opinion has a lot of merit in solids processing as we never can identify all potential problems. We just need to consider them in the design. When promoting a new type of equipment, I lobby management to send the operators to a site already using the device. (Of course, I cherry-pick the location.)

A classic example was when I suggested a fluid bed to replace a rotary drum dryer. The workforce knew how to replace the broken hammers with minimal downtime and didn't mind hauling an entire load of product made unusable because of overheating or agglomeration. I took them to a vendor to observe our material and, later, to a facility that had replaced a rotary dryer. They endorsed the fluid bed and made some new friends. Oh, by the way, they got the right equipment.

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See the Positive Side of Insecurity

Review of past decisions can show if they really were right

Second-guessing can lead to a better product.

THE JAPANESE company I worked for during an expansion project periodically reviewed previous decisions. While this drove the American managers nuts, I realized that it was a wonderful idea — if you have the heart for it.

During this exercise, all our past choices passed muster but that wasn't a given. The tank layout had changed a little; operators wanted more room to make sampling easier. Revisions to the stainless steel containment made the walls taller and reduced the area to prevent tripping.

This step, which I call second-guessing a project, can create opportunities to improve it. Chances are that not everyone who might use the equipment being installed was available during project review. In addition, decisions cause ripple effects. For example, eliminating the local read-out on an instrument might save a few dollars but force an operator to rush into the control room or wait on the radio for a reading while sweating in the hot sun.

I can hear the nay-sayers now: "Anytime you give operations time to change a scope, the budget leaps out of control." However, if you followed my advice on budget estimating by taking the highest bidder ("Processing Equipment: Pad Your Cost Estimate," https://bit.ly/3zrwU2u), you'll have included some fat. Spend it to make a better product. Besides, nobody will remember that you saved two hundred dollars on the local read-out; the success of your project depends on whether it works!

Second-guessing should include all phases of a project, from design to handover. These reviews also should create a list of countermeasures, i.e., plans for addressing potential problems, another idea borrowed from Japanese engineering practices. Countermeasures answer the "what-if" questions in the project. For example, how will you make up production if one of the centrifuges you're installing goes down? Or, have you selected the right vendor if its repair facilities are much further away than those of competitors? Second-guessing means bringing up previously closed problems, examining them, and possibly discovering overlooked or forgotten questions.

To structure a review like this, use a template for a what-if hazard and operability (HAZOP) review as inspiration; I recommend "Safety and Security Review for the Process Industries: Application of HAZOP, PHA, What-If and SVA Reviews," 4th ed., by Dennis Nolan.

Start with:

a) What happens when the power goes out?;

b) What if freezing occurs?;

c) How would a "once-in-a-100-year-intensity" flood affect the project?;

d) How would disruptions to the supply chain impact the project? (Consider the current cut in automobile production because of chip shortages.);

e) Is the startup or shutdown clunky?;

f) Is it simple to expand the project at a later date?;

g) Can the equipment be turned down easily?;

h) How susceptible is the project (product) to fouling or contamination?;

i) Can you reduce the volume of any problematic process waste?;

j) Should you use rupture discs instead of relief valves for pressure relief of some equipment (e.g., ones with viscosity issues)?;

k) Are utilities adequate? (Think summer and winter, remember reliefs, vents and drains.);

l) Are the materials of construction correct and what are the choices based on (coupons or literature references)?;

m) Have you properly allowed for corrosion? (Opting for a thinner wall of a more-corrosion-resistant material may seem sensible today but trading thickness for resistance may look like a dumb choice later.);

n) Does the design make it easy to insulate, replace, modify and install?;

o) Is your sampling and instrumentation barely adequate (without redundancy) or excessive (swamping the control system with inputs)?;

p) Are safety settings too close to operating conditions (raising the risk of alarm overloads)?;

q) Are your safety countermeasures (showers, grounding, etc.) correct?

After you've compiled a list, send it to the stakeholders. Don't be surprised if they ignore it.

Take a walk and ambush a few people! Walk in with a quick presentation of your project to refresh their memory. Spark their interest by asking what they think the project goals are and do they see anything that could trip up the effort. Use this process to scope out your list of potential problems. Once you've got the input you need, compile it into a memo; circulate it and amend your scope if needed. ●

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Hybrid Catalyst Targets End-of-Life Plastics

Tuning of one or both constituents can increase yield of particular polymers

SINGLE-USE PLASTIC waste, such as bottles and food containers, can provide ready-to-use molecules for creating jet fuels, diesel and lubricants, thanks to a hybrid catalyst, report researchers at the Center for Plastics Innovation (CPI) at the University of Delaware (UD), Newark, Delaware. Their method uses low temperatures, thus saving two to three times the energy needed and doesn't emit carbon dioxide, they say.

"The catalysts can handle various plastics and mixtures and perform almost equally well. We also can regenerate and reuse the catalyst," notes Dion Vlachos, who led the project and also directs the Delaware Energy Institute and the Catalysis Center for Energy Innovation at UD.

The process, reported in a recent issue of *Science Advances,* uses a hybrid dual catalyst combining zeolites and mixed metal oxides to quickly break down polyolefins. The team subjected the plastics to hydrocracking at 250°C to break them down into smaller carbon molecules, then added hydrogen molecules on either end to stabilize the material for use.

"This makes them ready-to-use molecules for high-value lubricant or fuel applications," states Vlachos.

The dual catalyst can be engineered in multiple ways to tune product distribution and provide higher yields for particular polymers. "We can choose each of the components from a library of materials to make different products… and easily vary the percent of each component. For example, we can make zeolites with larger or smaller pores. These allow larger or smaller molecules to enter the pores and crack and thus to make more diesel or more gasoline. As another example, we can vary the weight percent of Pt and WOx and tune the support and change the synthesis to vary the proximity of each component in the PtWOx catalyst," Vlachos explains.

Using the dual catalyst on a larger scale poses no issues, say the researchers. "Having a dual catalyst gives you more freedom to optimize each component to make the right product. Many real-world processes run with multiple functions on the same material or multiple materials," notes Vlachos.

HYDROCRACKING PROCESS

Figure 1. Low-temperature treatment breaks down shredded plastic into smaller carbon molecules used to create jet fuels, diesel and lubricants. *Source: University of Delaware.*

The catalyst materials are inexpensive and well-known to industry, making their use in manufacturing straightforward, believe the researchers. "We can create small systems that can be deployed all over the country," adds Vlachos. However, translating the method to industry will require more work, he admits.

For example, any impurities in an actual waste plastic could deactivate the catalyst. "Solving this problem can overcome all main barriers to commercialization. We have made significant progress on this front that we will publicize in the near future," hints Vlachos.

Heating plastics is another hurdle. "It takes 10–100× more than other materials because they don't allow heat by conventional means or microwaves to penetrate. This means 10× to 100× bigger reactors and much larger cost. We need to solve this challenge," he acknowledges.

In the meantime, tremendous potential exists for multiple component catalysts to treat different plastics and multiplastics all in one pot. "This is the ideal scenario because polyolefins are one thing in large fraction but other plastics have functional groups, including chlorine, oxygen, etc., and targeting the catalyst for these can better optimize mixed, real-world streams. Whether we treat them all in one pot or in sequence needs optimization," says Vlachos.

The researchers have focused mainly on polyolefins, but plan to explore the method's ability to combat other polymers such as polyethylene terephthalate, polyvinyl chloride and polyurethanes, in addition to additives, dyes, etc. "It is important to extend the catalyst composition and the process to handle all of these," he stresses.

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How would you characterize your site's interest in using drones for inspection?

More than one-third of respondents report a moderate or higher interest.

Carbon Dioxide Conversion Gets New Option

A STABLE, relatively cheap perovskite catalyst (Figure 2) opens up a novel route to convert carbon dioxide (CO_2) into useful substances such as methanol, other chemical base materials and synthetic fuels, claim its developers at the University of Vienna, Austria.

Researchers led by Christoph Rameshan at the Institute of Materials Chemistry of the university have focused on the reverse water-gas shift (rWGS) reaction that converts CO_2 and hydrogen into water and carbon monoxide — with the latter capable of further processing.

"We tried out a few things and finally came up with a perovskite made of cobalt, iron, calcium and neodymium that has excellent properties," he says.

The host lattice of the perovskite itself is active for the WGS and rWGS reactions. The key to the high activity achieved is doping it with cobalt, which is easily exsolved under rWGS conditions. Importantly for the rate of catalytic reaction, the nanoparticles formed by exsolution are finely dispersed across the surface and not prone to sintering.

"The advantages easily compensate for the slightly more complex synthesis route. To really quantify the benefits, we would need additional testing in a pilot plant, which we are currently preparing," notes Rameshan.

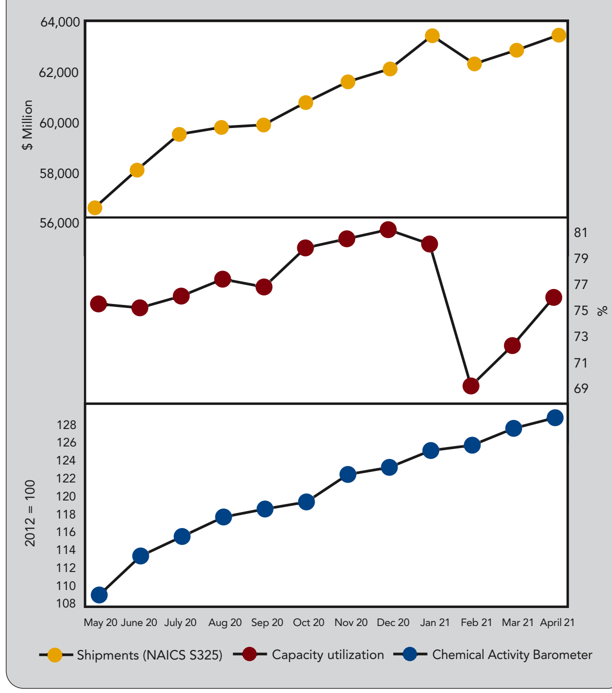
His team now is trying to improve the reactivity of the catalyst, including by tuning the exsolution properties to control the temperature at which nanoparticles form during the rWGS reaction. This could boost catalyst performance by a factor of 10–50 times, Rameshan believes. He also has found a replacement for the expensive neodymium currently used and is actively searching for new dopants.

To be economically feasible, the reaction would need coupling to a large source of CO_2 such as a power or chemical plant, he reckons.

"From an engineering point of view, all the technology is available. The two most crucial parts are: on the one side, the supply of the required hydrogen — that can be produced ideally by electrolysis — as this is a cost-intense factor; and the production of our catalyst on an industrial scale is still missing. For this, we just started a cooperation with a chemical engineering department to go to the next scale with a lab-scale demo plant."

Rameshan already has contacted industrial companies and is confident this will lead to future cooperation and funding.

ECONOMIC SNAPSHOT



All three metrics continued to rise. *Source: American Chemistry Council.*

PEROVSKITE CATALYST

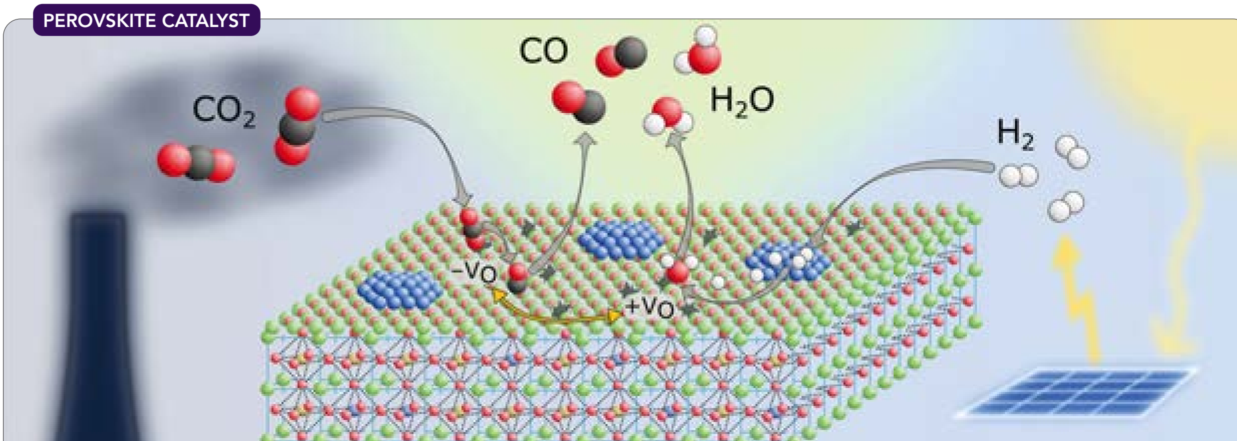


Figure 2. Material offers a tunable host lattice for efficient CO_2 adsorption. *Source: Applied Catalysis B: Environmental, 5 September 2021.*

Drive Energy Efficiency with Decarbonization

Three potential approaches could reduce both carbon dioxide emissions and energy costs

Many challenges to achieving deep decarbonization still exist.

I STARTED my career in the chemical industry in the wake of the 1970s oil crisis. Rising energy prices loomed forever. Companies were scrambling to save energy to stay profitable.

Times change. Comparatively low energy prices now make it much harder to justify projects based on energy cost savings alone, especially in the United States. However, another driver has emerged — decarbonization, the reduction of emissions of carbon dioxide and other greenhouse gases.

Unlike most other approaches to decarbonization, energy efficiency reduces operating costs. This makes it a very attractive option. However, energy efficiency has limits. Some of these are due to fundamental science: there is a thermodynamic minimum energy requirement for every process. Others are economic: many processes have practical limitations that are prohibitively difficult and expensive to overcome. To achieve the deep decarbonization society now demands, we must supplement energy efficiency with other approaches. Three leading candidates have emerged:

Electrification. Almost all heating in oil refineries and chemical plants is done by burning fossil fuels in boilers and furnaces; steam turbines or gas turbines drive much of the power requirement. These are the main combustion-related sources of CO_2 emissions.

Replacing fired boilers and furnaces with electric boilers and furnaces, and turbine drivers with electric motors, in principle can eliminate most of these emissions. New technologies, such as electric reactors, also are emerging. However, both the capital costs and operating cost typically are higher for electrical equipment. Also, for some applications (e.g., cracking furnaces), no commercially demonstrated electric technologies exist, although research and development is ongoing (see: "Interest in Electricity Heats Up," p. 20).

Electrifying all of this equipment would greatly increase the electric demand at each site. It would mandate expansion of onsite electrical infrastructure and the offsite electric grids that serve the industry. In addition, it would require new low-carbon or carbon-free power generating facilities. Without them, plant electrification would simply move the carbon emissions to power generation facilities.

Hydrogen. When pure hydrogen burns, it produces no CO_2 — only water. This makes it an obvious candidate as a decarbonization fuel. However, achieving deep decarbonization would require commercially pure hydrogen to displace fossil fuels for all combustion needs in process plants — boilers, furnaces, gas turbines, etc. This would necessitate major modifications, including replacing many very expensive equipment assets.

For hydrogen, as in the electrification scenario, we have to consider not just the consumers, but also the sources. Fossil fuels produce most hydrogen today, with a large carbon footprint. So, if we want to use hydrogen as a decarbonization fuel, we must decarbonize its production process. Two possible options are: 1. recover the CO_2 coproduced with fossil-fuel-based hydrogen and store it geologically; and 2. produce hydrogen by electrolysis of water, using renewable electricity.

Biofuels. Biomass is plant or animal material used as fuel. A biofuel is any fuel derived from biomass. Biofuels can be tailored as "drop-in" substitutes for existing fuels and used in existing equipment with little or no modification. For example, biodiesel is a drop-in replacement for petroleum diesel. For the process industries, biomethane (renewable natural gas) is of great potential interest as a substitute for natural gas; existing natural gas networks can supply it. Consuming sites would need no major modifications.

Burning biofuels does produce CO_2 but crops can reabsorb it to make more biomass and biofuels — a virtuous cycle that, in theory at least, results in "net zero" carbon emissions.

However, large-scale production of biomass for biofuels would compete with other land-use options, most notably food production, and for irrigation water. In addition, the harvest and transportation of biomass requires significant amounts of energy, and can also create a nuisance for nearby communities.

Energy efficiency remains an important priority in the process industries — not only for energy cost reduction, but also, increasingly, for decarbonization. Yet, there are still many challenges to overcome for electrification, hydrogen, and biofuels to achieve deep decarbonization. ●

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EPA Announces Blockbuster PFAS Actions

Agency updates two reporting rules and withdraws a compliance guide

It isn't surprising the EPA withdrew the compliance guide.

WHEN IT comes to per- and polyfluoroalkyl substances (PFAS), the U.S. Environmental Protection Agency (EPA) is not messing around. The agency announced on June 10, 2021, three actions intended to protect communities from PFAS. This article summarizes the actions.

Reporting on PFAS manufactured in the United States. In the fiscal year 2020, the National Defense Authorization Act (NDAA) amended the Toxic Substances Control Act (TSCA) to add Section 8(a)(7), mandating the EPA promulgate a rule "requiring each person who has manufactured a chemical substance that is a [PFAS] in any year since January 1, 2011" to report certain information. The proposed rule would require all manufacturers (including importers) to report information related to chemical identity, categories of use, volumes manufactured and processed, byproducts, environment and health effects, worker exposure and disposal.

Manufacturers must report information to the extent known to or reasonably ascertainable by them. This would include "all information in a person's possession or control, plus all information that a reasonable person similarly situated might be expected to possess, control, or know." This would require reporting entities to evaluate their current level of knowledge of their manufactured products (including imports), as well as evaluate where they might find additional information. Submitters would need to inquire within the full scope of their organizations, not just use the information known to managerial or supervisory employees. This standard may also entail inquiries outside the organization to fill gaps in the submitter's knowledge.

Withdrawing compliance guide on PFAS significant new use rule (SNUR). In accordance with the Biden Administration's Executive Orders and other directives, the EPA withdrew a compliance guide it believes weakened the July 27, 2020 final SNUR for long-chain perfluoroalkyl carboxylate and perfluoroalkyl sulfonate chemical substances. The final rule prohibits companies from importing certain long-chain PFAS as part of a "surface coating" on articles without prior EPA review and approval. The EPA states examples of such articles include, but are not limited to, automotive parts, carpet, furniture and electronic components. The agency issued the compliance guide in January 2021 in the last days of the previous Administration and limited what would be considered a "surface coating" subject to the SNUR. The EPA removed the compliance guide from its website and it is no longer valid; however, the July 2020 SNUR continues to be in effect.

Toxic release inventory (TRI) reporting on PFAS. For TRI reporting year 2021, the NDAA automatically added three PFAS to the TRI list because they are now subject to a SNUR under TSCA. The EPA issued a final rule on June 3, 2021, incorporating these requirements into the Code of Federal Regulations for TRI. Per the NDAA requirements, the PFAS additions became effective as of January 1, 2021. Reporting forms for these PFAS will be due to the EPA by July 1, 2022, for calendar year 2021 data.

DISCUSSION

It isn't surprising the EPA withdrew the compliance guide and added PFAS substances to TRI. However, the Section 8(a) reporting rule is unexpected. The EPA proposes that a PFAS includes any substance with at least two fluorine atoms on one saturated carbon and at least one fluorine on an adjacent saturated carbon, with neither carbon bound to a hydrogen. Based on this definition, the EPA provides a list of substances listed on the TSCA inventory and a list of low-volume-exemption substances that would be subject to reporting.

The requested information is similar to but more comprehensive than typical chemical data reporting (CDR). Major departures from CDR standards include no exemptions for small businesses, PFAS produced as byproducts, and PFAS-containing articles (including those containing PFAS as part of surface coatings). The EPA acknowledges some article manufacturers, including importers, may meet the "now known or reasonably ascertainable" criterion.

The EPA also seems to be missing various potentially affected North American Industry Classification System codes, given that the agency is proposing to have the reporting rule apply to articles. Trade associations and other industry stakeholders should engage in suitable outreach efforts to avoid the PIP (3:1) experience of earlier this year (see April 2021, "Better Understand TSCA's Long Reach," https://bit.ly/3gJcZDs). ●

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Survey Shows How Job Satisfaction Stacks Up

Salary and satisfaction remain steady, even optimistic, amidst the pandemic's impact

By Amanda Joshi, Managing Editor

CHEMICAL PROCESSING'S job satisfaction and salary survey has always been a great way for us — and our readers — to build a clear picture of the workforce's take on the industry. And this year's results stack up well despite the global pandemic impacting jobs and leading to some statistical anomalies in our year-to-year comparisons.

As COVID-19 continues to present work-from-home challenges and exhaust Zoom calls and screentime, we weren't entirely surprised to receive a lower-than-usual number of responses to the survey — this seems to afflict many surveys at the moment. Fortunately, it doesn't appear to have had a major impact on the data pool. The only standout abnormality: a chemical engineer's average salary.

In 2019 and 2020, chemical engineers reported an average salary of $113,000, the highest we've tabulated since the 2008 recession, but in 2021, this number fell to just $106,000 (Figure 1). However, the survey revealed several factors that could play a role in this lower average.

The main likely reason is that a larger pool of young, less experienced engineers took the survey (Figure 2). In fact, the average age of our respondents is just 47, the youngest we've ever reported; in 2020 and 2019 the average worker was 50 years old.

Another, is far fewer respondents report receiving raises this year, with many directly blaming the pandemic for the freeze. This led to an average raise of just 3.7% compared to 2020's 4.12%.

THE SURVEY PROCESS

A total of 680 people participated in this year's online survey on alchemer.com. From April through June, respondents accessed the survey questionnaire via ChemicalProcessing.com, e-newsletters and e-mail blasts sent to subscribers.

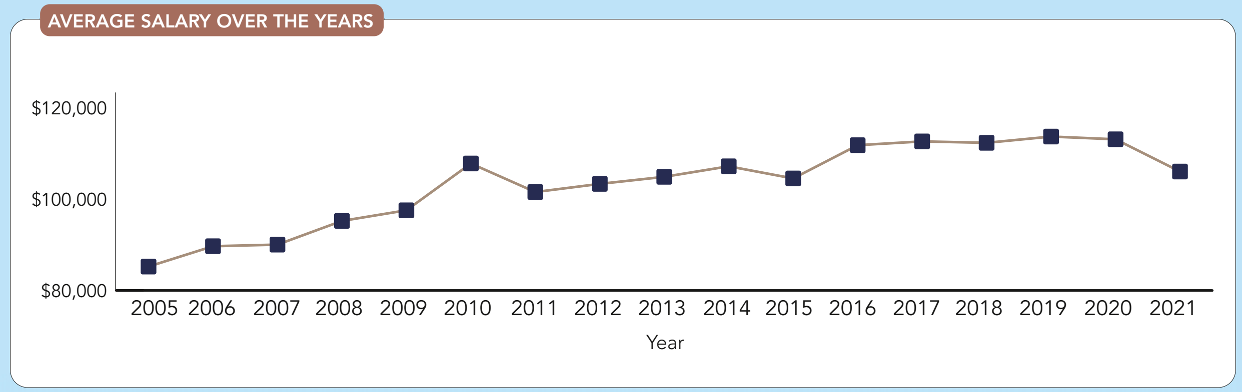


Figure 1. The average salary fell for 2021 to $106,000 but the average age of respondents was lower this year.

"I'm happy with my overall salary and benefits, but not happy with how my company has handled the pandemic. They cut raises for the next year, but the company did perfectly fine on the balance sheet. Pretty disappointing," grumbled one survey respondent.

"There was a dramatic reduction in salary and benefits instituted in 2020 blamed on the pandemic. It's a challenge to experience that when there is much inefficient spending, inexperienced people managing projects inefficiently, and lack of experience in the management organization," griped another.

"I feel my compensation and benefits are fairly good... I think the bonus plan is nice and so are pay raises, but during the pandemic those were cancelled last year," shared one participant.

"Although raises this year were less than in the past, I'm satisfied with my compensation as a result of a long history of recognition resulting from hard work. My company provides a very good benefits package that was largely unchanged this year," said one satisfied individual.

Bonuses also fell, but only slightly. The average bonus for 2021 sits at $6,015, compare to $6,101 in 2020 (Figure 3).

"Over the last several years our annual salary increase has continued to be a lower percentage and our bonuses as well," revealed one participant.

"We did not get bonuses because of the pandemic, but did get an extra week off," shared another.

Initially, we expected a potential upswing in retirements to play a major role in the lower salary levels this year, but in our March 2021 issue, we polled readers online asking how has the pandemic affected retirement plans

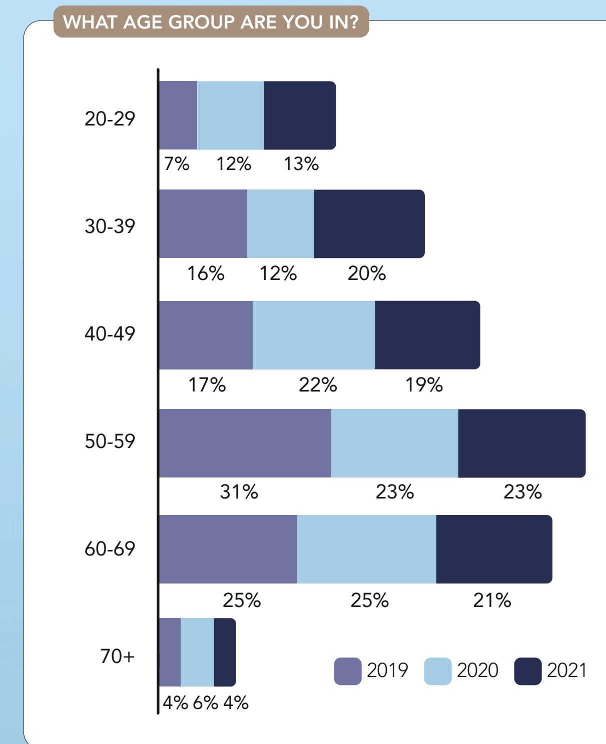


Figure 2. The 30–39 age demographic saw the largest change from 2020.

DOWNLOAD THE 2021 SALARY SURVEY EHANDBOOK

Our detailed survey contains more information than we can cover here, so be sure to download our eHandbook that includes additional data, charts and comments from respondents about the industry's outlook as well as advice for aspiring chemical engineers. To download this free resource, visit https://bit.ly/2T20lrB.

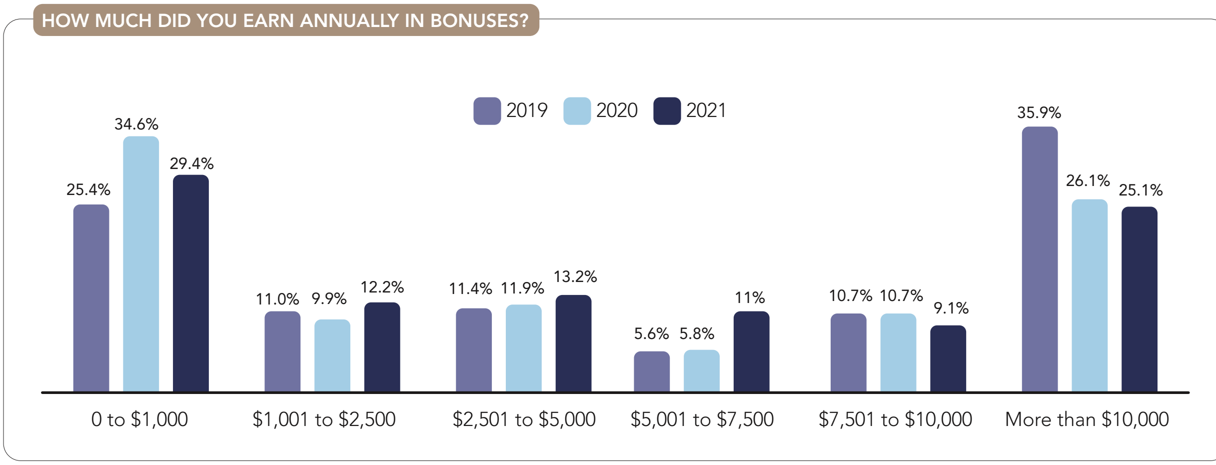


Figure 3. More than two-thirds of respondents reported getting bonuses, with the average bonus exceeding $6,000.

(https://bit.ly/3gDQNLi). The majority disclosed their plans remain on track, and only 10% shared they were retiring earlier than planned or were forced into retirement this year.

Echoing this trend in the salary survey, retirements increased only 1% from last year's numbers.

We also noticed an increase in more part-time workers, some retired, and of course, layoffs.

"I work part time and get a very good salary. It will do fine until I retire," shared one participant.

COVID-19 IMPACT

In 2020, our salary survey kicked off right as the pandemic was starting to shut down the country, and when we asked readers if the restrictions had any impact on their salary, 72% said, "No, not at all." Now, more than a year into the pandemic, that number has dropped considerably, with only 58% of respondents revealing that COVID-19 hasn't influenced their salaries (Figure 4).

Furthermore, in 2020, 26% said they did receive pay cuts due to the slow downs. This year, that number increased to 32%. On a more positive note, those reporting pay increases as a result of the pandemic jumped to 10% for 2021, compared to just 2% in 2020.

Meanwhile, 4% report taking on more work. And nearly 40%, compared to 23% in 2020, say they are now working on-site regularly (Figure 5).

Similar to last year, the remaining 11% say they were furloughed temporarily, given reduced hours, or lost their job.

HIRING IS A MIXED BAG

"My employer dropped staffing by over 60%."

Per last year's outlook, we expected Covid-19 to hinder hiring and staffing levels. Sure enough, nearly 38% say their sites workforce is either somewhat or significantly smaller than it was 12 months ago (Figure 6). In comparison, 30% last year reported staffing declines. On the

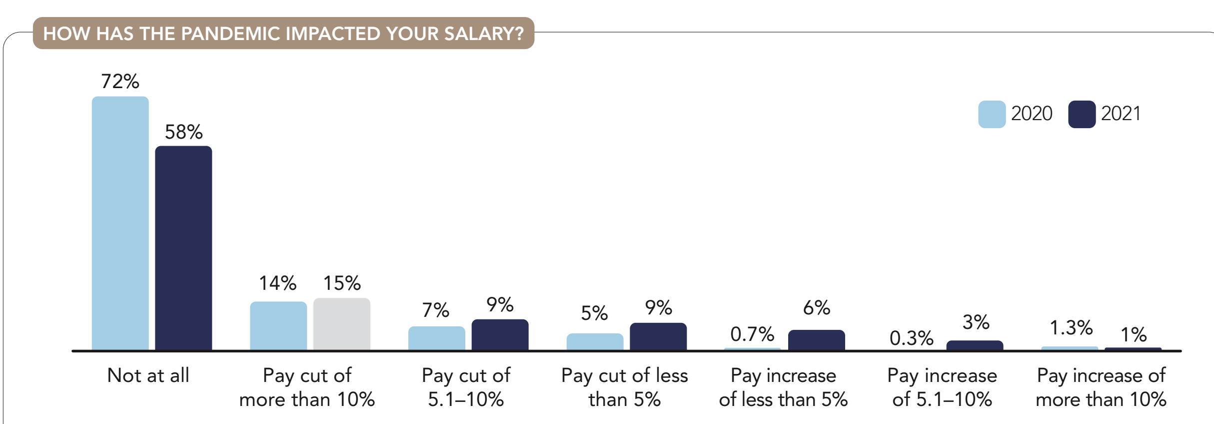


Figure 4. An increasing number of workers report their salaries were affected in some way by the pandemic.

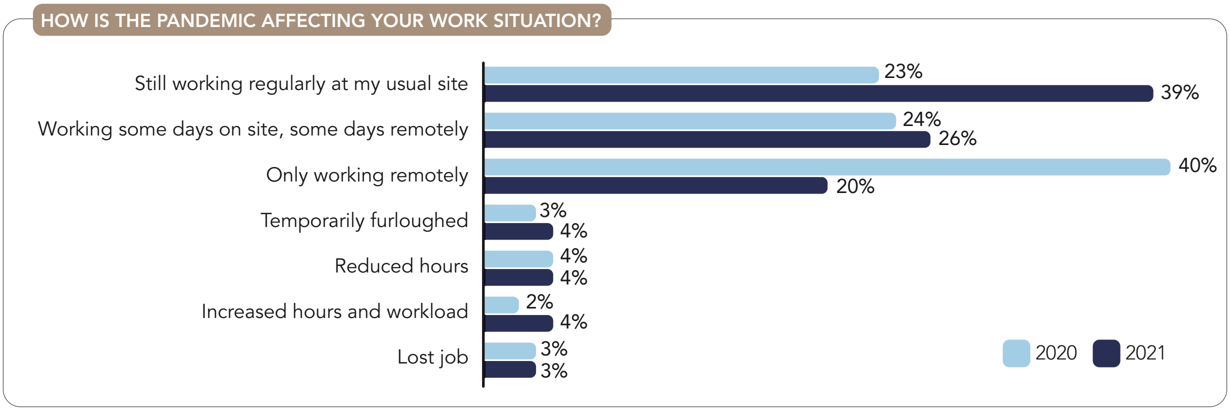


Figure 5. In the height of the pandemic in 2020, 40% worked entirely remotely. Now, just 20% are working from home full-time.

WHAT IS THE PROFESSIONAL STAFFING LEVEL AT YOUR SITE NOW VERSUS 12 MONTHS AGO?

	2013	2014	2015	2016	2017	2018	2019	2020	2021
The same	44.0%	45.3%	45.5%	43%	44.8%	45.6%	50.4%	52%	45%
Somewhat smaller	18.8%	16.9%	16.4%	23.9%	20.7%	18.9%	14%	23%	27%
Significantly smaller	5.0%	4.7%	4.1%	6.7%	6.7%	5.6%	4.8	7%	11%
Somewhat larger	28.2%	29.9%	29.9%	23.7%	24.1%	27%	27.8%	17%	13%
Significantly larger	4.0%	3.2%	4.1%	2.8%	3.7%	2.9%	2.9%	1%	4%

Figure 6. Reports of both smaller workforces and significantly larger staffing levels increased by as much as 3 to 4%.

flip side, nearly 4% say staff has grown significantly larger, compared to just 1% last year. And 45% say staffing levels remain the same; the remaining 13% say hiring resulted in a somewhat larger number of personnel.

Echoing this trend, when asked about current employment status, 79% report they are working full time (88% in 2020); the number of unemployed increased by 2% and the number of part-timers more than doubled from last year.

Adding to this, in an online poll in January, 40% of readers reported a moderate level of turnover of engineers at their sites (https://bit.ly/3gABKmM).

Despite these numbers, more than half of respondents (53%) remain confident in their job security. In 2020, 51% said they were not concerned about potential job loss.

"The profession pays well and comes with strong job security," stated one respondent.

In addition, more than a quarter of participants believe there's no chance they'll lose their job in the next 2 years, but 45% (compared to 41% in 2020) say there's a slight chance. However, those strong job security feelings were on display in the remaining groups; those expressing a moderate to very high likelihood of losing their jobs dropped by 10% from last year.

"I believe we have stabilized and will start coming back, and have to hire, as 2021 progresses," forecasted one respondent.

TAKE A LOOK BACK

Chemical Processing has been conducting an annual salary/job satisfaction survey for more than 15 years. For a more detailed look at past surveys, visit any one of these conveniently listed links:

2020 — https://bit.ly/39iASOq
2019 — https://bit.ly/3f8HTD3
2018 — http://bit.ly/2S6sEQD
2017 — http://bit.ly/2mnxZEo
2016 — http://goo.gl/NOaC4R
2015 — http://goo.gl/YtU0xd
2014 — http://goo.gl/IroA1C
2013 — http://goo.gl/NckQ5c
2012 — http://goo.gl/x00kEt
2011 — http://goo.gl/2ZkSVR
2010 — http://goo.gl/InxZ2N
2009 — http://goo.gl/WYDx0Y
2008 — http://goo.gl/MbYYcP
2007 — http://goo.gl/VmESyE
2006 — http://goo.gl/mZFICx
2005 — http://goo.gl/OZEPN7

HOW SATISFIED ARE YOU WITH YOUR JOB?

	2016	2017	2018	2019	2020	2021
Very satisfied	13%	13%	10.5	12.7%	13%	16%
Satisfied	42%	40%	37.9	40.2%	42%	40%
Somewhat satisfied	36%	36%	38	36.5%	34%	33%
Unsatisfied	9%	11%	13.5%	10.6%	11%	11%

Figure 7. The majority of respondents are between "somewhat satisfied" and "very satisfied" with their jobs.

WHAT SINGLE FACTOR CONTRIBUTES MOST TO YOUR JOB SATISFACTION OR DISSATISFACTION?

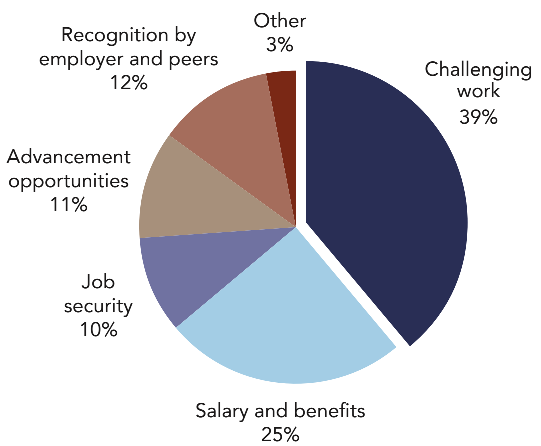


Figure 8. Challenging work continues to play the biggest role in job satisfaction, followed by salary and benefits coming.

CONGRATULATIONS TO DRAWING WINNERS!

Five lucky respondents received $100 gift cards to vendors of their choice. The winners, randomly selected via www.random.org are:

- Paul Cygielman, Consulting Engineer, PHC Enterprises Inc.
- Jason Hadley, Former Sr. Process Control Specialist, Jacobs ECR
- Violet Karow, Quality Control Manager, Le Chef Bakery
- Dennis Kuntzelman, EHS Manager, Seymour of Sycamore
- Roy Milum, Director, Product Development, Petrotech, Inc.

We appriate all the responses and comments we received from this year's survey participants.

HAPPY ENGINEERS

Even with the challenges the pandemic has brought to new ways of working, job satisfaction remains strong; nearly 90% of respondents express they are happy with their careers (Figure 7). Many also feel adequately compensated for their experience and skillsets, with 66% (64% last year) sharing their salary is on par with their expertise.

"I am well compensated and have very good benefits," said one participant.

"I'm very satisfied with the compensation and benefits that I currently receive," mentioned another.

"I'm happy and very grateful to have been able to advance the way I have within my current company," noted another content engineer.

Compensation and perks certainly play a key role in job satisfaction, but the challenging work continues to remain the top factor for happy engineers (Figure 8).

"I feel like the position that I'm in pays well, but that my company is not always competitive with others in industry. The tradeoff is getting to work with awesome salt of the earth people and make a difference in people's lives."

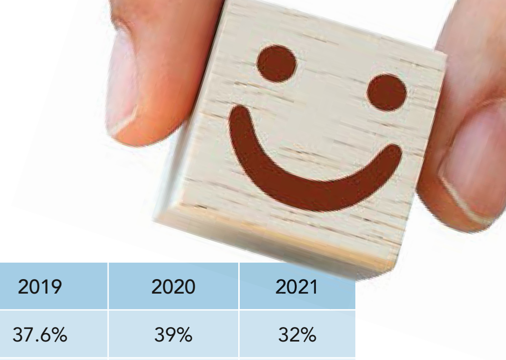
Lack of recognition and the hours and workload tied this year as main detractors to the job. Salary and benefits and the work environment also hindered satisfaction (Figure 9).

THE VIRTUAL FUTURE

Over a year ago, the idea of finding a vaccination for COVID-19 was still in its infancy and many people worked from home to prevent the spread of the virus. Last year, 41% reported they are currently working remotely full time; now, as more people are vaccinated, that number has dropped to just 20%.

However, in a February 2021 online poll, we asked what role do you see for virtual meetings after the pandemic. More than 75% suggested moderate to extensive usage of virtual meetings in the future (https://bit.ly/3gxnz1u). Respondents to this survey seem to agree with this outlook.

Even as the number of remote workers has dwindled from the beginning of the pandemic, many respondents believe the work-from-home mandates will result in future workplace policy changes.



WHAT DO YOU DISLIKE ABOUT YOUR JOB?

Factors	2016	2017	2018	2019	2020	2021
Lack of recognition	38%	37%	38.5%	37.6%	39%	32%
My company's work environment	29%	30%	32%	29%	22%	23%
Hours and workload	29%	24%	30%	26%	25%	32%
Salary and benefits	26%	27%	25%	23%	27%	24%
The commute and traveling	25%	28%	24%	27%	25%	22%
Lack of challenge	12%	11%	14%	10%	14%	17%

Figure 9. Lack of recognition and the hours and workload tied as major deterrents of the job. (Multiple responses allowed.)

"I am working full time hours but at significantly reduced pay, and am working remotely. I think long term the workplace will be more flexible for remote vs in person work. I also think it may take some time for the industry I am in to return to pre-pandemic levels."

"I think the pandemic will change the company culture on work from home. Previously it was frowned upon, but now I believe it will be an accepted part of work life."

"There will be much more telecommuting in the future unless your job demands your direct presence at the work site," suggested another.

INTEREST IN ELECTRICITY HEATS UP

Efforts target thermal processes such as cracking that now use fossil fuels

By Seán Ottewell, Editor at Large

GENERATING "GREEN" electricity from renewable sources to replace the fossil fuels used by chemical plants presents an attractive way for operating companies to achieve their sustainability and net-carbon-zero goals. One angle companies such as BASF, Borealis, BP, Dow, Linde, LyondellBasell, SABIC, Shell and TotalEnergies (formerly Total) all are pursuing is boosting the use of such electricity in their processes. However, these efforts face myriad challenges — technical, economic and governmental.

In August 2019, BASF, Ludwigshafen, Germany; Borealis, Vienna; BP, London; LyondellBasell, Rotterdam; SABIC, Riyadh, Saudi Arabia; and TotalEnergies, Paris, launched one of the first efforts, when they teamed up to form the Cracker of the Future consortium. The six companies agreed to jointly investigate the possibility of using renewable electricity instead of fossil fuels to provide heat for naphtha or gas steam crackers.

"Phase one of our work included literature and patent searches to identify the state of the art in terms of electro-heating technologies. From this, we produced a 200+ page report," explains Walter Vermeiren, chair of the consortium and head of technology and scientific intelligence at TotalEnergies Corporate Research & Development.

Based on that report, consortium members selected five undisclosed concepts for further consideration.

Following this study phase, BASF and SABIC decided to leave the consortium, citing obligations to a pre-existing partnership on a similar topic.

Vermeiren notes that Repsol, Madrid, has since joined the consortium, with other companies expected to become members shortly.

Meanwhile, phase two of the project continues apace, with the aim of winnowing down the five concepts to one or two.

"Consortium members will then decide on which concept or concepts to pursue and make a start on the research, prototyping and design work needed," says Vermeiren.

As part of phase two, the consortium is consulting with technology companies in the petrochemicals sector, together with those involved in electro-heating that already supply their products to energy-intensive industries such as material processing.

"There's a lot of talk and announcements and patents being filed but, if you dig deep, you realize how much work there is still to do. For example, not even the smallest prototype is there yet and most of them are still at the drawing table to develop their heating concepts," adds Vermeiren.

If all goes well, phase two should finish during the summer. Then work should begin in late 2021 on the research and development needed for whichever option or options get the thumbs up from consortium members. The prospective timeline includes a pilot plant in 2025 followed by a full-sized furnace demonstration plant on one of the member's sites by 2030.

COORDINATING THE INITIATIVE

The Brightlands Chemelot Campus (Figure 1), Sittard-Geleen, The Netherlands, is facilitating the effort, acting as an independent coordinator for the consortium. The level of information exchange between the consortium members is unprecedented in her experience, stresses Lia Voermans, director of innovation and strategy at the Brightlands Chemelot Campus. "It highlights what a big, big step this is in terms of how major processes will operate in the future," she notes. High level meetings also are taking place with European Union (EU) committees and relevant national governments, all of which know about and are very interested in the project's aims, she adds.

RESEARCH CAMPUS

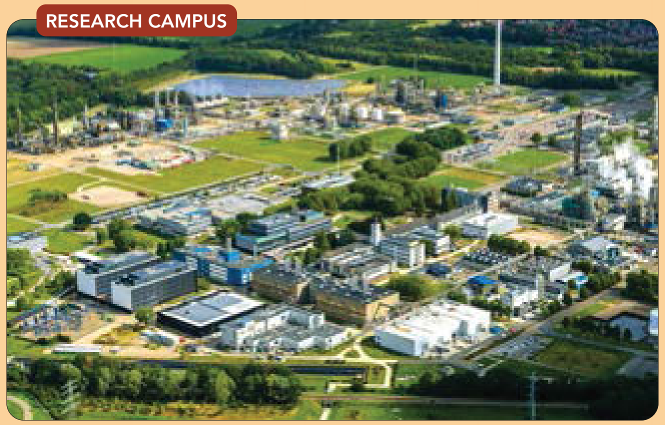


Figure 1. Cracker of the Future consortium may benefit from work of chemicals-related start-ups at Dutch site. *Source: Brightlands Chemelot.*

The EU's deadline for net-zero greenhouse gas emissions is 2050 but consortium members already feel a sense of urgency because the complex technologies necessary likely will take at least ten years to develop from demonstration to commercial scale.

Vermeiren explains: "The process essentially involves a big furnace box with multiple reactor coils that needs heating to a high temperature for the cracking to occur. The question really is, do we provide decarbonized electricity to heat the same coils in a similar way — outside in — to how heating occurs today, or do we adopt a totally new concept such as heating from the inside? So, there's no change from a chemical point of view because all you are doing is raising the hydrocarbons to high temperatures. However, the mechanical and hydrodynamic engineering involved in current cracker technology and the inside-heating designs couldn't be further apart."

In the meantime, the consortium is pursuing the EU for help with development costs, which likely will run between €30 million (≈$37 million) and €50 million (≈ $61 million) for the pilot and demonstration phases, excluding financial and in-kind contributions from the partners.

"We have a lot of different chemicals-related start-ups and pilots on the campus, who are working independently and we are in conversations with them to see if we can find different pathways to get quick results with the project," adds Voermans.

EARLIER PACT SPURS EXIT

Meanwhile, expanding on the reasons behind the departure of BASF and SABIC from the consortium, Andrea Haunert, BASF's senior global technology manager, basic petrochemicals, Ludwigshafen, says, "Some of the selected technical options would interfere with BASF's obligations in the partnership it already had with SABIC and Linde [Dublin]."

The three previously had been investigating different concepts for using renewable electricity instead of the fossil fuel gas that typically serves for process heating and, in late March, announced a formal joint agreement to develop and demonstrate technologies for electrically heated steam-cracker furnaces.

BASF and SABIC have extensive knowhow and intellectual property in developing chemical processes as well as longstanding experience and knowledge in operating steam crackers. Linde brings intellectual property, plus expertise in developing, constructing and bringing steam-cracking furnace technologies to the market.

RELATED CONTENT ON CHEMICALPROCESSING.COM

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"Chemical Makers Turn to Renewable Electricity," http://bit.ly/2lyAJSB

Commenting on the tie-up, Juergen Nowicki, executive vice president of Linde and CEO of Linde Engineering, Pullach, Germany, explains, "With this project, we are singling out a particular industrial CO_2 producer. Cracking furnaces are one of the largest CO_2 emission sources in the whole petrochemical value chain. This is a time-tested, optimized technology that we are now putting on a completely new footing, not in the laboratory, but on a large industrial scale. The effect this project will have is significant."

The three partners already are breaking new ground, notes Haunert. "We have not only developed novel electrical heating concepts for steam crackers but also want to demonstrate the reliability of key components, like metallic materials and other custom-made components such as electrical connections, for use in these types of high-temperature reactors. Other key aspects are the new furnace design targeting high operating efficiency, high operating time and operating safety."

The companies currently are evaluating construction of a multi-MW demonstration plant at Ludwigshafen, which might start up as early as 2023. Ludwigshafen was chosen for this as BASF operates two steam crackers there, while it also is the headquarters for both BASF's carbon-management research-and-development program and its process research and chemical engineering platform (Figure 2).

"This makes it an ideal environment to drive development activities and investment in the demonstration plant, although, looking forward, the use of this new technology is not focused solely on Ludwigshafen," adds Haunert.

While the project concentrates on cracker technology, other endothermic processes such as reforming, dry-reforming and dehydrogenations might benefit from the development as well, she points out.

Nevertheless, all of this still depends on positive funding decisions from the EU's Innovation Fund and the German Federal Ministry for the Environment's Decarbonization in Industry Fund. The first is a €10-billion (≈$12.2-billion) fund designed to bring clean innovative technologies to the market. The German government is providing €2 billion (≈$2.4 billion) towards the second.

"Both seem a good fit for the intended project," notes Haunert, adding the partners won't comment on the specific level of funding they seek.

If the project is successful, the companies plan to share relevant project experience with other European- or German-funded projects by participating in local, regional, national or EU events and conferences. They also plan to organize specific workshops and events to disseminate new results and project findings while at the same time protecting their intellectual property.

"BASF, SABIC and Linde plan to license the technology to olefin producers via Linde," reveals Haunert.

"If funding is granted and a demonstration plant could be installed as currently planned in 2023, then we think the technology can be offered to the market for full-scale applications starting from 2027, so electric furnaces could be installed in subsequent years," she concludes.

STEAM CRACKER

Figure 2. German complex that will host demonstration plant already operates two steam crackers. *Source: BASF.*

BROADER INITIATIVE

This technology fits into a cooperative agreement recently unveiled that promises to impact future operations at Ludwigshafen and elsewhere. In late May, BASF announced plans to work with RWE, an Essen, Germany-based energy firm, on new technologies for climate protection.

The project would rely on a new 2-GW offshore wind farm providing electricity to Ludwigshafen, where it would be used for the CO_2-free production of hydrogen.

The aim is to electrify the production processes for basic chemicals that currently use fossil fuels.

Commenting on the plan, RWE CEO Markus Krebber notes the new wind farm already is at the planning stage and coupling its output to an industrial customer for use with green production technologies would be a first for Germany. "The realization of our proposal would represent a true acceleration of the expansion of renewable energies. Of course, there are still some open questions, but we want to push this forward — the faster, the better," he adds.

One question involves the regulatory framework. For example, the partners would like to see priority being given to applications for offshore wind farms whose electricity will be used in industrial transformation processes.

Also, they insist that green electricity shouldn't have to pay levies imposed on other electricity production to support renewable energy sources. A final cause for concern for BASF and RWE is the complete absence of any regulatory framework for CO_2-free hydrogen production.

Another issue that could affect future operations of such processes is the status of nuclear power in the EU — in particular, if it is seen as "green."

A report carried out by the European Commission's Joint Research Center (JRC) was designed to clarify this point. A version of the report, marked "sensitive," was leaked in March. In it, the JRC notes that analyses did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included as activities supporting climate change mitigation. Further, it went on to state that recent lifecycle analyses show the impacts of nuclear energy are mostly comparable with those of hydropower and the renewables as far as non-radiological effects.

Nuclear power, if termed "green," would open up possibilities for other ways to supply new, electrically operated chemical processes — especially for countries such as France that have a large dependence on nuclear power.

However, environmental organizations such as Greenpeace Europe insist that no list of sustainable activities should include nuclear power.

ANOTHER JOINT EFFORT

Dow, Midland, Mich., and Shell, The Hague, The Netherlands, signed a joint development agreement in June of last year to accelerate economically feasible technologies to electrify ethylene steam crackers. The two had been collaborating prior to the announcement, led by innovation project teams in Amsterdam and Terneuzen, The Netherlands, and Texas in the United States.

However, other than the obvious aim to prove innovative process technology in the laboratory and pilot operations before scaling to commercial crackers, details remain sketchy. ●

VETO VIBRATION IN ROTATING EQUIPMENT

Addressing some contributing factors can help solve problems

By Amin Almasi, mechanical consultant

A LOT of widely used process equipment, such as pumps, compressors and mixers, rely on rotation of an element (impeller, blade, etc.) attached to a rotor. In a perfectly balanced machine, all rotors or rotating parts turn true on their centerline and all forces are equal. However, imperfections always exist and lead to some unbalance, which can cause vibration. Other effects such as misalignment, forces from working fluids, etc., also may create vibration.

The combination of all applied forces (including those from unbalance, working media, misalignment, etc.) and the stiffness and damping of the rotor-support system (including bearings and bearing pedestals) determine the vibration of a piece of equipment. Rotor-support stiffness is important because forces from different sources (unbalance, etc.) can deflect rotating elements from their true centerline; the stiffness resists the deflection.

Keeping all dynamic forces under control and practically in balance requires a clear understanding of the mechanical movement of the machinery and its components, as well as all involved forces. These are the foundations for vibration analysis and rotor-dynamics.

Here, we'll look at vibration and its effects, focusing on practical pointers and useful guidelines related to vibration, rotor-dynamics, condition monitoring and operation of equipment. Most points apply to a wide variety of rotating machines and equipment.

COMMON CULPRITS

Factors that regularly contribute to vibration include unbalance; part loads, deviations and turbulence; and misalignment.

Unbalance. Mechanical unbalance is the condition where more mass is on one side of a rotor's centerline than on the other. While mechanical unbalance generates a unique vibration profile, it's not the only form of unbalance that affects rotating elements. In many cases, rotor unbalance results from an unbalance between centripetal forces generated by the rotation. A rotor assembly might not rotate on its true centerline. This offset rotation creates an unbalance and a measurable level of vibration. Rotor vibration also can stem from an unbalance between the forces on the rotor assembly.

Part-load, deviations and turbulence. Working outside the optimum operating range may lead to higher vibration. Deviations from a machine's specified operating envelope can directly affect the vibration profile. For example, the vibration level of a centrifugal compressor typically is low when operating at around 100% load with laminar gas flow through the compressor. However, running at decreased load can radically change vibration level. Operation at 60% load can result in a vibration increase of as much as 350% with no change in the mechanical condition of the compressor. In addition, a radical change in vibration level can come from turbulent flow in either the inlet or discharge piping. Turbulent or unbalanced media flow (aerodynamic turbulence, hydraulic instability, etc.) doesn't usually have the same quadratic impacts on the vibration profile as that of load change but does increase the overall vibration energy.

The dynamic profile generated by unbalanced fluid flow usually is visible at the vane or blade-pass frequency of the rotating element. In addition, the profile shows a marked increase in the random noise generated by the flow of gas or liquid through the machinery.

Misalignment. If a driver connects to driven equipment by any form of coupling, there's a risk of parallel and angular misalignment. This will cause vibration at both 1× and 2× rotational speed in both radial and axial directions. The force generated by the misalignment can deform sensitive parts and components such as the bearing housing, seal cartridge, etc., in the driver or driven equipment. A distorted bearing housing can result in bearings that are out of line. For machines with rolling-element bearings, the additional loads and forces can reduce bearing life to 25% or 20% (or even less) of the original expected life. Many cases of rolling-element bearing failures have been traced back to the misalignment.

FREQUENCY OF VIBRATION

A vibration reading of a typical machine usually is complicated and contains many frequencies. It often is very challenging to relate these records or measurements to operating parameters and possible developing problems.

Many unique frequencies contained in the vibration signature of a machinery train can be directly attributed to a corresponding mechanical motion within the machinery. For example, the constant end play or axial movement of the rotating element in a typical machinery train generates an elevated amplitude at the fundamental (l×), second harmonic (2×) and third harmonic (3×) of the shaft's true running speed. Forces resulting from gas or liquid movement also generate unique frequency components within the machinery's signature. In relatively stable or laminar-flow applications, the movement of fluid through the machinery slightly increases the amplitude at the vane or blade-pass frequency. In more severe, turbulent-flow applications, the flow generates a broadband, random profile directly attributable to the movement of fluid through the machinery. It is sometimes a kind of white noise profile.

Other forces, such as the side-load, also generate unique frequencies or modify existing component frequencies. For example, the side-load on the shaft of a machine using rolling-element bearings can generate a unique frequency to identify the problem. This increase in side-load changes the load zone in the machine's bearings, resulting in a marked rise in the amplitude at the outer-race rotational frequency of the bearing(s). Applied force or induced loads also can displace the shafts in a machinery train. As a result, the shaft will rotate off-center, which dramatically increases the amplitude at the fundamental (1×) frequency of the machine.

Another example is 0.5× frequency (referred to as half frequency) measured in some equipment with sleeve oil-film bearings. An oil-film bearing that has too much radial clearance or too small a radial load may become unstable. This results in the shaft orbiting in the bearing at just under 50% of the shaft speed. Theoretically, the basic problem is that insufficient damping exists to dissipate the vibration energy. An effective practical solution to avoid such 0.5× frequency problems is to use modern bearings such as tilting-pad ones.

RECIPROCATING AND LINEAR-MOTION EQUIPMENT

Vibration profiles generated by most reciprocating or linear-motion machines reflect a combination of rotating and linear-motion forces. However, the intervals or frequencies generated by these machines aren't always associated with one complete revolution of a shaft. For instance, in a two-cycle reciprocating engine, the pistons complete one cycle each time the crankshaft revolves 360°. In a four-cycle engine, the crank should complete two complete revolutions, or 720°, to complete a cycle of all pistons. Because of the unique motion of reciprocating and linear-motion machines, they generate a level of unbalanced forces substantially higher than those produced by ordinary rotating equipment. As an example, a reciprocating compressor drives each of its pistons from bottom-center to top-center and returns to bottom-center in each complete operation of the cylinder. The mechanical forces generated by the reversal of direction at both top-center and bottom-center result in a sharp increase in the vibration energy of the machine. An instantaneous spike in the vibration profile repeats each time the piston reverses direction. Linear-motion machines generate vibration profiles similar to those of reciprocating machines. The major difference is the impact that occurs at the change of direction with reciprocating equipment. Typically, linear-motion-only machines don't reverse direction during each cycle of operation and, as a result, don't generate the spike of energy associated with direction reversal.

DEFECTS, DAMAGED COMPONENTS AND BENT SHAFTS

Damage due to careless installation or assembly of parts and components has been the root cause of many failures or incidents. Installing a machine component with an undersized bore can damage sensitive parts such as bearings, especially if the installation tool is a hammer. The shock loads can pit rolling-element bearings or even crack a race or rolling element. Many cases exist of rolling-element-bearing installation using a punch and hammer rather than an appropriate method (such as a sleeve) that resulted in a bearing race that's distorted or not square on the shaft.

Manufacturing defects and errors also too often lead to machinery failure. For instance, shaft problems can result from machining errors. It's not uncommon for fork-lift trucks to get off course and cause fatal impact damage to equipment.

Tolerances and small irregularities may create some additional forces that affect machinery. For example, consider a fan with several equally spaced and identically shaped blades. In practice, each blade differs slightly, which results in one section of the fan producing more thrust than another. A fan, compressor or pump that is mounted in an irregular housing also will have unbalanced thrust or pressure.

A shaft that is straight at room temperature may bend when running at full load (heated or cooled), especially if the heating/cooling effect is uneven. Excessive load on the shaft can bend it. In addition, this can cause rapid failure of rolling-element bearings.

An eccentrically mounted rotor (of a pump, compressor, etc.) may have variations in pressure causing vibration that looks similar to unbalance. These effects generally are termed aerodynamic or hydraulic unbalance.

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Machinery that's not bolted rigidly to its foundation will have excessive vibration. The foundation controls the energy absorption; lack of a good connection to the foundation can lead to very high amplitudes of vibration. Too often, the vibration also shows itself at 2× or 3×. Frequently, it relates to a resonance of part of the system and occurs at other frequencies. The problem may arise from an irregular mounting surface or the use of a number of thin shims under a motor foot rather than a single piece of the correct thickness.

HOW TO REDUCE VIBRATION

Many different methods can reduce the vibration generated by a machinery package. Firstly, check if better balancing, alignment or operation can lower the vibration to the intended low levels. However, those steps alone won't cut vibration enough for some equipment. In such cases, evaluate other methods such as isolators, vibration absorbers, etc., and incorporate a suitable option. Generally, any change in the mass, mass distribution, stiffness or stiffness distribution can change the vibration; so, a set of intelligent modifications of these (mass, stiffness or their distribution) can reduce the vibration. Traditional systems of base isolation such as springs or viscoelastic materials often can mitigate vibrations. However, these options often aren't feasible or convenient for rotating equipment supported on complex structures (such as plate structures, structures fabricated of thin-walled profiles, etc.). In some cases, changes in the support structure or the operating conditions produced unexpected high levels of vibrations. An attractive alternative is to change the mass distribution, for instance, by incorporating masses (e.g., equal to 3, 5 or 10% of the total mass of the vibrating machinery) into the supporting structure. Obviously, addition of large masses (say, more than 15% of total masses) isn't a desirable way to reduce the vibration. The key point is to check whether smart and effective addition of some relatively small masses to the system would suffice. This evaluation should be done based on very robust calculations and simulations to reduce the vibration.

In theory, a broadband damper using a large number of inertial absorbers distributed in space and in frequency can facilitate energy dissipation over a specific frequency band. In some cases, minor modifications to structures have sufficed to change the frequency response of a member (even a narrow plate, etc.) to suppress transmission of vibrations in a given frequency band. An alternative is to use masses incorporated into the support structure to mitigate vibration — e.g., loading a member or a plate with a number of small point masses at various positions. Sometimes, only one or two masses located in the antinodes of the first flexural modes reduced the vibration. Another alternative that has been used is attachment of a series of annular plates to main structural members. However, adding masses might not be very effective in addressing high levels of vibration in locations close to the exciting machines. In other words, at locations nearer the equipment, it becomes more difficult for the built-in masses system to reduce the vibration.

Many high-vibration cases have stemmed from lubrication problems and associated damage. Proper lubrication of bearings is a major requirement for many machines. A lack of lubrication will cause noise and rapid wear. On the other hand, too much lubrication can result in problems. For instance, it can cause the rolling elements of bearings (balls or rollers) to skid rather than roll; this can generate excessive heat and subsequent problems. Over-lubrication is a common problem. Use of the correct lubricant (viscosity, grade, etc.) is critical. Many problems can be traced back to incorrect or contaminated lubricant (lubrication oil, grease, etc.).

GEAR UNITS

Many machinery trains rely on gear units to match the speed of the driver to the needed speed of driven equipment. Gear units usually are maintenance intensive and, too often, provide poor performance. They can suffer from excessive rates of wear, high levels of vibrations and lubrication oil problems. The vibration issues can stem from unbalance, misalignment and gear errors.

Often, increasing the performance of a gear unit or reducing its vibration requires comprehensive upgrading and renovation. Potential improvements to gears and bearings include removal of excessive gear transmission error, elimination of excessive gear pitch line eccentricity, replacement and renovation of bearings, among others. For the bearings, the target usually has been the modification of radial bearing inserts to proper running clearances and a stabilized multi-pocket bore design to reduce vibration level of the running speed (1×) and stabilize possible fractional frequency components, respectively. Many gear units in machinery trains have experienced torsional problems. Addressing the low-level excitation of the fundamental torsional natural frequencies of the train is the first step for a lower torsional vibration. ●

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Optimize Combustion Using a Digital Twin

Improving fired asset operation always requires attention to implementation issues

By Kevin L. Finnan, Yokogawa Corp. of America

FIRED ASSETS such as boilers, furnaces and heaters represent major opportunities for performance improvements at process plants. New developments in technologies ranging from process analyzers to advanced analytics and, most recently, digital twins can significantly assist in optimizing these assets.

Plant process operators are realizing benefits such as increased energy efficiency, reduced emissions, higher quality, improved safety and less unscheduled production downtime. In addition, they are gaining asset management and lifecycle benefits through protection of equipment and component investments. Most of the benefits directly impact the bottom line, providing justifiable return on the investment (ROI) plus lower operating costs over the long term.

In the wave of disruptive technologies that recently have come on the scene in the process industries, the digital twin potentially could be the most powerful. It is a virtual digital copy of a device, system, human or process that accurately mimics actual performance in real-time. A digital twin is executable and configurable. It operates in the present, mirroring the actual physical entity but with full knowledge of its historical performance and an accurate understanding of its potential in the future.

A digital twin replicates real-world events and actions by combining live inputs from sensors on the physical asset with historical performance data. Digital twin technology relies on a first-principles model, with the physical process feeding input into the model, which then uses those data to generate an accurate digital representation of the real-life event.

The digital twin concept encapsulates a broad set of dynamic but intangible interactions occurring within and around the physical asset, such as fluid flow, heat and material balances, yield and energy inputs/outputs, thermodynamics, human operator behaviors and other factors. These interactions are critical for asset performance management and maintenance of facilities within optimum operating windows for safety, reliability and profitability that provide optimum integrity.

Unlike advanced statistical models, even including those using artificial intelligence (AI), the first-principles model incorporates physical properties. The model is the same as those used in process simulators.

However, unlike a simulator, the digital twin accurately represents the asset over its complete range of operation and entire lifecycle, rather than just for a particular operating case. Instead of the static provision of a snapshot in time, the digital twin captures the full history and future of an asset. It operates in an automated manner, making regular model runs that are incorporated in business workflows. The digital twin provides a centralized, single version of the truth, with outputs delivered directly to all interested personnel.

A digital representation's ability to process enormous amounts of data into understandable formats enables better decision-making for manufacturing processes; real-time monitoring, forecasting and optimizing; and predictive maintenance — while ensuring that performance of a process meets or exceeds expectations.

SCENARIO TESTING AND FAR MORE

A key feature of a digital twin is its ability to test scenarios. Data consumers can use a digital twin to experiment with various scenarios and assess the outcomes and impacts of each without any real-world risk. Users can run "what if?" scenarios up and down the supply chain and manufacturing process to determine which strategies maximize profitability.

Process modeling allows a digital twin to identify potential safety and reliability vulnerabilities. By streamlining safety processes and improving predictive maintenance, a digital twin reduces the risk of employee injuries, environmental contamination and damage to the facility.

These aspects particularly suit assets such as boilers, furnaces and fired heaters. For example, a control system operations team created a digital twin to test the key factors influencing fired heater control and evaluate potential improvements. The digital twin modeled a fired heater in a continuous catalytic reforming process with single-fired tubes in three radiant sections.

The team used the digital twin to test scenarios related to excess air control, fuel composition changes, downstream pressure and temperatures, feed composition and rate, and heat distribution between the convection and radiant sections, among others, to assess their impact on daily operations.

A digital twin also can optimize energy management, emissions compliance and predictive asset management for fired heaters. In addition, it can work in conjunction with other digital twins to optimize the entire process and enterprise value chain. The digital twin regularly executes and updates the model with live information from the actual fired asset.

During initial configuration, the engineering team loads the model with as much historical information from the asset as possible. Going forward, the digital twin will continually compare actual operations with the history and report on parameters trending away from their optimal states or values. It also will check parameters versus limits, and warn about impending problems such as deteriorating asset components.

The digital twin can adapt as live conditions change. For example, it can automatically respond to altered fuel composition by adjusting the air/fuel ratio control. This requires the control system to accept a download of the new setpoint from the digital twin, which could reside in the Cloud. Given cybersecurity measures, plant operations will need to provide for a setpoint change from the Cloud in standard operating procedures. Some operations will have to rely on manual operator intervention or, as an alternative, run the digital twin on premise.

KEY CONSIDERATIONS FOR FIRED HEATERS

Excess air control is perhaps the most important control system function for fired assets. Heater efficiency, emissions and safety strongly depend on the excess air volume. Unused fuel poses a safety hazard; so, to ensure complete combustion, operators typically provide more combustion air than theoretically required. However, an unnecessarily high air volume results in excessive fuel consumption, high CO_2 and NO_x emissions, and reduced production efficiency.

OXYGEN MONITORING

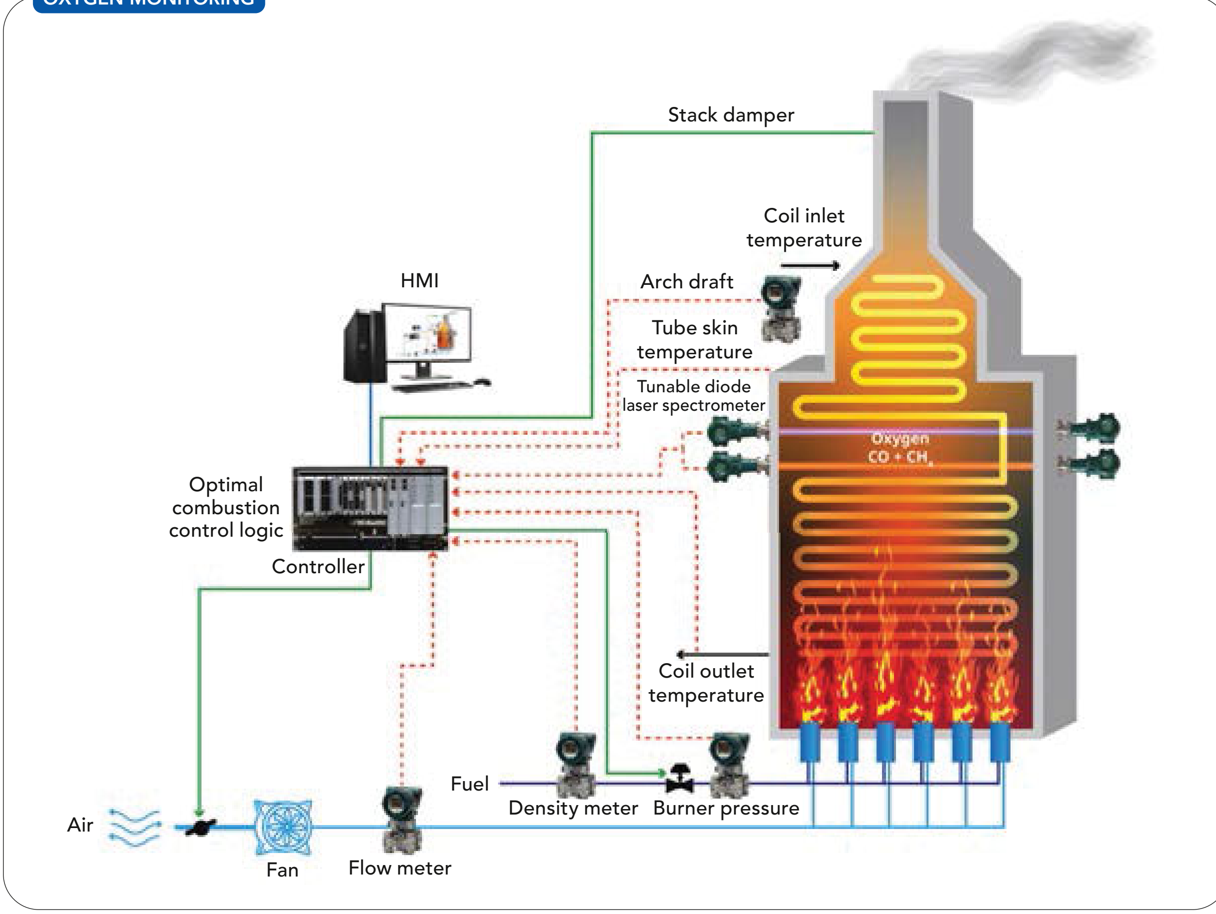

Figure 1. Use of TDLS technology enables a digital twin to quickly respond to a change in air/fuel ratio.

The air/fuel ratio is burner-specific. Setting the ratio correctly requires taking into account the burner properties, fuel composition and particular operational conditions.

Because tunable diode laser spectroscopy (TDLS) technology can directly measure the amount of oxygen (O_2) in the radiant section of a fired heater on a 2–4-sec. cycle, the digital twin uses the amount of oxygen instead of the excess air for reference (Figure 1). Normally, a slight variation of excess air exists for different fuels.

The digital twin improves upon the trial-and-error process that operators often use to find the optimal excess air volume. A holistic approach, which applies considerable experience to combustion control, will include carbon monoxide (CO) trim control and use the CO breakthrough point to determine the optimal excess air volume. This breakthrough point is unique for every fired asset and depends on burners, fuel composition and furnace pressure. The digital twin is able to assist in automating the process of ascertaining the CO breakthrough point.

Petrochemical plants that use a mixture of natural gas and processed gas as fuel face an added wrinkle in air/fuel ratio control. The fuel's composition can fluctuate considerably. Common components include butane, butylene, methane, ethane and ethylene. To evaluate the potential impact of fuel composition fluctuations, a digital twin can assess natural gas and up to five different mixtures of light hydrocarbons. Those scenarios can establish a matrix for air/fuel ratio control setpoints based on fuel composition.

A digital twin is control-system agnostic as it can supply this and other information to practically any system. By accounting for all the physical phenomena and lifecycle dynamics in the asset, the digital twin offloads those responsibilities from the controllers, removing the need for custom programming.

Digital twins have produced results with bottom-line impacts. Applications at more than ten European installations demonstrate a reduction in O_2 level to 1% in flue gas for refinery gas and 2% for a combination of oil and gas. Depending on heater design and operating conditions, fuel consumption was cut by 0.6–4.2%. Additional savings could accrue from stabilizing the coil outlet temperature. Further scenario runs showed an extra 2–6% decrease in fuel consumption was achievable.

MORE FACTORS

Another issue is that the feedstock composition can vary. When the feed is in line with desired throughput, changes in the outlet temperature and behavior of the process flow controller can cause additional disturbances. Variations in the inlet temperature of the feed can create further ones. Altogether, feed rate and composition affect stability, safety and energy efficiency across the entire process.

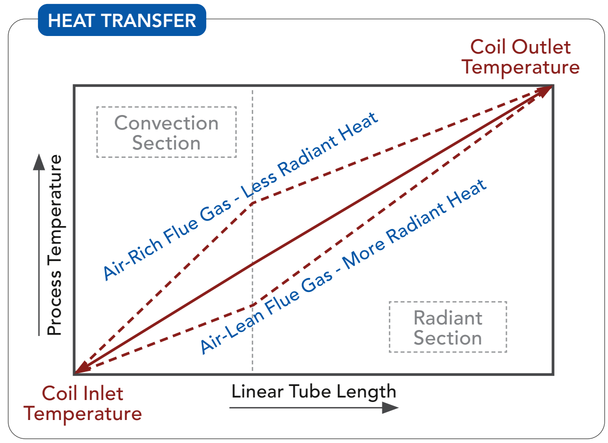

Figure 2. The temperature profile inside the tubes of a vacuum heater changes depending on air level in flue gas.

Effects that operators sometimes overlook include downstream pressure and temperature. In a downstream process unit, a higher temperature increases the pressure in the process and, in return, influences evaporation inside the heater tubes, thus causing an additional disturbance to combustion control.

For units such as vacuum heaters, it's important to consider the temperature distribution along the tubes in the radiant and convection sections (Figure 2). A higher volume of excess air results in higher absorbed heat in the convection section, increasing the crossover temperature.

Stabilized coil outlet temperature and O_2 content in flue gas lead to substantially fewer trips and increased asset life. For fired assets such as steam methane reformers that utilize catalyst in the tubes, trip avoidance can be critical to extending the life of the catalyst and delaying an extremely expensive catalyst-change turnaround.

Sophisticated control systems use holistic approaches by applying extensive knowledge and experience to account for feed composition, downstream pressure and temperature effects, and heat distribution between the radiant and convection sections of the fired asset. This can help balance burners, equalize loading and smooth out temperature peaks.

Balanced burners reduce maintenance costs and allow longer run times between turnarounds. Balancing the burners and stabilizing the coil outlet temperature equalize the load and slow the aging of all radiant section components.

Less coking results in savings in fuel and maintenance costs. Stabilized combustion decreases tube deposits, which accelerate at high temperatures. By smoothing out temperature peaks, fired asset operators reduce the amount of decoking and maintenance required.

In addition to simplifying controllers by eliminating custom code, a digital twin provides the benefit of tracking all fired asset operations over time. It can adjust to dynamics such as aging pipes that affect flow rates. It also can inform

predictive maintenance by sending rich information to a predictive maintenance application.

Also, over the fired asset lifecycle, the digital twin can ensure compliance with regulations and standards such as NFPA 87 "Standard for Fluid Heaters" by tracking parameters that indicate trending toward non-compliant performance.

POTENTIAL DIGITAL TWIN ISSUES

A digital twin isn't a "quick fix" remedy. Operators wishing to rapidly improve a few key performance indicators typically can do so simply by upgrading instrumentation or enhancing control strategies. A digital twin is best for achieving continuous improvement over the lifecycles of assets and plants.

Because the digital twin uses a first-principles model with deep knowledge in terms of physical properties, its setup time can exceed that of an analytics approach such as AI or machine learning (ML), which operates purely on data sets without regard to physical properties. A digital twin requires more tuning to take advantage of deep knowledge.

A digital twin performs best with rich information. Poorly managed, inconsistent information sent to a digital twin could undermine the quality of its output. The digital twin won't present a hazard but could provide a less-than-optimal outcome. Given incomplete information, the digital twin could fare no better than a simpler and less expensive option.

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HOW IT COMPARES

Because the digital twin works in conjunction with a control system, comparing it against control or burner-management systems isn't relevant. By offloading all physical phenomena and lifecycle effects, the digital twin can simplify a control system by eliminating custom code, easing selection of a controller in a manner that's manufacturer-independent.

A variety of advanced process control (APC), multivariable control, model-free and model-based systems have successfully addressed combustion control. These technologies provide stability that improves energy efficiency. Dynamic process models can increase throughput, conserve energy and reduce quality giveaway. These approaches do require attention to the cycle time, which could result in the necessity for rapid disturbance response, for example, to a CO excursion. Typically, approaches such as APC don't sufficiently consider fired heater safety by running the heater with minimum excess air.

A digital twin often is compared with data analytics using AI. While a digital twin incorporates one aspect of AI technology that allows automatic improvement from experience, key differences exist between a digital twin and contemporary AI applications such as ML. While ML algorithms observe asset behavior patterns and correlate them with outcomes, they lack the deep knowledge of the underlying physical properties that are fundamental to a digital twin.

For example, given information such as pressure, temperature and the composition of fluid flowing through tubing, a digital twin can model degradation in the tubing over time, while an AI/ML approach would need to infer trends from empirical information. Lack of availability of this sort of information is a common problem.

CONSIDER A DIGITAL TWIN

A digital twin accurately mimics the actual performance of a device, system, human or process in real-time. It operates in the present, mirroring the actual physical entity but with full knowledge of its historical performance along with an accurate understanding of its potential in the future.

For a fired asset, the digital twin encapsulates a broad set of dynamic but intangible interactions occurring within and around it, such as fluid flow, heat and material balances, and thermodynamics. These interactions distinguish a digital twin from technologies such as APC and AI/ML, and are critical for asset performance management and maintenance of facilities within operating windows for safety, reliability and profitability that offer optimum integrity.

The digital twin provides the ability to test "what if?" scenarios and assess the outcomes and impacts of a multitude of approaches without real-world risk. Scenarios run by the digital twin typically produce justifiable ROI in areas such as energy efficiency, reduced emissions and increased asset lifespan. Key additional benefits include safety improvements.

A digital twin also can offload all physical phenomena and lifecycle effects from a control system, simplifying its operation by removing required custom code. Unlike a control system, the digital twin provides for asset sustainability, continual optimization and, therefore, recurring ROI over the lifecycle. ●

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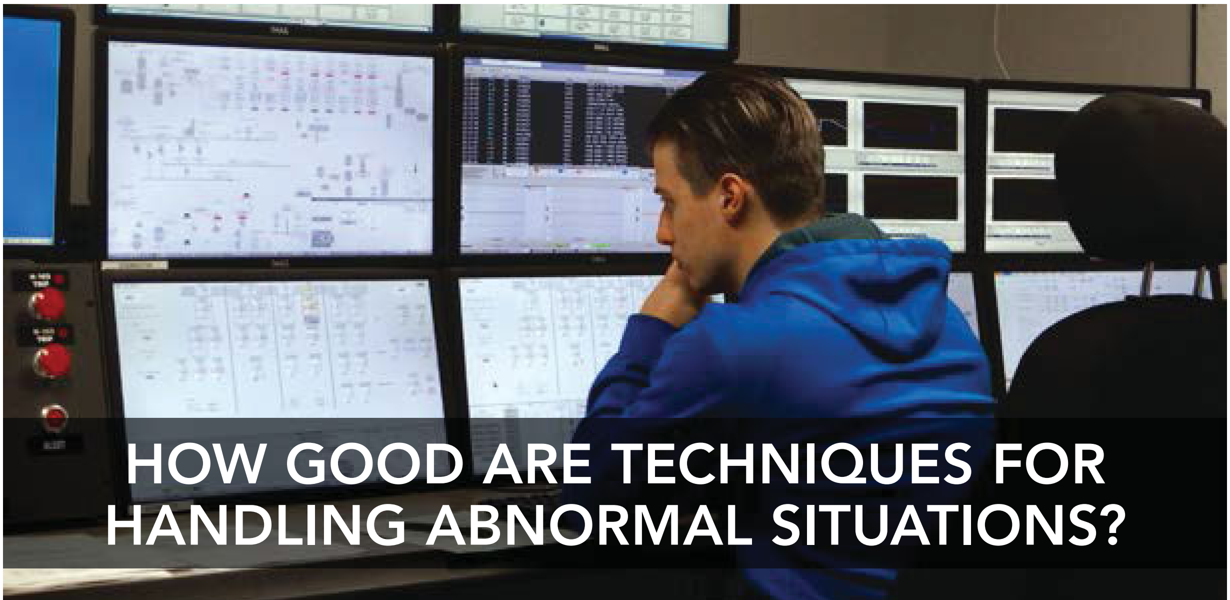

HOW GOOD ARE TECHNIQUES FOR HANDLING ABNORMAL SITUATIONS?

A test of alarm management and upset automation with real operators provides insights

By Ron Besuijen, major ethylene producer; Beth Blickensderfer, Richard Simonson and Joseph R. Keebler, Embry-Riddle Aeronautical University; and David Strobhar, Beville Engineering/Center for Operator Performance

DO ALARM management and upset automation (safe park) really improve operator and plant performance? In theory, good alarm management will result in more concise information to direct the operator to a problem while upset automation should relieve the operator of routine tasks, freeing the person to focus on monitoring and troubleshooting. To date, though, faith rather than proven results has underpinned their use. Alarm management has been shown to reduce the number of alarms and provide better prioritization. Upset automation has been shown to cut the number of control actions necessary during an upset. However, can tests demonstrate that either or both techniques actually improve plant performance during an abnormal situation? And if so, by how much?

This was the subject of an investigation by the Center for Operator Performance, https://operatorperformance.org. The goal was to measure operator and plant performance in response to an abnormal situation. Use of actual operators and a high-fidelity simulator would ensure the results reflect real-life as much as possible. The experimental design, developed by human factors researchers from Embry-Riddle Aeronautical University, Daytona Beach, Fla., added to the confidence that the outcome would accurately indicate the effectiveness of alarm management and upset automation.

METHOD

The study focused on the indoor control-panel operating tasks for the finishing side of ethylene manufacturing. It used a high-fidelity dynamic simulation of the cold side of the process, modeled by software from CORYS, Grenoble, France (lead photo).

Simulated scenario and independent variables. The simulation began with a malfunction of the propylene refrigeration compressor unit (i.e., "601 trip"); hence, the plant was in "upset" mode and not steady state. When the refrigeration compressor unit trips, the control room operator must isolate the plant, which includes closing valves, shutting off pumps, and flaring (i.e., burning off excess gases). As the operator was isolating the plant, a valve malfunction occurred. This involved an open valve that the operator closed as part of the standard procedures following the 601 trip. The issue was that the operator's display showed the valve as closed but it actually remained open in the (simulated) plant. The operator's task was to detect the valve malfunction while continuing to resolve the 601 trip. Accomplishing this required approximately 100 process moves. The simulation specialist administered the modeled scenarios and acted as a role player when necessary (e.g., responding as the "cracking panel operator" and "outside operator" during the scenarios).

Alarm design. The study included two types of alarm design. No rationalization (which yielded approximately 250 alarms) and smart/state-based alarms (which gave approximately five alarms).

Automation. The study also incorporated two levels of automation: presence or absence of the safe park application. With safe park, operators would perform approximately eight moves in responding to the simulated events. Without the

OPERATOR PERCEIVED WORKLOAD

	Not Rationalized Mean (SE), 1–100 scale	Smart Alarm Mean (SE), 1–100 scale	Total
With safe park	58.4 (5.8)	34.5 (6.8)	46.4 (5.5)
Without safe park	73.0 (4.5)	57.1 (5.9)	65.0 (4.5)
Total	65.7 (4.2)	45.7 (5.8)	

Table 1. Alarm design and automation affected perceived workload. (SE is standard error of the mean.)

FLARE RELEASE

	Not Rationalized Mean (SE), megagrams/h	Smart Alarm Mean (SE), megagrams/h	Total
With safe park	19.8 (5.2)	10.5 (3.2)	15.1 (2.5)
Without safe park	31.9 (8.6)	36.6 (6.5)	34.3 (5.6)
Total	25.8 (4.8)	23.6 (4.6)	

Table 2. Alarm design and automation also impacted the amount of flaring. (SE is standard error of the mean.)

safe park app, operators would carry out approximately 120 moves in response to the simulated events.

Study conditions. Each operator experienced four separate, simulated scenarios:

- Safe park automation app:
  - Scenario A — no rationalization;
  - Scenario B — smart alarm;
- No safe park automation app:
  - Scenario C — no rationalization; and
  - Scenario D — smart alarm.

To avoid learning effects, the study used four different scenarios (one per study condition) with the malfunctioning valve differing in each.

Measures. Each operator's perceived workload level and the flare released were measured. A subjective questionnaire, NASA-TLX, measured the perceived workload. Every operator completed the NASA-TLX after each simulated scenario, resulting in four unique workload scores per operator (one per scenario). The amount of flare (i.e., the amount of excess chemicals released) was recorded by the simulator's historian function. In the actual plant, after a 601 trip an application reduces furnace feed by 22% within 3 minutes. For consistency in this study, the feed rate was left at that level, although in a non-simulated 601 trip event, operations would have cut the feed rate further. The total flare released was collected by importing historian data into a spreadsheet in one-minute averages. The averages then were totaled over the period of time between the onset of the first alarm and when the operator identified the anomaly.

Procedure. Upon arriving for the simulation day, each operator completed the scenarios one by one. The order of the scenarios for each operator varied, being randomly assigned, to avoid order effects. Each scenario lasted between 10 and 45 minutes. After finishing a scenario, the operator completed the NASA-TLX questionnaire. The simulation specialist then debriefed the operator about the scenario and the operator was given a short break. This process repeated until the operator had gone through all four scenarios.

TESTING AND RESULTS

Eleven finishing-side operators currently employed at an ethylene facility in Canada participated. All the operators were shift workers on a five-week rotating schedule who were slated for their required simulation-based training. They were active panel operators and familiar with the equipment, processes and procedures of the particular plant and specific to their job. The operators experience levels ranged from several months to 30 years; the average was about 7 years.

The operators were informed in advance that the scenarios involved a propylene refrigeration compressor trip, which is documented in an emergency procedure, and that a secondary valve failure also would occur. The details of the valve failures were not disclosed. Each operator completed all four scenarios on a single day.

To ensure consistency, a script was created for implementing each step at the same time for all the scenarios. This included all the required steps by the cracking panel operator and field operator as well as changes to the simulator. The simulator trainer performed the steps and gathered the results. In addition, a feed ramp and a program to shut down pumps in the same sequence and timing was used. A process historian validated the timing of the results entered by the trainer.

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Tables 1 and 2 show the descriptive statistics. Use of safe park significantly impacted operator perceived workload and the amount of material flared. Specifically, operators indicated lower perceived workload and the system released less material to the flare when using the safe park automation compared to without it. In terms of alarm design, operators reported substantially lower perceived workload when using smart alarming versus the non-rationalized alarm schemas. However, about the same amount of flare was released with non-rationalized and smart alarming. These statistically significant reductions in the performance variables measured in this experiment present valuable evidence that implementing alarm rationalization schemas and automation techniques to assist the human operators does improve system performance.

IMPLICATIONS

The risk of a loss of containment event increases during outages because of the sudden changes in pressure and temperature. Freeing up the panel operator from the bulk of the tasks and preventing emergency alarms from being buried in an alarm flood can allow operations to recognize these events early and respond quickly to minimize their severity.

Using alarm automation to reduce the number of alarms to five for a unit outage was new; this was termed a "no brainer" by some of the operators involved in the test.

The operators were familiar with the upset automation, as it was implemented at the site shortly after the start of the simulator training program 20 years ago and has been very helpful in unit upsets. We now have data that support the benefits. One of the keys to developing upset automation was testing the software on the simulator.

Overall, results showed dramatic improvements for use of advanced alarming techniques (state-based) and upset automation. Operator response time, mental workload and flaring were reduced by 35–70%. ●

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Mind the Mettle of Packing Materials

Change from plastic to metal raises a number of issues

THIS MONTH'S PUZZLER

We just replaced a high-density polypropylene (HDPP) mesh pad and glass-filled polypropylene packing at the top of our distillation tower with a metal mesh pad and metal packing. We had installed the packing and mesh pad because we needed greater efficiency than we were getting with the simple tray design below in the tower. Unfortunately, we now can't seem to make purity in the condenser.

Operations was concerned about spikes in temperature beyond 200°F during start-up and maintenance's desire to steam the packing and pad to speed up cleaning. Our condenser set point is 162°F. The project engineer fought long and hard against the metal replacement because he says it's less efficient than the HDPP and can crust over, making removal difficult.

Maintenance also worries about carryover of broken mesh into the condenser and product. Quality control has seen no sign of mesh in the three years we have used HDPP packing.

Even with that concern, maintenance said a bed limiter wasn't needed for metal packing like it was for plastic. So, one wasn't installed with the metal packing.

Currently, cleaning the distillation tower involves washing with a detergent and then muriatic acid, followed by hot water. Maintenance insists that a high-pressure gun easily can steam clean the metal packing and metal mesh.

Did we make the right choice? Is there any other way to get higher efficiency in the upper section of the distillation tower? What kind of trouble might we face using metal packing and a metal mesh pad?

INVESTIGATE VARIOUS ISSUES

Look into four key aspects:

1. Check liquid and vapor flows in the column. Do a pressure and temperature survey on the column. Issues such as channeling, liquid or vapor maldistribution or flooding could cause purity problems. If the project also involved changing the size or configuration of the overhead condenser, make sure flow of cooling medium is adequate and air has been vented, and address any other issues that could impair condensation.

2. Compare the current operation with that with HDPP packing. If the rates are comparable to those in the HDPP column, then evaluate the possibility of liquid/vapor maldistribution:
   - The liquid distributor may not have been installed properly (not plumb level). Try varying liquid traffic and boil-up to see if you get improvement in product quality. If you don't get any improvement, misalignment is a possibility.
   - Fouling may afflict the liquid distributor. (The problem statement doesn't say if the liquid feed is fouling or corrosive.)
   - Poor vapor distribution, though not as common as liquid maldistribution, could exist for large columns.
   - You might consider X-raying the column to get visual confirmation about mis-installation of internals. This approach, though effective, is cost-intensive. However, a possible reduction in shutdown duration (because of more effective planning of repairs) might more than compensate.

3. Check the design basis used for changing HDPP to metal packing/demister.
   - Compare the HETP used for metal packing with that of plastic packing — they should be comparable.
   - Likewise, the HDPP and metal designs for the liquid distributor and other internals should be similar.
   - If significant carryover of packing (to the condenser system) occurs, a bed limiter would be beneficial. Because metal is heavier than plastic, there's less of a need for a bed limiter with metal packing than plastic packing, strictly on a weight basis. However, you also should account for abnormal operations, sudden spikes in vapor flows, start-up and shut-down conditions.
   - Packing is available in various sizes and configurations such as pall rings, snow flake, tri-pack and many others. Some of the configurations may be prone to locking (of adjacent packing) which could cause lower separation efficiency. Check with the vendor.

4. Your vendor can provide information on wettability of metal versus plastic packing. Some literature indicates minimum flows for good wettability are lower for metal than for plastic packing; metal packing seems to be more "tolerant" than plastic packing as far as wettability goes. However, the type of fluid, temperature and pressure as well as the particular metal and metal structure could influence wettability.

GC Shah, consultant
Houston

CONSIDER METAL'S DOWNSIDES

My experience steam-cleaning metal mesh pads belies your maintenance engineer's experience. Metal mesh pads are inflexible and easily become encrusted. These encrustations are difficult, perhaps impossible, to remove without damaging the pads. In addition, damaged metal pads cost about four times as much as HDPP packing to replace — and require 4–8 weeks lead time while HDPP packing usually is available via next day air.

HDPP pads are more efficient than metal ones. It's easier to weave strands of plastic than metal, so a finer weave is possible. By the way, the absorption coefficient for "packing" for any mesh pad typically is 4–5 times greater than the best random packing available today. This is true even for a metal mesh pad.

Wetting is very important with random packing and mesh; a thick fluid layer is preferred. So, the fluid should have good affinity to the material. Water and plastic packing have poor affinity; oil and plastic have good affinity. Water and metal have excellent affinity; oil and metal have poor affinity. Plastics and ceramics initially have poor affinity for water but this dissipates somewhat after the first couple of days' operation.

Obviously, the HDPP packing performed better than the metal packing. The engineering before the installation should have included a review of the performance of the two materials. I've been in the situation overseas where packing was switched without notice. Fortunately, I always kept an ace up my sleeve: the pumps always were oversized 10–20% to compensate for some loss in packing performance.

While maintenance may have some concerns about cleaning, you can use the muriatic acid on the HDPP and allow for a soak. This should provide the sought-after results.

Dirk Willard, consultant
Wooster, Ohio

SEPTEMBER'S **PUZZLER**

I'm a new process engineer hired to sort out a botched expansion. The plant tried to increase production by replacing our reliable pressurized batch reactor with a vessel with double the capacity. The new system (Figure 1) has operated for three months but isn't performing well.

In the new setup, we boosted the agitation by a factor of 30% but kept the same heat exchanger because, according to corporate, it was oversized by a factor of two — now, the capacity matches the theoretical heat load. In addition, we increased the pump motor size and added a variable frequency drive — before the scale-up, the pump ran at the bottom of its curve. We retained the steam control valve; the cooling water is on an open-closed valve. We got rid of the bottom shell baffle and also the pre-batch tank, which our researchers believe we don't need. We largely duplicated everything else. The previous plant owners left scant records, so we had to go by modeling. The designers didn't bother talking to any of the operators; it was a hostile takeover so the old managers and engineers aren't cooperating.

I inspected the old vessel in the boneyard and noticed the bottom baffle was added later; the code stamp agrees. The agitation nozzle appears to have been beefed up, perhaps afterwards as well. I checked the motor and it's always been in the same bucket.

Currently, we're having difficulty starting the reactor. We also are having trouble cooling it down between batches. The relief valve on the vessel has popped twice in the past month — an operator told me that never happened before. The valve sticks open when it relieves. The viscosity is lower than expected, about 180 cP, suggesting a reversal of the reaction or incomplete reaction, and the temperature spikes above 180°F at the reactor outlet. I had the operators reduce the batch size by 30% and we seem to be making good product with the process in control.

Further complicating my troubleshooting, the new management changed the batch ingredients. The surviving lab technician from the old days says the viscosities and densities are higher.

What was done wrong? How can we get this process producing at the desired rate?

Send us your comments, suggestions or solutions for this question by August 13, 2021. We'll include as many of them as possible in the September 2021 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.

VISCOUS BATCH REACTOR

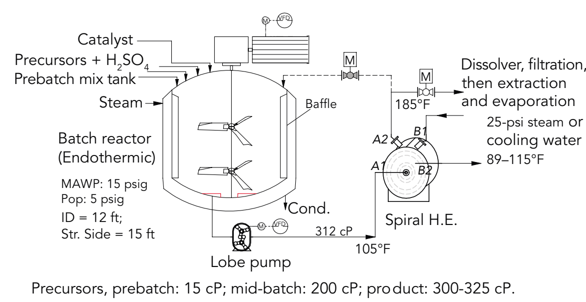

Figure 1. New reactor has twice the capacity of old, trouble-free unit, but poses all sorts of problems.

Don't Skip Development Steps

Pushing technology too fast can cost a company dearly

Most process developers are optimists.

THE TIME will come when you need to try something new in your plant. This can range from installing a recently introduced variant of existing equipment all the way to building a unit for a first-of-a-kind process. Understanding the scope of the change and the various risks involved can help identify if opting for what's "new" is a good idea or not. Let's take "good" idea to mean one that has an acceptable economic return and meets all required safety, environmental and social license requirements. Today, we'll focus on one extreme of this range, the first-of-a-kind plant or major modification.

The traditional path for process development goes from idea to laboratory to pilot plant to small unit to full-scale plant. Every step requires work as new discoveries arise. Few ideas make it all the way to an operating plant.

The National Aeronautics and Space Administration formalized the path of technology development in the 1970s by defining nine technology readiness levels (TRLs). Table 1 shows my adaptation that includes definitions more suited to the process industries. The break point between TRL levels should match step changes in operation where many problems occur. Technology should move to the next TRL level only after achieving success at the current level.

Only a miniscule fraction of the ideas that start at TRL 1 actually ever get to TRL 9. So, here, we'll focus on technology that's promising enough to have reached TRL 5 and what's involved in moving it to TRL 9. These are the levels most likely to involve engineers experienced in commercial plants.

TRL 5 is a pilot plant that succeeds in making the sought-after product at the desired conditions. If multiple steps are required, each may run independently, with the product from the previous step sent to storage until needed.

TRL 6 involves operation of a small-scale unit. Here, small-scale means a plant built using the smallest size of typically available industrial equipment that gives a reasonable scale-up to a full commercial unit.

TRL 7 mainly differs from TRL 6 by integrating units. Most commercial processes try to avoid intermediate storage because of various issues it can raise. Making a flow-through process with minimum storage always is an attractive option. A key step in the small-scale plant is developing operating procedures for handling startup, shutdown, unusual events, quality changes and other operating conditions.

TRL 8 scales up from a small plant to a full economic-capacity unit. It uses normal-size equipment. Standards and procedures developed in the small-scale unit are the starting point for further development.

Finally, at TRL 9, the demonstrated success of one plant leads to building others. Experience gained from the first unit may enable improvements in economics, safety, quality and other performance areas.

Most process developers are optimists. Most process developments fail. Perseverance in spite of repeated failure requires a certain character and outlook on life. This same optimism can lead developers astray, though. If the economics look attractive enough, companies may skip steps. Some recent clients have been tempted to do the equivalent of jumping from TRL 5 (pilot plant, decoupled) all the way to TRL 9 (multiple units running) to grab a current opportunity.

I reckon (based on observation, not statistics) that 15% is on the high side of the probability for success in getting from TRL 5 to TRL 9, even when doing all the steps. And the jump, even if successful, likely will incur much higher development expenses. The cost of figuring out how to make larger equipment work and the costs of off-performance operation on larger stream flows rapidly escalate.

Process industry history is full of seemingly good ideas that took their investors to their financial graves. Before making the decision to skip development steps, truly think through the consequences of units that don't work and devise plans to mitigate financial and performance risks.

TECHNOLOGY READINESS LEVELS FOR A PROCESS PLANT

1	Basic principles observed
2	Technology concept formulated (new product or process identified)
3	Experimental proof of concept
4	Technology validated in lab, usually decoupled
5	Pilot plant, may be decoupled
6	Small scale, may be decoupled
7	Small scale, all steps integrated
8	One unit running
9	Multiple commercial units running

Table 1. A successful technology typically goes through nine levels of development.

ANDREW SLOLEY, Contributing Editor
ASloley@putman.net

Sensors Safely Transfer Liquid Analysis

Memosens 2.0 digital technology provides simple, safe, and connected liquid analysis. This new technology currently is available for pH/ORP, conductivity and dissolved oxygen sensors. The technology converts the measured value to a digital signal and transfers it inductively to the transmitter, offering safe data transfer for increased availability of the measuring point and trouble-free operation. The sensors store numerous relevant data points, such as operating hours, minimum and maximum temperatures, measured values, calibration histories, and load matrices. The sensors also afford a sound basis for predictive maintenance strategies when used in conjunction with Heartbeat Technology, along with enhanced IIoT services via the Netilion ecosystem.

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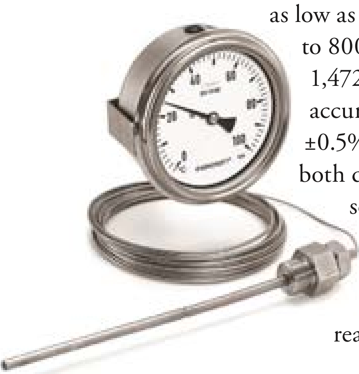

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More-accessible software for the design of shell-and-tube heat exchangers offers greater freedom for teams to collaborate on projects, improving project flow and speeding up design, approval and manufacturing, the company reports. Local cloud-based design software allows users anywhere in the world to share their designs and collaborate on projects. The software is designed for anyone with a moderate understanding of the engineering or thermal basis of heat exchange technologies. Holding project data on a secure central server means those data can be shared across teams, businesses and locations. Users can also export data in standard formats for use in other systems, such as spreadsheets.

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PoE Flowmeters Increase Installation Options

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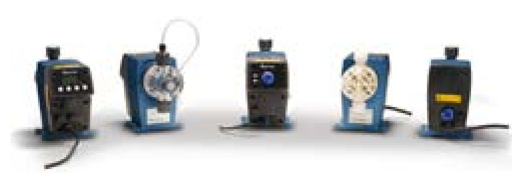
Pumps Suit Precise Dosing Applications

Thirty-five additional models join the Neptune NSP Series solenoid metering pumps and NXP Series stepper-motor-driven metering pumps. The additions include more models with the acrylic degassing head option, along with the standard polyvinyl chloride, polypropylene and polyvinylidene fluoride material options. The models feature capacity ranges from 0.09 gph (0.35 L/h) to 8.1 gph (30.66 L/h) and back pressure capabilities of 43 psi (3 bar) to 232 psi (16 bar). The additional units and material options increase the application range of the two series for use in numerous chemical-handling applications that require reliable and accurate dosing.



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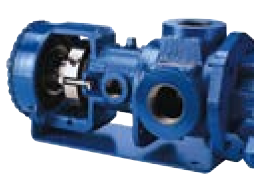

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ADVERTISER INDEX

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Hardy Process Solutions	22
Industrial Magnetics	44
Krohne	19
Lechler	3
Material Transfer	39
Meyer, Wm. W. & Sons	2
Myron L	4
Rembe	39
Spraying Systems Co.	23,39
Vac-u-Max	39
Vanton Pump & Equipment	6
WEFTEC	43

Is a Circular Economy Really Sustainable?

Researchers point to how large-scale renewable energy sources are powered

The challenge comes as humanity diverts renewable energy fluxes to its own activities.

RESEARCH ON the concept of a circular economy typically focuses on closing material cycles — the idea being that it avoids the environmental impacts of extracting raw materials and solves the waste problem. However, a team of Swiss researchers believe this approach is too narrow to use as a foundation for a sustainable society because it leaves open the questions of how much and how quickly materials can be cycled and — most importantly — what energy powers these cycles. Largely neglected in such work, they claim, is that such cycles will require large-scale development of renewable energy resources which themselves must be powered in a sustainable manner.

So, Harald Desing and his team from the Swiss Federal Laboratories for Material Science and Technology (EMPA), St. Gallen, Switzerland, have posed this question: "Is there enough renewable energy available globally to sustainably manage material flows without violating planetary boundaries?"

Writing in the open access journal *Energies*, they start from the point of view of Earth as a system that only exchanges energy with space. Solar radiation accounts for most of the energy brought into the system and — with small contributions from planetary motion and geothermal energy — the Earth uses this to power subsystems such as oceans, forests and the atmosphere. These, in turn, extract free energy (exergy) from the incoming energy fluxes and convert it to wind, water currents and biomass production.

Whether energy conversions are taking place in the natural Earth system or in a technosphere created by humans, all energy ultimately radiates back into space, the authors note.

The challenge comes as humanity diverts renewable energy fluxes to its own activities and reduces those available to the Earth. If this becomes too large, it will exceed "tipping points," the authors warn, leading to rapid and irreversible changes in the Earth system — melting ice caps and the resulting acceleration of climate change, for example.

Desing and his co-researchers estimate that Earth needs 99.96% of the energy arriving from space to power its systems, leaving 0.04% for use by mankind. However, they add, this small fraction is still roughly ten times higher than today's global energy demand.

The researchers used a system of electrical energy equivalents to further study various renewable energy possibilities. This showed some substantial differences in conversion losses depending on whether solar energy, wood or hydropower generates the electricity. In fact, direct solar energy conversion involves fewer conversion steps and fewer energy losses than other renewable options.

However, the scale of solar parks needed to achieve this present its own threat to the Earth's existing system in terms of disruption to biodiversity, evaporation and, thus, the water cycle, the radiation of heat back to space and much more.

The land issue also applies to harvesting of what they refer to as chemical energy from agriculture and forestry. This, in turn, competes with food production.

The paper proposes a new method to estimate the global appropriable technical potential (ATP), which considers and respects Earth system boundaries and the human demand for chemical energy.

The new method could be used in global, national and even local scenarios to evaluate questions such as: "Can the current food waste be a significant renewable energy resource?" and "How would an improved conversion technology increase ATP?" Furthermore, with additional data and robust assumptions, the method could answer policy-relevant questions for moving towards a sustainable circular economy such as: "What are priority renewable energy resources for investments?" or "What maximum levels of circularity are achievable with the appropriable renewable energy?"

The authors acknowledge their findings are essentially preliminary and their judgment is subjective and restricted to the selected data sources. "Refined and policy-relevant results could be obtained with more data, more-detailed models and experts' knowledge in the respective fields of energy options," they note. All calculation sheets and Matlab code files are available in the supplementary materials section of the paper.

Similarly, adding lifecycle impact assessments for state-of-the-art technologies to the current method could offer a broader perspective.

For now, the EMPA team is exploring what such a pathway from a fossil to a solar society might look like; the solar energy system must not only be large enough to meet global demand but also replace the fossil fuel system quickly enough to avert the climate catastrophe in time, they caution.

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