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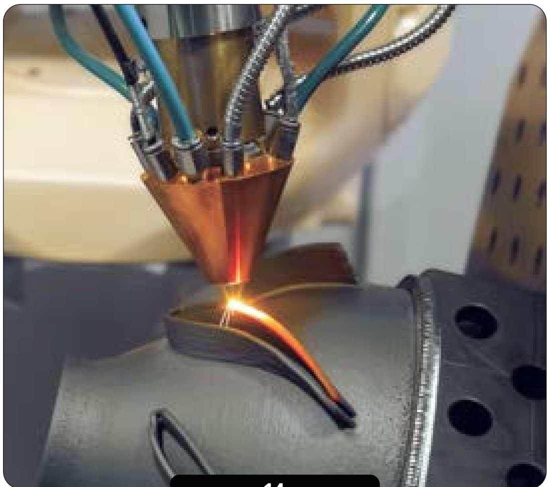

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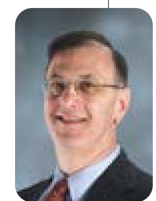
See the Forest Not Just the Trees

Chemical makers' efforts on CO_2 address only part of the problem



Preventing further deforestation is gaining growing attention.

REDUCING EMISSIONS of carbon dioxide is an imperative for many companies in the chemical industry. Of course, ongoing — but hopefully much lower — emissions of CO_2 are inevitable. So, chemical makers also are focusing considerable efforts on better ways to capture, store and utilize CO_2. Fortunately, much progress is occurring in all these areas, as *CP* has detailed in recent cover stories "Collaboration Promises a Winning Hand," https://bit.ly/3zB2bCL, and "Net Zero Efforts Add Up," https://bit.ly/37kcWxr, and in ongoing news items such as "Surface Layer Improves CO_2 Capture," https://bit.ly/3b1i0rY.

Nature always has played a crucial role in dealing with CO_2 in the atmosphere. Most notably, forests serve as a critical resource for converting CO_2 into oxygen by photosynthesis. Unfortunately, demand for certain commodities has spurred substantial loss of forest acreage. Thus, preventing further deforestation is gaining growing attention.

Here, chemical makers largely must sit on the sidelines, with other firms necessarily taking lead roles.

A report "From Commitments to Action at Scale — Critical steps to achieve deforestation-free supply chains" provides a perspective on such companies efforts. It was issued in late May by the Accountability Framework, https://accountability-framework.org, a coalition of groups including the Rainforest Alliance, and CDP, www.cdp.net, an organization that operates a disclosure system for firms to report carbon emissions, water use and deforestation.

In the report's preface, Jeff Milder of the Rainforest Alliance and Thomas Maddox of CDP caution: "Without the right systems in place to address deforestation — including effective traceability, supplier engagement, monitoring, verification, and landscape-level collaboration — companies will be unable to address GHG [greenhouse gas] emissions and other environmental impacts in their supply chains." They continue: "How much progress has been made? Unfortunately, it would be generous to say that the glass is half-full."

The report, available at https://bit.ly/3MT6PyP, uses data from disclosures to CDP's 2021 forests questionnaire — in particular, the responses of 675 companies that produce or source one of the seven commodities responsible for the bulk of commodity-driven forest loss: palm oil, timber, cattle, soy, natural rubber, cocoa and coffee.

Among the key findings are:

- Only 36% of these firms have public company-wide no-deforestation or no-conversion policies. A mere 13% have no-deforestation/no-conversion commitments that align with good practice.
- Just 26% report monitoring systems in place to assess compliance with rigorous no-deforestation/no-conversion policies or commitments.
- Timebound quantifiable targets related to supply-chain control systems largely are lacking. Only 23% report third-party certification targets, and just 14% say they have a traceability target related to their commitments.
- Traceability efforts generally have significant gaps. Only 23% of firms can trace more than 90% of the volumes they produce or source, while 38% have no information about the origins for at least half of their commodity volumes.

The chemical industry certainly must step up its efforts to deal with CO_2, but so too must companies responsible for deforestation. ●

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Dry Your Solids Properly

Focus on the characteristics essential to the final product

Drying is controlled by partial pressure not temperature.

ONCE SOLIDS are crystallized in the form of a wet cake, we normally would dry that cake. However, this step can alter the finished product in detrimental ways such as phase changes, lumpy material or solids that are much finer than intended. To prevent such issues, the first thing we need to evaluate is the particle strength — at least if we want to retain the particle size we spent so much time producing.

An alternative approach to drying may be to select and run the dryer so the particles enlarge; this saves time in the crystallization step. At one point, we had developed a new detergent that avoided some major environmental issues. The chemists had laid out the crystallizer to make particles in the 300-μ range. While these particles were easily separated from the mother liquor, they were fragile; the most economical dryers produced too many fine particles, which would create a dust problem for the consumer. The solution was to make 50-μ particles in the crystallizer and run the fluid bed as an agglomerator. The crystallization time was very short, and the fluid bed produced a stronger particle. Also, we could mix fines from the dryer with the wet cake.

The conventional route for producing particulate solids is:

1. crystallize;
2. filter or centrifuge the solids along with a washing step; and
3. dry to the final solvent content.

Another option is to crystallize the solids, follow with a liquid separation step, and then redissolve the solids before a second crystallization. Often, the product can be spray-dried to the final material. Many precipitations are processed in a similar manner. Sometimes, the better route is to change the crystallization endpoint, as described above, to get the desired particle strength or some other characteristic.

As I emphasized in my July 2018 column ("Develop Drying Curves," http://bit.ly/2CO4Woy), a drying curve is very important. I'm not talking about a test at one temperature but instead running a series of temperatures and humidities. Remember, the primary determinant of drying rate is the difference between the partial pressure of solvent in the gas that surrounds the particle and the partial pressure of the solvent at the surface of the solid. One way to improve the quality of the drying curve is to measure the single-particle drying characteristics, as described in the 2018 column. Using that technique, you can design most dryers without doing the test in each type of dryer (i.e., spray, fluid bed, drum, rotary, flash, etc.) to assess the feasibility of your selection. Then, you can focus your attention on the details of the dryer design and how it integrates into your overall process design.

EXPLORE ISSUES POSED BY SOLIDS
Check out previous Solid Advice columns online at www.ChemicalProcessing.com/voices/solid-advice/.

Now armed with a good drying curve and data on particle strength, what else should you consider? Most people start their dryer selection by asking about the wet cake characteristics. I always start a process design by asking the question, "What do you want the final product to look like?" After all, the most important part of a process design is making final product with the desired characteristics.

Each dryer has strengths and weaknesses. Starting from the wet cake side of the process will emphasize the feeding of material, rather than discharge and downstream handling of the product. For example, a drum dryer does a nice job of removing very low amounts of solvent; however, perhaps it will have to deal with clumps that may have pockets of wet product. Maybe a belt dryer would give a more uniform product.

While hundreds of dryer designs exist, I only can focus on a small subset in this column. So, we'll concentrate on the workhorses — fluid beds, spray dryers and rotary dryers. I picked these because they behave quite differently and have unique advantages and disadvantages. They all rely on dispersion and highly depend on convective heating. We find them primarily in continuous processes but they sometimes do appear in batch operations. Fluid beds can be heated in the dryer by direct contact with an internal heat exchanger or by heating the gas. Internal heating is especially useful for heat-sensitive materials. Rotary dryers can handle slurries or sticky solids better than most fluid beds; spray dryers will take on high solvent concentration feeds. Also, as we'll see in the next column, they all require gas cleaning systems.

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Get Fired Up About Combustible Dust

Take adequate steps to defuse dangers posed by such particles

Safety is situational: count on measurements.

LIGHT FLASHED innocently from a small dust cloud. A pressure wave from this tiny ignition suddenly exploded. The cloud swallowed an operator nearby, who began to choke as it seared his nose and throat. A larger explosion, like a flash bulb, erupted out of nowhere. He was thrown across the room and killed by the pressure wave from the chain reaction resulting from the dust explosion. Pretty grim.

Combustible dust demands respect. The U.S. Chemical Safety and Hazard Investigation Board cited 119 deaths from dust explosions from 1980–2005. (Dust also can pose a variety of other risks, as noted in "Dust Never Sleeps," https://bit.ly/3QkOL3p.)

I've broken this subject into five aspects: 1) understanding the risk; 2) identifying the risk; 3) classifying the risk, i.e., creating electrical-area-classification drawings; 4) mitigating the risk; and 5) establishing and maintaining a structure of vigilance.

This column focuses on the first two aspects. A key resource is NFPA 499, "Recommended Practices for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas," 2021 ed., https://bit.ly/3HnHjkk, issued by the National Fire Protection Association (NFPA), Quincy, Mass.

Let's now turn to definitions.

A combustible dust is one identified by the U.S. Occupational Safety and Health Administration and the NFPA as providing enough heat to ignite and sustain a flame. Many factors affect combustion: moisture, particle size, degree of dispersion, surface condition of the particles, oxygen presence, etc. Typically, testing begins with a 200-g sample for a go/no-go screening involving pre-treatment to sift 200-mesh particles (95% efficiency) and dry to less than 5% moisture. If that shows potential risk, then other tests are performed to determine explosive pressure (K_{st}, P_{max}), minimum ignition energy (MIE), minimum autoignition temperature (MAIT), minimum explosive concentration (MEC), hot surface ignition temperature (HSIT), limiting oxygen concentration (LOC), resistivity and charge relaxation, and chargeability. Of course, testing at the conditions of your dust, i.e., particle size, etc., will yield the most realistic results. Chapter 2 of NFPA 499 presents several useful references for tests and definitions.

NFPA 499 identifies four groups of combustible dusts: E — metal dusts, e.g., aluminum, zirconium, beryllium, magnesium (e.g., $K_{st} > 300$); F — carbon dusts with more than 8% volatile (flammable) liquid, e.g., coke dust, wood dust, sugar, sulfur (e.g., $0 < K_{st} < 200$); G — dusts from chemical, food or pharmaceutical manufacturing, such as those from plastics, cellulose and grains as well as fibers longer than 500 µ; the fourth group generally doesn't occur in the chemical industry.

NFPA 499 Section 3.3.6 describes a "hybrid mixture." This is "an explosible heterogeneous mixture comprising gas with suspended solids or liquid particulates" under the following criteria: ≥ 10% of the lower explosive limit (LEL) for the volatile and ≥ 10% of the MEC for the combustible solid. A hybrid can pose a magnitude greater danger than any of its components. The lesson here is that, though standards and textbook references are helpful, safety is situational: count on measurements.

For example, as a researcher on rocket propellants for the U.S. Air Force, I worked with a contractor to design and build a zirconium particle grinding factory to replace one in San Francisco that blew up, also taking out a neighboring noodle factory. The new plant was a step forward, designed to produce a strict particle-size distribution because even a small percentage of fine particles would ignite in air and destroy the rocket containing them. This underscores that particle distribution is critical to safely handling dusts. The finer the dust, the lower its layer ignition temperature and the easier it is to ignite.

NFPA 499 barely touches on two other dangers with dust well known to safety experts in the business: 1) dust can insulate an electric motor or, contrarily, conduct electricity where it isn't supposed to, resulting in over-heating, fires and even ignition; and 2) some dusts can melt and behave more like flammable or even combustible liquids than solids. In the second case, NFPA 499 recommends determining if the cloud ignition temperature is lower than the layer ignition temperature.

We'll get more into identifying combustible dust risk in the next column, and then selecting proper electrical area classification.

For more insights on dealing with combustible dusts, check out *CP*'s ongoing "Combustible Dust Round Table" webinars at www.chemicalprocessing.com/webinars.

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Nanoscale Membranes Boost Organic Separations

Tunable pores enhance selectivity and energy efficiency

RESEARCHERS AT the University of Pennsylvania, Philadelphia, have adapted self-assembling membranes for more-energy-efficient nanofiltration in organic solutions such as ethanol and isopropanol. These membranes are compatible with organic solvents and can be tailored to address different separation challenges. Organic solvent nanofiltration can reduce the footprint of traditional thermal separation processes, note the researchers, who add the uniform pore size of the membranes they developed provide compelling advantages in terms of membrane selectivity and, ultimately, energy efficiency as well.

NANOFILTRATION

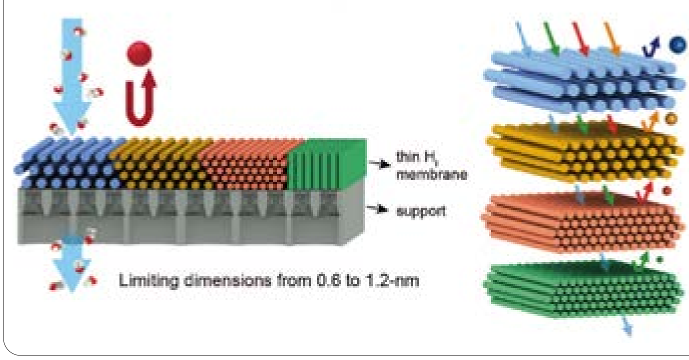


Figure 1. Methods used to create membranes allow for fine-tuning the spacing of the nanostructures within the resulting filter. *Source: University of Pennsylvania.*

Their study, published in *Science Advances*, describes how the uniform pores of the membrane can be fine-tuned by changing the size or concentration of the self-assembling molecules. The researchers believe this tunability enables the membrane technology to help solve more diverse real-world organic filtration problems.

"The membranes provide the ability to change the pore size in small increments, and also the surface chemistry of the pore walls. Some of the real-world organic filtration problems of interest include acetone recovery, homogeneous catalyst recovery, recovery of hexane and ethanol used in solvent extraction, and aromatic enrichment (e.g., separation of benzene from cyclohexane, as model systems). We anticipate that tuning of the pore size and surface chemistry will make it possible to tailor the membrane performance for the particular applications of interest," says Chinedum Osuji, a professor in the school's Department of Chemical and Biomolecular Engineering.

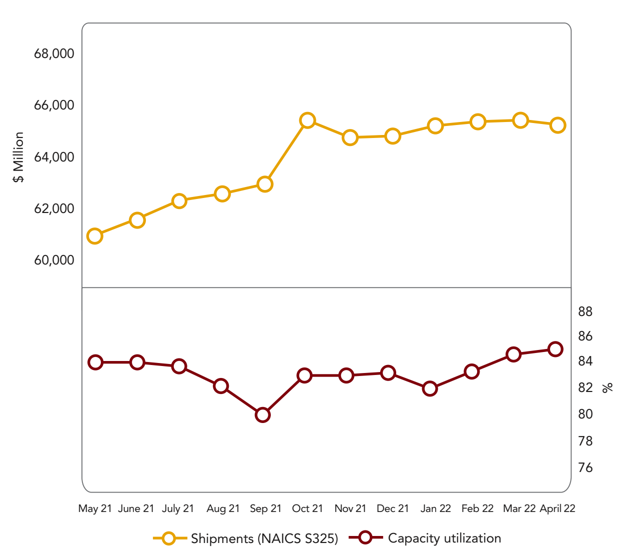
Maintaining membrane stability in organic solvents with different polarities posed a challenge. To combat this, the team created membranes by first forming lyotropic mesophases of surfactants in water, spreading the soft gel as a thin film, and then using a chemical reaction to link the surfactants together to form a nanoporous polymer. The size of the pores in the polymer are set by the self-assembled structure of the lyotropic mesophase.

"At a certain concentration in an aqueous solution, the surfactant molecules aggregate and form cylindrical rods, and then those rods will self-assemble into a hexagonal structure, yielding a gel-like material," explains Osuji. "One of the ways we can manipulate the permeability, or size of the pores in our membranes, is by changing the concentration and size of the surfactant molecules used to create the membrane itself. In this study, we manipulated both of those variables to tune our pore sizes from 1.2 nanometers down to 0.6 nanometers."

"A specific application for this technology is biofuel production," notes Osuji. "We are working on separations of model mixtures, and specifically, on examining separation of butanol-water. This is work that is currently in progress in the lab," he adds.

Moreover, because the manufacturing of many pharmaceutical products requires the transfer of a chemical intermediate from one solvent to another miscible solvent, this new membrane may provide a perfect solution to drug development filtration needs, say the researchers.

ECONOMIC SNAPSHOT



Shipments eased but capacity utilization rose. *Source: American Chemistry Council.*

The team also notes that larger-scale membrane fabrication can use roll-to-roll solution processing rather than the current solution-based spin-coating method.

"Spin-coating is a solution-based fabrication process, as is roll-to-roll processing. Industrial-scale membrane fabrication typically uses roll-to-roll processing, with dip coating or blade coating for deposition of material from solution onto a large support film. We need to translate our current process conditions (defined by solution concentration, spin speed and spin duration) into conditions that yield the same result for a roll-to-roll compatible deposition. (e.g., concentration, blade height, film speed)," Osuji further explains.

"We are conducting experiments on the mechanical properties of the selective layer materials, but in practice, the durability in service is what is important," stresses Osuji.

Furthermore, the membrane's chemistry (rich in quaternary ammonium groups) makes it robust against bio-fouling, say the researchers. "We have not examined other types of fouling or scaling behavior," he notes.

"The technology we are pursuing is opening up fundamentally new possibilities for rationally designed uniform nanostructured membranes. We are excited about the potential to affect a broad range of selective transport applications," concludes Osuji.

Plastic Waste Yields Hydrogen and Nanotubes

RESEARCHERS AT Nanyang Technological University (NTU), Singapore, have developed a two-stage process to convert waste plastic into hydrogen and carbon nanotubes. It especially targets difficult-to-recycle plastic litter containing contaminated food packaging, polystyrene foam and plastic bags. While applicable anywhere, the process particularly promises to help Singapore deal with the about 868 million kg of waste plastic annually generated there; currently only 4% of that is recycled, with most of the rest incinerated.

The first stage of the NTU process involves high-temperature thermal decomposition of plastic waste into a syngas that also contains low concentrations of hydrogen molecules.

In the second stage, the gases enter another reactor filled with an unspecified catalyst. There, hydrogen gas is produced and carbon nanotubes are synthesized via a chemical vapor deposition process. The nanotubes then can be purified and functionalized using water-free techniques, allowing for efficient metal recovery and avoidance of liquid waste, note the researchers. Functionalized nanotubes in a powdered form are ideal for many uses including batteries, coatings and films, they add.

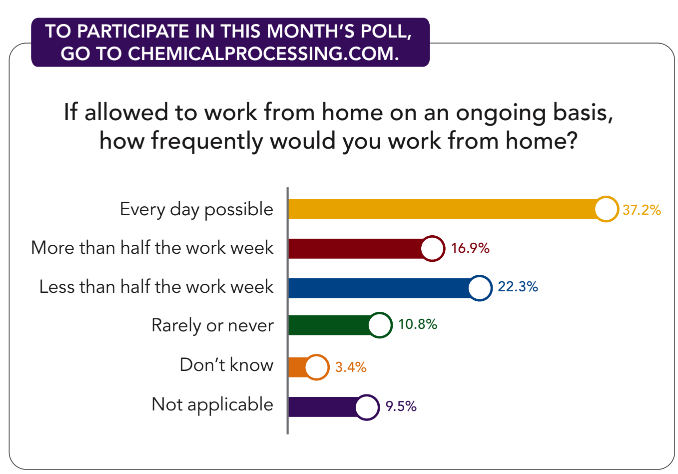
The researchers say their pilot, laboratory-based reactor can produce 70–150 kg of hydrogen and 700–800 kg of solid carbon from 1,000 kg of plastic waste.

"The novelty of our invention is actually not the pyrolysis system that converts plastics into gases, but that we can convert these gases into solid carbon using our catalyst. So we are looking to convert waste plastics that cannot be recycled into high-value chemicals and resources, such as hydrogen fuel, synthetic fuel that could replace petrol [gasoline], and carbon nanotubes used for many industrial applications," explains associate professor Grzegorz Lisak from NTU's Nanyang Environment and Water Research Institute.

The multimillion-dollar research joint project, supported by Singapore's Industry Alignment Fund-Industry Collaboration Projects, aims to develop feasible solutions to economically scale up the conversion of waste plastics to hydrogen over the next three years.

To further refine the new conversion method and assess its commercial feasibility, the research team is test-bedding it on the NTU Smart Campus to treat local plastic waste, in partnership with Bluefield Renewable Energy (BRE), Singapore, an environmental firm that specializes in mobile waste-to-resources technologies.

BRE is bringing to the test bed knowhow developed from its own flexible pyrolysis process called Thermo Disintegration Waste to Resource (TDWR), which already is deployed commercially in Singapore. That technology can handle feeds including biomass, gardening and food wastes, as well as discarded plastics such as polyethylene and polypropylene. TDWR breaks down the wastes in a reactor running at 900–1,000°C to produce biochar, syngas and electricity.



More than half of respondents want to work from home at least half the work week.

Yes, It Does Matter

Incorrect installations can hinder recouping any energy savings

The root problem was poor communication.

I WAS talking to the energy manager at a large oil refinery. I had worked on the design for a crude unit revamp there the previous year. He casually commented, "By the way, they decided to put E-15B in parallel with E-15A." He paused for a moment when he saw the look on my face. "That doesn't matter, does it?"

"They did what!?" He was rather shaken by my vehement response.

A key part of the preheat train design was a new shell-and-tube heat exchanger, E-15B, added in a countercurrent series arrangement with an existing heat exchanger, E-15A, to recover additional heat from a major product rundown stream. As discussed in my March 2022 column, "Squeeze Out the Heat," https://bit.ly/3tNkhhf, this configuration improves the use of temperature differences, thus increasing heat transfer. Unfortunately, during implementation of the revamp project, the construction team found the piping would be simpler if they placed E-15B in parallel with E-15A, so they installed it that way. That change turned out to be significant: It reduced the heat recovery benefit of the revamp by about 50%.

I asked the energy manager if they could correct this error. He was skeptical. The first opportunity to make any changes was several years away, at the next turnaround. Even then, the change would be mechanically difficult; he doubted it would be given priority.

A heat recovery project at a petrochemical complex posed a different problem. This project added a new heat exchanger to preheat deaerator feed water, using heat from a product rundown stream. The project was intended to reduce both the steam demand in the deaerator and the air cooler's heat load.

We had to limit the deaerator feed water temperature to 230°F. I recommended a system that bypassed a portion of the rundown stream around the new heat exchanger to control this temperature. However, the project was installed with the bypass on the deaerator feed water instead (see Figure 1).

Shortly after the project came online, operators reported the preheated water temperature frequently exceeded the 230°F limit; the pressure drop in the deaerator feed line was excessive due to vapor locking in the heat exchanger. The problem was in the control scheme. Bypassing deaerator feed water around the heat exchanger reduced heat pickup, as expected. However, though the heat pickup decreased, the amount of water passing through the heat exchanger fell even more. Consequently, the temperature of the water leaving the heat exchanger rose as the bypass opened, and often reached its boiling point — hence, the vapor locking. This would not happen with a bypass on the rundown stream.

These projects I designed failed because they were installed incorrectly. The root problem was poor communication, as is so often the case. I have often wondered how many projects have failed because of mistakes in my designs — but I am unaware of any such cases. If you happen to know of any, please don't tell me about them, and leave me in my blissful ignorance!

For More Information: Alan P. Rossiter, 'Back to the Basics,' *Hydrocarbon Engineering*, Vol. 12, No. 9, pp. 69–73, September 2007.

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IMPROPER INSTALLATION

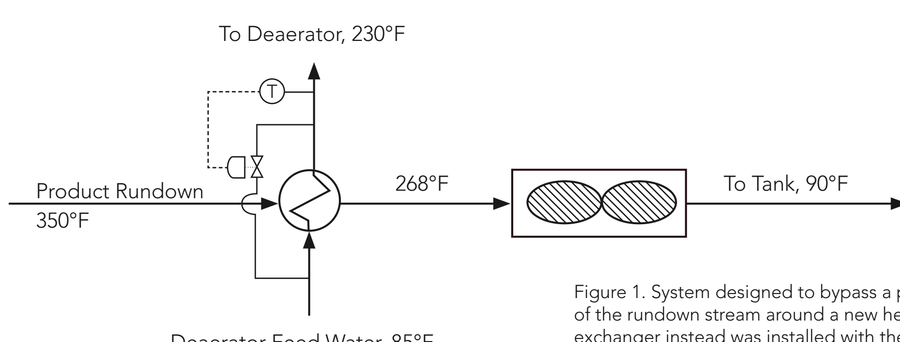
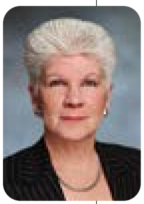


Figure 1. System designed to bypass a portion of the rundown stream around a new heat exchanger instead was installed with the bypass on the deaerator feed water.

Get Ready for Superfund Excise Tax

First deposit of reinstated tax used to fund cleanup of hazardous waste sites is due July 29



The return of this tax is catching many off guard.

ON NOVEMBER 15, 2021, President Biden signed into law the Infrastructure Investment and Jobs Act (IIJA), reinstating the Superfund excise tax on certain chemical substances under Sections 4661 and 4671 of the Internal Revenue Code (Tax Code). Effective July 1, 2022, the tax many were glad to see expire is back; the first deposit of the tax is due on July 29, 2022. This article discusses the tax and the challenges it poses.

Prior to its expiration in 1995, the Superfund excise tax was used to fund the Hazardous Substance Superfund, established by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. Since the Superfund excise tax expired almost three decades ago, the industrial chemical community's familiarity with its application has diminished substantially. The U.S. Environmental Protection Agency (EPA) used the funds to clean up domestic hazardous waste sites. The application of the tax and the deployment of funds were well understood; the U.S. Internal Revenue Service (IRS) developed robust guidance documents to explain how the tax operated.

Fast forward to today. Many in the chemical community are unfamiliar with the Superfund excise tax legacy, and the IRS is unprepared for the learning-curve challenge reactivating the tax has created. The Superfund excise tax will apply to a list of taxable chemicals and taxable substances, as of July 1, 2022, through December 31, 2031, if not extended. The excise tax applies to companies that manufacture, produce, or import any of the 42 specific chemicals listed in Section 4661 of the Tax Code, including ammonia, butane, benzene and mercury. Manufacturers, producers or importers that sell or use any of these chemicals must pay a tax of $0.22 to $4.87 per ton, depending on the chemical. The tax rates have doubled from the previous iteration of the Superfund tax.

Exemptions from the excise tax are listed in Tax Code Section 4662(b). These include taxable chemicals that are exempt due to their specific use — for example, methane or butane used as a fuel; or nitric acid, sulfuric acid, ammonia, or methane used in production of fertilizer. Ethylene and propylene may also be exempt, but only when used in the production of fuel (motor fuel, diesel fuel, aviation fuel or jet fuel). Section 4662(c)(2) provides an additional exemption from tax liability where a company imports a taxable chemical and exchanges that chemical as part of an inventory exchange with another entity. In these cases, the other entity would be liable for paying the excise tax, not the initial importer.

The IIJA also reinstated the Superfund excise tax on the import for sale or use of any taxable substance under Section 4671 of the Tax Code. Section 4672 defines a taxable substance as any that, at the time of sale or use by the importer, is listed as taxable. Taxable substances include the initial list of 50 taxable substances in Section 4672(a)(3) and 101 others added by the IRS in December 2021, through IRS Notice 2021-66.

Notice 2021-66 does not specify the tax rate for each taxable substance. Section 4671(b) provides the amount of tax imposed is equal to the amount of tax that would have been imposed by Section 4661 on the taxable chemicals used as materials in the manufacture of the taxable substance, if such taxable chemicals had been sold in the United States for use in the manufacture or production of the taxable substance. As of press time, the IRS is expected to issue guidance prior to July 1, 2022.

Companies required to report Superfund excise taxes must do so on their third-quarter 2022 Form 720, due by October 21, 2022. This is for the period July 1–September 30, 2022. Semi-monthly deposits are required, however. This makes the first tax deposit covering the first half of July 2022 due by July 29, 2022. Under the rules, a late fee of 5% may be applied on the amount due for each month the form remains delinquent up to a total penalty of 25%.

It has been almost 30 years since the Superfund excise tax was in effect and, so, its return is catching many off guard. Companies need to be aware of this tax, evaluate the chemicals and substances they import, determine whether they owe any excise taxes, and make a deposit soon. ●

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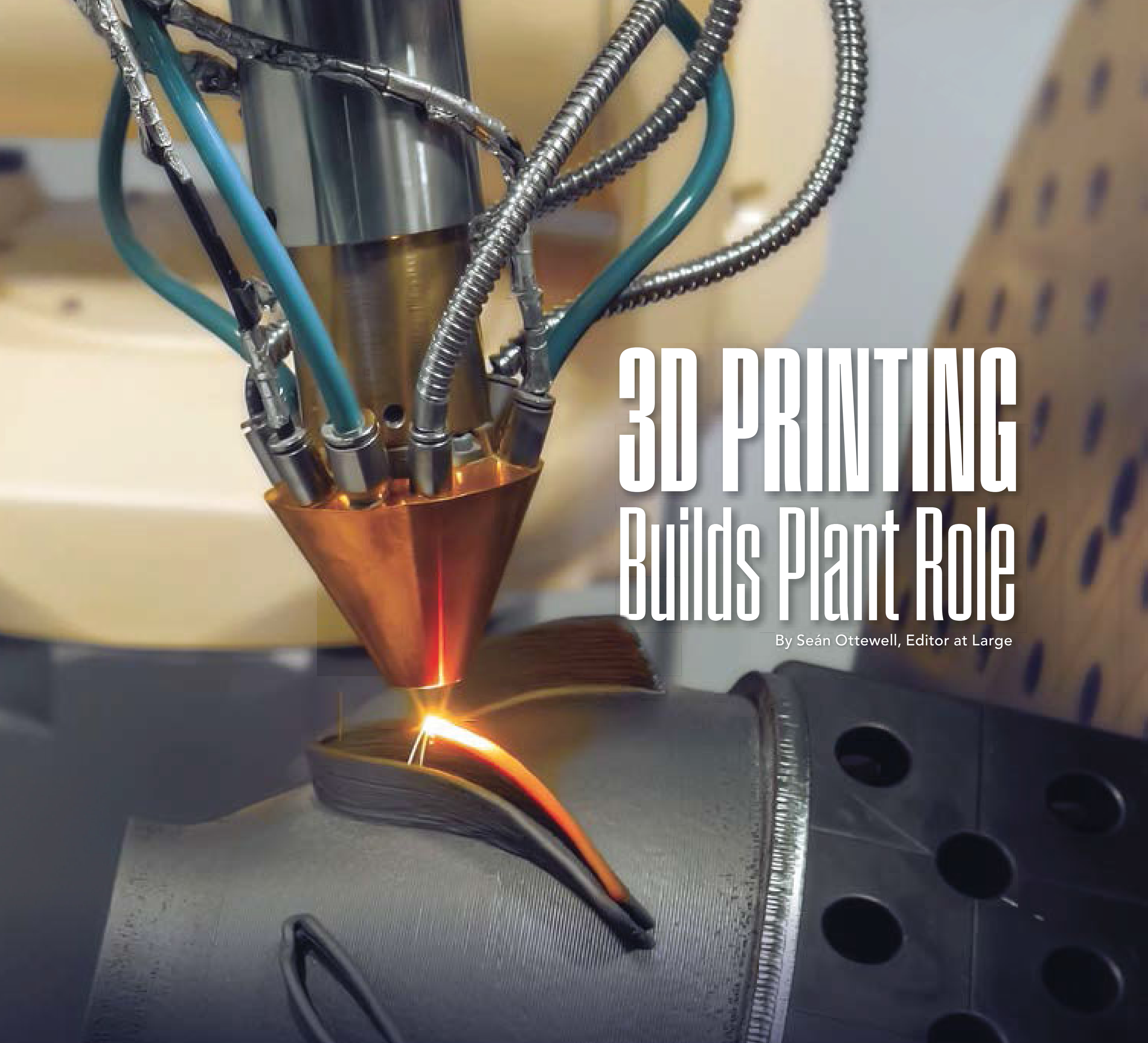

3D PRINTING Builds Plant Role

By Seán Ottewell, Editor at Large

Fast turnaround and ability to produce complex parts are spurring acceptance

3D PRINTING, also known as additive manufacturing (AM), is gaining traction within the chemical industry, especially in the face of ongoing supply-chain challenges. Among the equipment vendors already are taking advantage of the technology are Mott, Lincoln Electric, Torftech and Ekato. Their efforts illustrate what's happening now and what's possible in the future.

LASER POWDER BED FUSION

Long experienced in providing answers to complex filtration and flow control problems for the process and other industries, Mott, Farmington, Conn., became interested in AM when looking to expand its product capabilities and offerings.

The company identified laser powder bed fusion (LPBF) as the best technique to pursue.

"LPBF affords the best resolution for fine features compared to the other metal additive techniques available. It also allows us to alter a multitude of build parameters to achieve the variety of porous structures for our applications," explains senior research scientist Vincent P. Palumbo.

LPBF is a form of laser sintering that begins with a 3D model of the part to be fabricated. The next step is the application of a layer of powdered material on the building platform. A laser then fuses the powder, which solidifies into a cross section of the model. The build platform then is lowered and another layer of powder added and fused by the laser. This lowering/powder application/fusion process repeats until the part is complete — which can take from hours to days, depending on the build volume.

Then, the loose powder is removed to reveal the completed part (Figure 1).

Currently, the company can print with Type 316L stainless steel and titanium alloy Ti-6Al-4V. It is exploring other alloys in anticipation of possible future need, notes Palumbo.

Mott's in-house metallurgical investigations suggest the superior flow performance exhibited by its AM parts — up to double in some cases — stems from the lack of density gradients seen in conventionally pressed-sintered parts.

In addition, this approach avoids secondary operations such as assembly, welding, press-fitting and sinter-bonding. Moreover, the company notes that metal AM parts offer advantages from a maintenance point of view, for example, robustness and the ability to withstand the high temperatures and vibrations experienced during thermal cycling.

In contrast to typical medical applications that employ lattice or pore structures on the order of 150–300 µ to encourage tissue and bone growth, Mott relies on a more randomized, tortuous path of interconnected pores. The pore sizes for its industrial applications in filtration and flow control are significantly smaller, ranging from 0.2 µ to more than 100 µ in diameter. These smaller pore sizes also enable applications that rely on capillary driven flow such as thermal management components (i.e., wicking heat exchangers).

Within this pore size range, the company offers roughly 15 different "media grades," which it calls an important factor when creating better capture efficiencies and flow performance in custom filter and flow-control components.

"So today we have a good combination of applications that haven't been done before. The increased surface area and decreased wall thickness of AM parts can achieve incredibly low pressure drops while also allowing us to incorporate structural supports and generate multi-porosity structures. This is why the chemical and bioindustries are becoming more open to development studies," Palumbo explains.

He cites two recent projects, both carried out at the company's new Farmington Customer Innovation Center, to illustrate this.

The first involves an agitator-sparger/filter blade media development for a bioreactor.

"By printing multiple versions — i.e., media grades — of the blade component, we were able to quickly test the various particle capture efficiencies and liquid flow rates and select the version that provided the best performance for the customer's application," he says.

The second involves a low-pressure-drop filter development. In this one-off, proof-of-concept project, Mott increased the filter's surface area almost three-fold while maintaining its design envelope and filtration capability.

This was an opportunity to mix and match different ratios of coarse and fine porous structures in one component to optimize its design to meet the customer's specific requirements, notes Palumbo.

Parts made via AM sell for a relatively high price, Palumbo admits. However, use of the technique often ultimately allows consolidating multiple parts into one, he stresses. Plus, iterations on performance and design are faster and easier to generate than with conventional techniques — an advantage that is especially useful for prototyping, he adds.

At the same time, the company is looking to increase the physical size of its AM offerings. The limit of the current system is a build volume of 250-mm width × 250-mm height × 350-mm depth. Beyond that, Mott would have to consider other LPBF systems with larger build volumes or other AM techniques. "However, we do have some polymer printing for very large vessel blades," Palumbo concludes.

PROVIDING PARTS QUICKLY

A Chevron USA refinery undergoing a routine maintenance shutdown earlier this year found that some needed replacement parts suffered from extended lead times and supply chain delays. So, to keep to schedule, the refinery switched from traditionally manufactured parts to ones made by Lincoln Electric, Cleveland, Ohio, using its proprietary 3D printing technology.

Chevron's additive engineering team worked with Lincoln Electric and industry experts from Stress Engineering Services, Houston, to print eight nickel-alloy replacement parts that averaged approximately 3 ft in length and over 500 lb each. Printing the entire lot took just 30 days, in contrast to the quoted delivery time of several months for traditional parts.

"Lincoln Electric is vertically integrated, with significant production capacity in both printing systems and wire feedstock, and using our own software we were able to begin

Figure 1. Fabrication technique enables fine resolution as well as easy alteration of build parameters. *Source: Mott.*

printing within a day of finalizing the components' CAD files with Chevron — no waiting on other suppliers. In addition, we are located in the U.S., which eliminates long travel times from overseas and import delays," says a spokeswoman.

"Chevron was actually able to incorporate design changes for improved performance and ease of installation — all of which were readily incorporated into our 3D printing strategy," she adds.

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Lincoln Electric's 3D printing also has saved other plants significant time, she notes.

In one case, a plant conducting a routine inspection discovered that the bearing housing for a large mixer was damaged. It had no spare parts in inventory.

Lincoln Electric 3D laser scanned and reverse engineered the component, created a CAD model from which it could 3D print, and then printed a 625-lb steel bearing housing — all within two weeks. A casting would have taken a couple months. Importantly, the company was able to readily incorporate design improvements from the manufacturing engineers.

The company also 3D printed a redesigned steel blade for the same mixer; it incorporates large, conformal cooling channels that significantly improve heat transfer compared to gun-drilled intersecting holes that require weld plugs. The 3D-printed blade costs about the same as a casting and can be delivered several weeks faster. Moreover, it does not require a foundry to manage pattern storage and, thus, avoids the all-too-common problem of damage or loss of patterns or molds during storage, which often is not discovered until the next order is placed.

Lincoln Electric currently is 3D printing an 8,000-lb component for a flux extrusion line. Obtaining a billet of steel large enough for machining would take five to six months. The company anticipates completing its 3D printing in less than two months. In addition, it cites two more bonuses: the wire has higher strength than the cast iron, and 3D printing near net shape reduces machining time and costs.

The company expects growing interest from operating companies in 3D metal printing and foresees it becoming an established option for quick-turnaround replacement parts, buoyed by its acceptance by companies such as Chevron. Lincoln Electric also believes original equipment manufacturers will adopt 3D metal printing for new components as well as spares.

For chemical makers chary of the AM route, the spokeswoman notes the company's 3D printed components are deposited weld metal — something well understood and already used in critical chemical operations every day. In addition, the company has extensive test data on the alloys it 3D prints and will generate more data in years to come. At the same time, other companies, universities and research institutes are generating data to characterize 3D printed metal, too, she adds.

The creation of codes and standards, for example, "Standard 20S" of the American Petroleum Institute and the "Boiler and Pressure Vessel Code, code case 3020," of the American Society of Mechanical Engineers (ASME), also will bolster chemical companies' confidence that 3D metal printed parts are sound. Additional industry codes and standards are on the horizon.

Lincoln Electric currently has 18 large-format 3D metal printers for 24/7 production, and plans to increase capacity in the U.S. and around the globe. Plus, it intends to expand the list of qualified materials to ASME code case 3020, and continue to enhance the speed and efficiency of its proprietary 3D SculptPrint printing software.

BIG PLUS AT SMALL SCALE

Torftech, Thatcham, U.K., long has specialized in gas/solid contact technologies such as compact bed and expanded bed reactors. At the heart of these are the company's proprietary patented Torbed process reactors, currently in use in over 150 chemical, mineral, food and waste applications.

While the largest members of the Torbed family are over six meters in diameter, Torftech's latest efforts are at

BLADE RING CURING

Figure 2. 3D printing plays crucial role in producing 50-mm processor made from resin. *Source: Jonathan McDonough/Univ. of Newcastle.*

the millimeter scale and rely on innovative 3D printing technology.

"The reduced price and complexity of 3D printers, especially for large print areas, has allowed us to make prototypes at a reasonable scale for the prototyping that we want to do on a day-to-day basis. The increased print resolution available has also allowed fabrication of very small-scale systems that would be incredibly difficult, time consuming and costly using conventional manufacturing methods," explains senior process engineer Dan Groszek.

Working with the Process Intensification Group at the University of Newcastle, Newcastle Upon Tyne, U.K., the company has developed a 50-mm micro-Torbed processor fabricated in resin (Figure 2).

They have investigated a range of different resins, from "basic" to high-temperature-ceramic-impregnated. Groszek notes this allows Torftech to print using resin for the higher temperature applications it specializes in.

In terms of metal AM, Torftech is looking at several potential designs, both for complex forms and monolithic structures.

"The main challenge is in cost of manufacture when going to larger equipment, especially in metal, but it will be interesting to see if this comes down over the coming years. The trending use cases that we see are: prototyping; use of novel forms that were previously difficult or impractical to traditionally fabricate; and the ability to use modeling to design systems without traditional constraints that can then go through the prototyping and fabrication stages. This allows a totally new engineering approach that can be more guided by modeling," he adds.

Such removal of constraints in the manufacturing process will facilitate, for example, a machine-learning algorithm having freedom to maximize the relevant design parameters without needing to step in and pare back the design to fit manufacturing.

"This will, I believe, lead to many incremental improvements in systems with many additive efficiency increases making overall significant overall process improvements," he says.

"The ability to rapidly prototype and make complex shapes is something that gives a huge boost to creative problem-solving in industry. R&D groups should really take note of the way that 3D printing can hugely improve the ability of a team to create and test new concepts in a very short time span," counsels Groszek.

BETTER IMPELLERS

Meanwhile Ekato, Schopfheim, Germany, introduced its new generation of 3D-printed gas-inducing impellers at June's "Mixing XXVII" virtual conference of the North American Mixing Forum.

The design of gas-inducing impellers is very challenging, notes the company, because it must account for multiple mixing tasks during typical applications such as hydrogenation. These include, for example, gas recirculation, gas/liquid mass transfer, suspending solid catalyst particles and heat transfer. That high complexity calls for a sophisticated geometrical design but conventional manufacturing processes limit what is possible.

Ekato's new generation of 3D-printed, gas-inducing impellers don't face such limits in their geometric design, while using common metallic materials such as grade 1.4404 (Type 316/316L) stainless steel or Inconel IN718.

First, the inner geometry of the gas-inducing impellers is flow optimized to reduce pressure loss of the recirculated gas. Second, turbine-like baffles underneath the impeller induce an axial liquid flow to ensure high gas/liquid mixing at the gas orifices. Third, gas recirculation and gas/liquid mass transfer are optimized for the specific power input by the complex baffle/blade design.

According to the company, these optimizations lead to a 60% increase in recirculated gas rate and an 80% increase in gas/liquid mass transfer for the specific power input compared to an industrial benchmark. This improved performance, in turn, reduces batch cycle time, leading to lower investment costs at similar operating costs. ●

PSM AUDITS UNMASK MYRIAD MISTAKES

This final part in our series covers a broad variety of commonly found issues

By James R. Thompson and James A. Klein, ABSG Consulting Inc.

PROCESS SAFETY management (PSM) audits serve two main functions: to provide feedback on process safety program implementation and effectiveness to identify potential opportunities for improved performance; and to verify compliance with process safety regulations such as the 29 CFR 1910.119 Process Safety Management (PSM) standard of the U.S. Occupational Safety and Health Administration (OSHA) and the 40 CFR 68 Risk Management Program (RMP) rule of the U.S. Environmental Protection Agency (EPA) [1,2]. A facility with a process covered by these regulations must conduct compliance audits every three years.

Previous parts of this series covered some common issues observed in PSM compliance audits related to operating/safe-limits tables [3], operating practices [4] and mechanical integrity [5]. Now, we will look at findings in the elements of process safety information (PSI); process hazard analysis (PHA); management of change (MOC) and pre-startup safety review (PSSR); contractors; incident investigation and emergency planning and response (EPR); compliance audits; and employee participation (EP) and trade secrets. (Industry guidance documents [2,6] provide additional information about PSM element requirements.)

PROCESS SAFETY INFORMATION

Process safety regulations and good industry practice (GIP) require companies to compile and maintain information on chemical and material hazards, process technology, and process equipment. Complete and up-to-date PSI documentation helps plant personnel understand the process design and its hazards, evaluate and control the hazards and risks, and maintain safe and reliable operations. In addition, PSI provides the basis for the operating procedures, mechanical integrity program and MOC evaluations.

PSI accessibility. Often, lack of an index hinders finding the required PSI (e.g., process diagrams, maximum intended inventory, relief system design/basis, ventilation systems, safety systems or equipment files). In most cases, information does exist but its exact location has been forgotten over time or it has been misplaced or misfiled (due to changes in responsible personnel). Developing and maintaining a PSI index or “road map” that 1) details the exact location of electronic or hard-copy documents for each required PSI item and 2) uses terms for each item consistent with the PSM regulations is invaluable to ensure quickly finding the right information to support process safety program activities.

Chemical and material hazards. Issues frequently arise in three areas:

- General safety data sheets (SDSs). Two common SDS issues are 1) the available SDSs do not match the most-recent SDSs available from vendors and 2) hard-copy sets of SDSs are not kept current. These issues can be reduced by 1) eliminating or minimizing the number of hard-copy sets and keeping the hard-copy sets current and 2) periodically reviewing online and hard-copy SDSs of regulated chemicals to ensure they are up to date.
- Corrosivity. Facilities often rely solely on the SDSs for “corrosivity” information, but SDSs frequently only address the corrosivity to human skin and not the important aspect of corrosion of materials of construction of process equipment. This issue can be addressed by 1) referencing the piping and service index (or similar) and engineering specifications that provide such information or 2) including common materials of construction and their interactions with the process chemicals in a chemical interaction matrix (see next bulleted point). An online chemical compatibility database also is available [7].
- Hazardous effects of inadvertent mixing. Facilities often depend on the “incompatibilities” (or similar) sections in the SDSs for the hazardous effects of inadvertent mixing. However, SDSs rarely address the specific chemicals present in a process or only address the incompatible types of chemicals (e.g., bases, oxidizers) that may not be specific or well understood by the operators. Industry typically provides and references a chemical interaction matrix (or similar) [6, 8] that shows all the process chemicals (and, possibly, materials of construction) and notes the hazards involved with each possible specific interaction within the boundaries of the process. The Chemical Reactivity Worksheet is a free tool for evaluating chemical and material interactions [8].

Process technology. While the most common findings in this area relate to safe upper/lower limits and consequences of deviation, which are discussed in detail in part 1 of this series [3], issues also regularly arise in another area:

- Maximum intended inventory. Common issues are 1) there is an inventory (or inventories) but the basis is not documented, 2) the inventory is not consistent with that reported in the facility’s latest risk management plan (RMPlan) and 3) the inventory does not appear to include material in process piping and smaller equipment or to account for onsite inventories in railcars, trucks or containers (an EPA RMP requirement). GIP is to 1) document (e.g., via spreadsheets) details of the maximum inventory for each covered chemical in storage tanks, major equipment and onsite storage and 2) include (or estimate) a reasonable amount (typically, at least 10%) to account for piping and smaller equipment. Plants should document any differences between the maximum intended inventories and RMPlan inventories for consistency during PSM audits and RMPlan resubmissions.

Process equipment. This element frequently shows failings in several areas.

- Electrical classification. The most common issues are 1) the basis for the electrical classification (typically, NFPA 497 [9] or API RP 500 [10]) is not provided on the drawings or associated documentation and 2) the existing boundaries of the classified areas simply stop at the process footprint or at the plant roadways. These issues can be addressed by ensuring 1) the classification is consistent with an appropriate standard, including the distances from possible flammable releases to the boundaries, 2) the standard used is adequately documented and 3) the classification documentation includes figures or notes to cover classified areas not easily shown on a plot plan (e.g., below grade or around vents).
- Relief system design. Available relief device calculations often lack documentation of all overpressure cases (e.g., design basis case and alternatives), inlet pressure drop, outlet pressure drop, reactive forces or venting to a "safe" location. API 521 [11] provides guidance for developing and documenting relief device data. Failure to provide complete data for the relief system design and design basis has resulted in many OSHA citations. Ensuring a facility has complete and up-to-date relief system design information typically involves 1) surveying to determine whether calculations exist for all the relief devices (including relief valves, rupture disks, conservation vents and emergency vents), 2) assessing each calculation to ensure it meets API 521 or other appropriate requirements and 3) updating the calculations, as necessary.
- Ventilation system design. Often, there is inadequate design basis documentation (as well as maintenance) of cabinets/shacks that house nonexplosion-proof equipment (e.g., process analyzers, gas chromatographs). Such equipment should be identified and should meet the design/operating/maintenance requirements of NFPA 496 [12] or other appropriate standard.
- Material and energy balances. The most common issues are the balances have not been updated for 1) capacity/throughput increases, 2) manufacturing recipe changes or 3) new chemicals additions. Also, simple or batch processes frequently lack documented balances. These issues can be addressed by 1) ensuring the MOC program reviews the balances for appropriate changes and 2) developing actual or representative balances for simple/batch processes.
- Safety systems. OSHA has requirements for safety systems in both operating procedures and PSI. The second article in this series [4] covers common audit findings.

PROCESS HAZARD ANALYSIS

PHAs must be performed periodically on processes that contain hazardous materials to develop an understanding of 1) what process hazards and risks exist, 2) how hazardous events can occur and how bad they can be, 3) what administrative and engineering safeguards are provided and 4) what, if any, additional safeguards can make the process safer.

Lists of incidents, MOCs, and previous PHA recommendations. The regulations require PHAs to identify and review previous incidents (with catastrophic potential) and GIP also includes review 1) of MOCs completed (unless a complete "redo" revalidation is performed) and 2) if the previous PHA recommendations were adequately completed and sustained. Typically, lists of each of these items are developed and then reviewed by the PHA team. However, 1) these lists often are not documented, 2) the PHA team fails to evaluate them sufficiently and include any required changes to the PHA worksheets or 3) the current team does not adequately evaluate whether the recommendations were implemented and suffice. These issues can be addressed by 1) evaluating all these items and 2) adding a column to the lists that documents whether there was an impact on the PHA worksheets (e.g., adding a new deviation from an incident or a new safeguard from an MOC or PHA recommendation that was implemented).

Detection methodologies. Toxic or combustible gas detectors are included in 1) the safety systems in the PSI and operating procedures elements, 2) the PHA element and 3) the mechanical integrity element (i.e., monitoring devices). The PHA requirement is to address: "Engineering and administrative controls applicable to the hazards and their interrelationships such as appropriate application of detection methodologies to provide early warning of releases." Often observed is a lack of such detectors in a process, and no documentation that the PHA team considered adding additional toxic or combustible gas detectors. This likely is because the team focused on evaluating the severity/likelihood/risk associated with each deviation and most of the risks are determined to be acceptable with the safeguards already in place. It is beneficial to 1) include a requirement to consider whether additional detectors would reduce the overall risk in PHA teams' scopes/charters and 2) document the results of these evaluations in the PHA reports.

Facility siting and human factors. Issues frequently occur in two areas:

- Checklists. Both facility siting and human factors evaluations typically are addressed by completing industry standard checklists in addition to use of standard hazard

- evaluation methodologies (e.g., hazard and operability studies). However, some PHA teams only document the items they had concerns about and do not provide answers to all the checklist issues. OSHA views this as documentation "by exception" (see Facility Siting question H.1 in OSHA's Refinery National Emphasis Program [13]). Also, it is not uncommon to see unresolved comments requiring some level of follow-up that could be recommendations but are not included in the PHA recommendation list. These issues can be addressed by ensuring PHA teams 1) justify/explain any nonstandard answers in the checklists and 2) resolve comments in the checklists by discussing why they did not believe any action was necessary for items that do not become recommendations.
- Facility siting studies. Many companies/facilities have expanded the facility siting review by performing detailed, sitewide facility siting studies per API 752/753 [14, 15] or other standards. PHA checklists (as discussed above) typically do not review these existing studies and whether the 1) related release scenarios and occupied buildings are still accurate and 2) recommendations have been completed or are in progress. This can be addressed by including a requirement for PHA teams to review the appropriate sections of the sitewide study and document this in the PHA report.

PHA communication. Actions resulting from each PHA are to be communicated to affected employees, but this often is not done or no documentation is provided indicating it was done. Common methods for adequate PHA communication are 1) providing a presentation that is reviewed in safety meetings with affected personnel (or with all personnel) and documented, 2) requiring signoff of the communication by each affected employee and maintaining these records or 3) providing a presentation via computer-based training with a short test or acknowledgement for the employee to indicate its review.

Completion of PHA recommendations. PHA recommendations should be resolved (i.e., reviewed by management, accepted/rejected, and assigned resources for completion with target dates) in a timely matter and actions taken should be documented and completed as soon as possible. However, recommendations often are 1) not resolved promptly (typically within 90 days), 2) rejected without appropriate justification and documentation or 3) not competed in a reasonable time (due to changes in assigned personnel, lack of funding, competing priorities, etc.). In addition, closure documentation frequently is inadequate (e.g., records just say "complete" and do not reference MOC numbers or provide pertinent attachments) or the resolution of a PHA recommendation does not address the specific issue(s) identified. In some cases, the final wording of recommendations also is not updated in the PHA worksheets as the report was edited and finalized. These issues can be addressed through 1) instituting a rigorous process for managing PHA recommendations, including timing requirements, 2) periodic reporting on the status of PHA recommendations, with extra "attention" to those becoming "overdue" or "old" and 3) cross-checking by supervisors or PSM department personnel of the adequacy of closure documentation. Care also should be taken to avoid closing recommendations based on the issuance, rather than the completion, of an MOC or other document that initiates implementation of the action.

MANAGEMENT OF CHANGE AND PRE-STARTUP SAFETY REVIEW

The purposes of the MOC element and the associated PSSR element are to 1) prevent changes in the process and supporting facilities from introducing unacceptable hazards and 2) provide a review that ensures all requirements are met before the introduction of any highly hazardous chemical into a new or modified process.

Management of change. Several types of issues often arise.

- Impact on safety and health. MOCs must consider and address the impact of the change on safety and health, but often this only involves a checkoff by the health/safety/environment group (or similar) or brief discussion rather than a formal, adequately documented evaluation. A thorough evaluation should be part of the MOC process. This frequently takes the form of a "screening" review or checklist of possible safety/health impacts.
- Temporary changes. Limits seldom are established for the number of "extensions" allowed to temporary MOCs or criteria established to allow an extension. GIP typically limits 1) the timing for temporary changes (generally to no more than six months) and 2) the number of extensions allowed before the change must be reverted or made permanent (usually only two or three extensions are permitted). Also, closure of the temporary MOC often is not documented or there is a poor "paper trail" (i.e., how the change was returned to the original design or was changed to permanent (via an expanded or new MOC)). The MOC system should 1) provide a maximum time limit for temporary MOCs (including extensions) and 2) ensure good documentation of all temporary MOCs, including reviews for extensions and the final resolution.
- MOC checklists. Paper or electronic systems usually use checklists (e.g., an extensive roster of PSI categories or other PSM element requirements) to ensure all required areas are adequately addressed. However, the checklists often are 1) very basic and short or are too long to be useful or 2) not comprehensive and lacking all pertinent topics of interest. While there is no requirement for use of a checklist, GIP MOC programs typically use a checklist with enough detail to ensure adequate review of changes.

Pre-startup safety review. A number of issues often afflict various aspects of these reviews.

- PSSR checklists. Frequently, a PSSR checklist is provided but it doesn't explicitly include the four specific regulatory requirements. Checking additional pertinent items is a good practice, but facilities should ensure the required items are not overlooked (or are clearly documented) in the checklist. For example, because the OSHA PSM regulation specifically mentions safety, operating, maintenance and emergency procedures, including all four types of procedures on the PSSR checklist is appropriate.

- PSSR team. In some cases, PSSRs are performed by one or two persons. Although there is no specific regulatory requirement for a team to be involved, GIP PSSRs typically use a multi-disciplinary PSSR team (e.g., usually including operations, engineering, maintenance and safety personnel as a minimum) to ensure a thorough review.
- PSSR approval. Sometimes no documentation clearly shows how and when the PSSR was performed and how any PSSR-identified deficiencies were corrected prior to startup. All potential action items from the PSSR checklist should be captured for follow-up, which is important from both a process safety and regulatory perspective. Documentation also should be provided if no follow-up is to be performed. Facilities should check that their MOC/PSSR system and its workflow ensures all deficiencies are tracked and corrected and there is documented management approval that the change is "safe to start up."

General issues. Failings frequently occur in two areas.

- Informing/training. MOC requires that affected employees be informed of and trained on the change, and PSSR requires confirmation that training of operations personnel has occurred prior to startup. Often, 1) people are "missed" when the communication is provided or 2) there is a lack of clear guidance and consistent application on when and how "training" is to be provided. Many MOCs typically are "simple" changes where "informing" personnel should suffice. These issues can be addressed by 1) ensuring designated employees are informed and sign-offs (or similar documentation) are complete and accurate and 2) establishing specific criteria for when formal training on an MOC is required and for which group(s).
- Management of organization change (MOOC). Although MOOC is not a specific regulatory requirement in the OSHA PSM regulation, OSHA has issued a memorandum [16] indicating that relevant organizational changes should be considered as part of the MOC system. However, often MOOC is not implemented or is implemented inconsistently for all personnel changes. Therefore, facilities should consider establishing an adequate MOOC program as part of their MOC system [17].

CONTRACTORS

The contractor element provides requirements for both the employer (plant) and the contractor employer for contract work in covered PSM processes.

Contractor orientation. Most facilities offer safety and health orientation training or a video to all contract employees on an annual basis to inform them of the potential fire, explosion or toxic release hazards and of the actions they should take in case of an emergency. However, it often is found that no test is given to verify their understanding of the information. So, administering at least a simple test on the plant requirements covered during the orientation is recommended.

Performance evaluation. Employers must periodically evaluate the performance of contract employers in fulfilling their obligations. Usually, this should include 1) meetings with each major contract employer (e.g., typically annually) and smaller contractors (e.g., based on work activities) to review their performance and identify any needed upgrades, 2) periodic, detailed audits of contract employee safety programs, qualifications and training records and 3) documented periodic field audits.

- Skills training evaluation. Facilities typically require basic "safe work practices" training, usually provided by a contractor safety council or by including it in the contractor orientation training. However, many facilities do not verify that each contract employee has been appropriately trained on the skills associated with the person's work (e.g., welding, crane operation, scaffold building). Some plants will accept a statement from the employer that the employee has received the necessary training or certification while other plants periodically audit, e.g., using a third-party service or company employees, a representative portion of contract employee training records for completeness and adequacy. Changes to contractor personnel assigned to the plant require additional review of qualifications.
- Field audits. Almost all facilities have practices in place to audit contract employees in the field as part of work

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INCIDENT INVESTIGATION AND EPR

Process incidents are preventable but, unfortunately, still occur with some frequency. The incident investigation and EPR PSM elements help facilities 1) prepare for responding appropriately to emergencies to mitigate their consequences, 2) ensure that employees and public responders are aware of possible hazards and the proper response and evacuation procedures and 3) learn as much as possible from incidents to prevent recurrence of similar events.

Incident investigation. Several aspects often have failings.

- Incident investigation timing. The regulations require prompt initiation of an investigation, i.e., no later than 48 hours following the incident. However, sometimes, the date/time the investigation began 1) is not documented in the incident investigation reports or 2) indicates it started "late." The latter often occurs when the documentation is based on the date/time of the first formal meeting of the incident investigation team, although the investigation usually begins when the pertinent facts and information are initially gathered and preliminary reporting occurs, which typically happens during the same shift or day of the incident. So, these issues can be addressed by ensuring the incident report documentation captures the date and time when the data collection for the preliminary incident report started.
- Incident reviews. Incident reports must be reviewed with all affected personnel, including contractors, if applicable. This is similar to the discussion earlier about communicating the results of PHAs to affected employees. However, OSHA uses "reviewed" rather than "communicated," suggesting a higher level of interaction is desired. The issues and suggestions provided for the PHA actions are valid here for the incident investigation reports as well as for ensuring documentation of the incident reviews is maintained.
- Incident contributing factors. Incident reports (for incidents

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that resulted in or reasonably could have resulted in a catastrophic release of a highly hazardous chemical) must include any factors that contributed to the incident. However, the reports sometimes focus only on physical issues (e.g., corrosion leading to a leak) or human errors, and do not adequately address management system issues. GIP applies root-cause failure analysis, with trained resources and thorough documentation, to determine and document the physical, human and system contributing factors. Simple incident investigation methods often are used for investigation of near-misses or incidents with minor actual or potential consequences.

- Completion of incident report recommendations. As discussed in "Completion of PHA Recommendations" above, recommendations from incident reports may not be 1) resolved in a timely matter or 2) adequately documented or completed as soon as possible.

Emergency planning and response. Here, too, failings often are found in a couple of aspects.

- Small spill procedures. The EPR element requires facilities to have "procedures for handling small releases." However, frequently, procedures that address handling of small spills of covered chemicals are not provided. This can be addressed by actions such as 1) defining "small" spills for the covered chemicals (e.g., in terms of the amount released or based on whether any flammable or toxic gas detectors are activated) and 2) developing specific emergency action plan procedures for handling each type of spill by plant personnel or contractors, including those not trained as emergency responders.
- Compliance with EPR-related regulations. Although OSHA's EPR element is very brief, it incorporates the following regulations via reference: (1) 29 CFR 1910.38(a) [Emergency Action Plan]; (2) 1910.165 [Employee Alarm Systems, which is referenced in 1910.38]; and (3) 1910.120(a), (p), and (q) [Hazardous Waste Operations and Emergency Response]. Common issues with meeting the requirements of these referenced regulations include 1) names or titles of persons who can be contacted for more information are not provided, 2) issues with the facility alarm system being audible/detectable in all locations have not been addressed, 3) places of refuge (e.g., shelter-in-place locations) are not formally designated or do not meet a set of adequate, consistent requirements, 4) critiques of

emergency responses or drills are not consistently issued or recommendations are not adequately addressed, 5) training of the emergency response team (or fire brigade) is inadequate or inconsistent and 6) required training levels through the facility are not well defined or consistently applied (i.e., first responder awareness, first responder operations, hazardous materials technician, hazardous materials specialist, and on-scene incident commander). Facility emergency personnel should 1) be knowledgeable of all these ERP-related regulations and 2) ensure their emergency action plan and emergency response plan (if they are a responding facility) and the associated program adequately complies with regulations.

COMPLIANCE AUDITS

The PSM regulations require that employers periodically evaluate (and certify) their PSM program by 1) determining that the PSM element practices comply with the provisions contained in the regulations and 2) verifying that the procedures and practices are adequate and are being followed.

Audit certifications. It is fairly common to find that 1) there is no formal "certification" of a previous audit(s), 2) the certification(s) has been lost or misplaced or 3) certifications are provided by third parties (e.g., independent auditors) rather than by the employer. These issues can be avoided by 1) establishing the form/format for compliance audit certifications to be made by the employer (e.g., typically the plant manager or designee) and 2) ensuring consistent retention of certifications along with the required two most recent compliance audit reports.

Completion of audit recommendations. As noted in "Completion of PHA Recommendations" above, recommendations from compliance audits often are not resolved in a timely manner, corrective actions taken are not adequately documented or corrective actions are not completed as soon as possible.

EMPLOYEE PARTICIPATION AND TRADE SECRETS

EP is intended to ensure facilities 1) develop a written program to consult with and involve employees (and their representatives) in PSM activities and 2) make PSM information available to employees (and their representatives). Just because information is viewed as a trade secret for the plant is not adequate justification to withhold details from employees when the information is required for PSM purposes.

Written plan. Although almost all facilities have a written EP plan, the plan often does not 1) discuss how employees are expected to participate in all the pertinent PSM elements and 2) identify the activities and associated documentation to be provided to ensure such participation. This can be addressed by making certain the EP plan adequately addresses both above aspects. Discussion of trade secret policies in the EP plan, if applicable, also is desirable.

Employee consultation. The EP element in the regulations requires the employer "consult with employees and their representatives on the conduct and development of process hazards analyses and on the development of the other elements of process safety management." While good employee participation on PHA teams often is observed, this frequently is not the case as far as consultation on the development/implementation of other PSM elements (e.g., lack of documentation the site safety and health or PSM committee, if one exists, is involved in the "development" or revision of the PSM procedures and also includes a cross-section of employees from various plant groups). One way to address this is to 1) ensure that safety and health (or PSM) committee meetings include employees from various plant groups or areas and are documented and 2) institute a "standing agenda item" to review any new/revised PSM element procedures. Also, document other methods of consulting with employees, such as participation in annual PSM-emphasis safety meeting for all employees.

ADDRESS THE ISSUES

The OSHA PSM regulation was promulgated almost 30 years ago. Yet process safety audits continue to identify poor understanding and ineffective implementation of PSM regulation requirements. This article completes the four-part series on common process safety audit findings and how to avoid them through appropriate understanding and implementation of the relevant requirements and GIP. We hope the information provided in this series will help you better evaluate these important parts of your PSM programs for improved regulatory compliance and safe and reliable operations. ●

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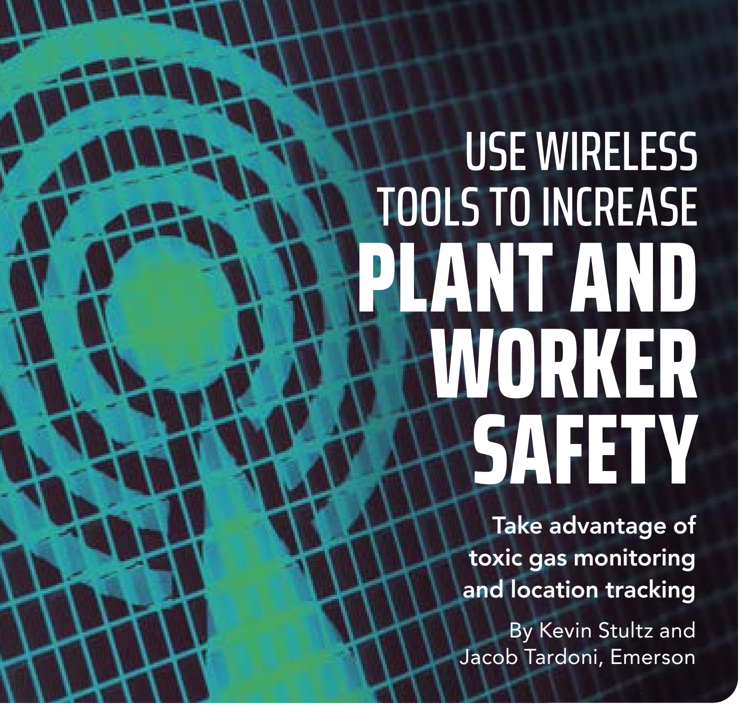

USE WIRELESS TOOLS TO INCREASE PLANT AND WORKER SAFETY

Take advantage of toxic gas monitoring and location tracking

By Kevin Stultz and
Jacob Tardoni, Emerson

THE PLANNING of an integrated safety system that includes all elements of plant monitoring, from toxic gas to personnel location and status, can seem a daunting task. However, quickly advancing digital technologies can make it simpler, faster and more cost-effective than doing so even a year ago. Now, it is possible to integrate many systems, such as basic process control, equipment condition monitoring, data historian applications and more, that once were separate. Linking these systems enables data sharing at a central location to build a more complete picture of operations. Many of the improvements that facilitate this integration are new networking technologies, especially wireless ones.

Separation no longer necessarily makes a facility safer. Capturing data from safety systems now is possible without interfering with critical functions such as pressure relief valves on a reactor filled with toxic product. Having real-time access to the health and status of that safety valve creates peace of mind and, in fact, can improve safety because such data combined with other process data can better predict stresses on safety systems.

A closer look at two different scenarios gives a good idea of how and where extending and integrating safety-related functions ultimately can enhance safety in and around a facility.

MONITORING TOXIC GAS

Such monitoring often just complements safety-instrumented systems. A gas monitor will sound an alarm, alerting workers to a problem, but won't close a valve or shut down a process. This is where integration and automation can provide value. An integrated system can do more than create awareness of a problem — it can trigger a direct action to mitigate the problem.

For example, if a faulty valve causes a toxic gas release, an adjacent pressure transmitter tied into the process automation system can register the change in pressure in the system and might trigger a safety instrumented function in response. However, adding new wiring for toxic gas monitors can be cost-prohibitive and challenging if space is tight or sensors require placement at hard-to-reach locations. Using wireless devices can eliminate these issues, allowing applications not previously considered. For instance, a plant operator can install monitors that communicate via an existing WirelessHART network (Figure 1).

Some current gas-monitoring instruments are modular, designed for wireless operations, and powered by long-lasting internal batteries that eliminate the need for new wiring. Emerson's are designed specifically for use in petrochemical plants, refineries and similar operations and can withstand temperature extremes, exposure to the elements (Figure 2), and remain operational in most hazardous areas such as IECEx Zone 0 and CSA and ATEX equivalents.

APPROPRIATE ARCHITECTURE

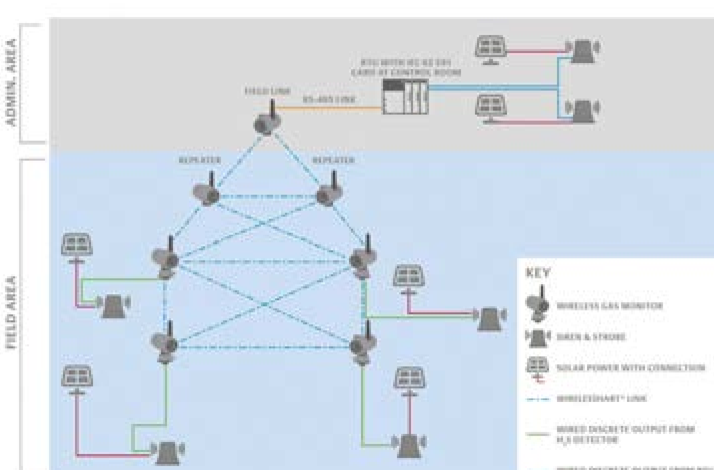

Figure 1. A wireless toxic-gas detection system can use an architecture such as this.

LOCATING PERSONNEL

Another important application of wireless monitors is to bolster personnel safety by providing up-to-date information on worker location. When seconds count in an emergency, knowing exactly where someone is can improve incident response and outcome. However, adopting a location monitoring system historically has been cost-prohibitive and difficult to design and implement. Process plants, for instance, often contain large vertical structures spanning a massive square footage, and can involve harsh temperatures and hazardous conditions.

Fortunately, today's wireless location sensors can cost-effectively provide spatial and time resolution sufficient for emergency response. Emerson's safety-oriented location systems for personnel exemplify the main functions now available:

Figure 2. Available devices can withstand temperature extremes and exposure to the elements.

Figure 3. Pushing a button enables a worker to signal an injury or emergency as well as the person's location.

- By pushing a button on a tag pendant (Figure 3), a worker can signal an injury or emergency in progress and provide his or her exact location.
- Geofencing shows whether an individual has moved into an area where the person doesn't belong due to hazardous conditions.
- Safety mustering indicates to first responders that people in the plant have moved to a designated safe area during a drill or actual emergency.
- Low activity alerts aid in detecting a fall or other emergency where the person is not moving.

Moreover, modern wireless sensors avoid the issues posed in the past — such as investing in expensive industrial routers to ensure reliable data transmission and the need to hardwire them, which again brings up the issue of running wire in potentially hard-to-reach places. Cellular, global-positioning-based systems also rely on external networks for security and struggle with locate-reliability in dense infrastructure.

WIRELESS COMMUNICATION

Location sensors such as those offered by Emerson communicate via WirelessHART; many plants already are running WirelessHART networks to collect data from other transmitters and systems, e.g., flow meters, not just for control but also for analysis to give efficiency and sustainability insights on the process in relevant time frames. That same network architecture can serve to host an effective, secure WirelessHART-based location system.

Building a location monitoring system using WirelessHART does involve more than just adding more process instruments to an existing network. A good location monitoring system using triangulation requires a beaconing device, which we call a location anchor. Plant workers must wear lightweight tags that are paired with the anchors. These wearables must be designed not to interfere or hinder turnaround or maintenance tasks in the facility. A server for the user interface (UI), plus adequate WirelessHART gateway capacity also are necessary. For mobile interface throughout the plant with the location system, teaming plant WiFi with the WirelessHART network will allow use of a tablet, mobile phone or other smart device to respond to emergencies or alerts.

Emerson's location anchor devices are small (<15-cm diameter), light (<0.5 kg), and self-powered for up to 5 years, which makes them easy to install in all places without requiring additional wiring. The anchors, along with the tags, meet the classification standard to be deployed throughout the plant, Class 1/Div 1 Zone 0. They require very little maintenance and can economically provide full coverage of a facility.

The WirelessHART anchors communicate completely wirelessly with other anchors, the access points, the rechargeable tags worn by each worker, and the network-hosted user interface (Figure 4). The communications network is self-organizing and can adapt to changing conditions without intervention. WirelessHART is proven through 50,000 deployed networks, is highly secure, with multiple

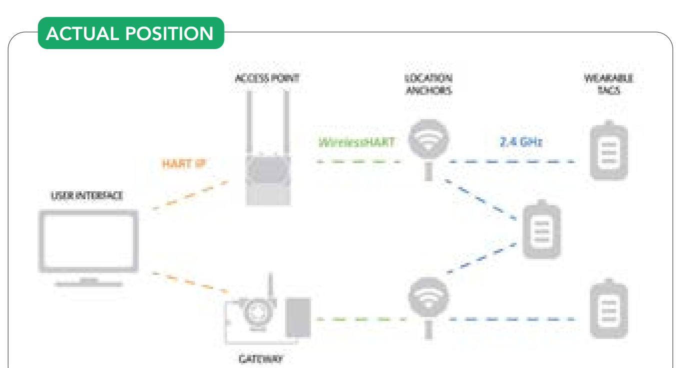

Figure 4. Tags worn by personnel communicate with anchors that, in turn, communicate with gateways and access points.

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authentication and encryption points, and can operate entirely within a corporate network or facility.

Moreover, the software platform, which is preconfigured and ready-to use, includes other applications beyond the location UI to monitor heat exchangers, steam traps, pressure relief valves, cooling towers, pipe corrosion and more. All this makes for a cost-effective and easy-to-implement way to keep personnel safe in a large facility with many potential hazards.

EXTEND YOUR CURRENT NETWORK

An existing WirelessHART network already carries data from field instruments to a main process automation system. Although toxic gas monitoring and location systems do not integrate directly, they exist side-by-side on that same network, bringing relevant data to a centralized system or dashboard.

Data from toxic gas monitors or a location system can be used in conjunction with other systems. For example, an alert from a wireless toxic gas detector might prompt operators to check the location of plant personnel as well as take preventative measures to secure other devices nearby, shutting valves and initiating pre-determined safety protocols to further reduce exposure risks.

Extending an existing network originally conceived to support measurement instrumentation to now support toxic gas monitoring and a location system seems to us a natural part of a facility's ongoing digital evolution. Improving analytical capabilities with the goal of enhancing plant operations and worker safety makes the investment in toxic gas monitors as well as location devices and anchors a worthwhile one. ●

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Novel Approach Improves Ammonia Process Efficiency

Use of artificial intelligence and first principles hybrid modeling provides gains

By Takuto Nakai, Nissan Chemical Corp.

AMMONIA IS one of the most important products in the global fertilizer industry, with applications also in pharmaceuticals, textiles, cleaning products, wastewater treatment and more. With the surge of interest in hydrogen as a fuel, ammonia has gained attention as an easily transportable way to store and reconvert hydrogen for applications such as fuel cells for cars.

While there is research focused on green ammonia produced by electrolysis and powered by renewable energy, the conventional ammonia production process uses natural gas through steam methane reforming. The process is highly energy intensive and significantly impacts carbon emissions worldwide. Therefore, a strong incentive exists to improve energy and resource efficiency in the manufacture of ammonia to reduce the environmental footprint. This is incredibly important as asset-intensive industries, and the rest of the world, strive to achieve net-zero emissions. (For details on some current efforts, see “Collaboration Promises a Winning Hand,” https://bit.ly/3zB2bCL, and “Net Zero Efforts Add Up,” https://bit.ly/37kcWxr.)

REDUCING ENVIRONMENTAL IMPACT

Nissan Chemical Corp., founded in 1887, was the first chemical fertilizer company in Japan. It currently has five manufacturing sites in Japan that produce a wide range of chemicals, performance materials, agricultural chemicals and pharmaceuticals.

Nissan Chemical’s philosophy is to contribute to society with superior technology, products and services, while striving for harmony with the environment. This is our main driver for lessening the impact of current operations, including the manufacture of ammonia.

The company was looking to decrease costs and improve energy consumption in the ammonia process at its plant in Toyama. This site currently produces ammonia and derivatives using natural gas, having switched from its previous reliance on coal, fuel oil and naphtha as sources. In 2005, we established a production and supply system for high quality urea for use in AdBlue, a solution of urea in demineralized water that serves as an operating fluid in diesel-powered trucks to improve emissions.

During ammonia manufacture, sulfur is removed from the natural gas to prevent catalyst damage in the reactor. The natural gas then goes through a reformer, where the reaction with steam produces hydrogen and carbon monoxide (CO). The CO then is converted to carbon dioxide (CO_2), which is removed before it can go through the ammonia synthesis process. Capturing, utilizing and storing the CO_2 is an essential step to deliver offsets needed to achieve net-zero targets through blue ammonia manufacture.

PARTNERING TO IMPROVE THE REACTOR

To increase the efficiency of the process, we determined that step number one would be to identify performance gaps at the reformer reactor. However, conventional rigorous reactor modeling requires an accurate temperature profile of the process fluid. The difficulty in measuring or estimating the temperature distribution in the furnace limited the application of a pure first principles simulation approach.

To address this challenge, Nissan Chemical approached AspenTech in early 2021 to develop a model based on Aspen Hybrid Models technology [1]. AspenTech develops asset optimization software and Nissan Chemical is an active user of its engineering tools, including process simulation and optimization software Aspen Plus. With the launch of Aspen Hybrid Models in October 2020 and the release of aspenONE V12.1 in May 2021, both companies identified the opportunity to leverage these technologies to help improve Nissan Chemical's operations.

With Aspen Hybrid Models, AspenTech uses machine learning (ML) to enhance the first principles knowledge captured in digital tools built on 40 years of experience. This allows engineers to:

- represent real plant behavior with models created from operational data and first principles constraints;
- create high fidelity models that can be used for rapid and accurate decisions in engineering and operations; and
- recalibrate models to changing process conditions more easily with artificial intelligence (AI)/ML.

To solve the modeling problem and improve the efficiency of the ammonia manufacturing process, Nissan Chemical and AspenTech collaborated to develop a First Principles Driven Hybrid Model of the reactor. This is an Aspen Hybrid Model that combines first principles modeling and ML, via neural networks, to capture unknown or unmeasurable details of phenomena in the plant. The first principles model framework ensures the results obey engineering fundamentals of material balance, energy balance, etc.; ML allows for a higher fidelity match with plant operating data. The technology is native to process simulators Aspen Plus and Aspen HYSYS, making it possible for the neural networks to tune existing process models to reality.

IMPROVING THE FIRST PRINCIPLES MODELS

The steam reforming reactor is modeled in Aspen Plus and improved using AI-enabled calibration embedded within the process simulator. Figure 1 depicts the final flowsheet. The top of the figure shows the equipment blocks used to model the process. These are the same as those in a conventional model using first principles knowledge. The AI technology is embedded in the calculator block on the lower half of the image. In this calculator block, a neural network performs the calculation of the kinetic parameters.

Creating the hybrid model involved a simple five-step methodology:

1. model creation in Aspen Plus using standard flowsheeting techniques;
2. data analysis and conditioning;
3. definition of the hybrid model;
4. training of the hybrid model; and
5. deployment of the predictive model in the flowsheet.

The model created in Aspen Plus represented the reactor model and the steam reforming and water gas shift reactions taking

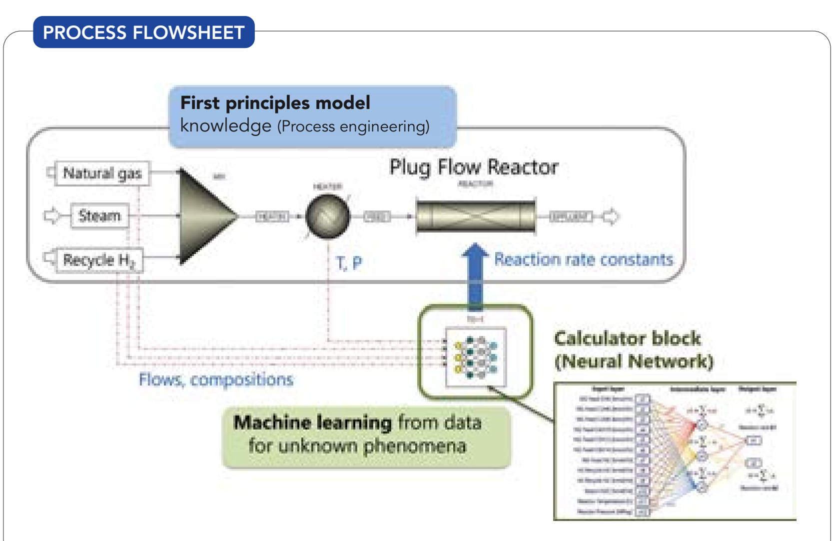

Figure 1. A neural network to calculate kinetic parameters augments a first principles model.

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place. Kinetics data in the literature served as a starting point for the reaction rates.

As part of the process, and to overcome concerns about data quality, data had to be cleaned thoroughly before feeding to the neural network for training; data points with material imbalances greater than 2% were removed.

The cleaned data then were used to train a neural network and predict reaction rates from feed temperatures, pressures, rates and compositions. The ML algorithms adjusted the neural net parameters to best match the reactor outlet conditions. Building a model from fully conditioned data took less than a day.

THE IMPACT ON ENERGY EFFICIENCY

Using Aspen Hybrid Models, we created a calibrated model in 2021 that could reproduce real plant data more accurately than the conventional, kinetic-based reformer model — and twice as fast.

Unlike a conventional modeling approach, where the reaction kinetics expression must be known or hypothesized before tuning parameters, the ML algorithm learns how to predict the reactor performance from the available operating data. This results in a much more efficient workflow and enables easy re-calibration to new operating conditions. An added advantage is that the resultant model typically is more accurate over a wider range of conditions.

With this First Principles Driven Hybrid Model, we evaluated steam requirements and identified the potential to reduce steam input up to 2% in the Toyama plant, thus helping us to align with our philosophy to strive for harmony with the environment by reducing the negative impact of operations. We have shared the recommendations with the control engineers at the plant to update the plant operating parameters.

To further optimize its ammonia production, Nissan Chemical is looking to extend the use of Aspen Hybrid Models to other unit operations and, eventually, to other processes. ●

TAKUTO NAKAI is a chemical engineer in the production department of the Toyama, Japan, plant of Nissan Chemical Corp. Email him at nakaitaku@nissanchem.co.jp.

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Avert Dryer Difficulties

Dealing with moisture is key to stopping clumping and corrosion

THIS MONTH'S PUZZLER

We use a conveyor belt dryer for drying our slurry to a fine powder that then falls through a chute to a bagger below (Figure online at https://bit.ly/3xZfiMx). The product goes into either super sacks or 40-lb paper bags.

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

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

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

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

SUPPLY DRY AIR

Consider the issues of moisture content in air to the conveyor, corrosion and static in winter:

1. Use a psychrometric chart to get the dewpoint of air to the dryer, and its dry-bulb temperature to get the relative humidity (RH), which is the driving force for removing moisture from the slurry on the conveyor belt. The higher the RH, the lower the driving force for removing moisture is. Because hot air apparently is not removing slurry moisture adequately, it is possible that air to the conveyor may have high humidity to start with. It is not clear from the drawing as to how close the air (air intake to the Blower 1) is from the discharge of Blower 2 and vent. Air intake close to Blower 2 and vent will end up recycling wet humid air to the Blower 1 intake, which, in turn, will impede moisture removal from the slurry. Make sure Blower 1 intake is sufficiently away from Blower 2 and vent to minimize potential recirculation of wet air from Blower 2 and vent.
2. To supply dry air, there are several approaches:
   - If feasible, a condenser on Blower 2 discharge and vent will remove moisture and help reduce wet air from entering Blower 1.
   - A condenser for the room air entering Blower 1; a 25-psig steam heater will remove moisture and help improve the driving force for getting rid of moisture from the slurry.
   - If you have spare instrument air supply (typical dewpoint -40°F), pipe it up to Blower 1. If not, consider an air compressor, intercoolers, and air dryer to supply dry air — preferably -40°F dewpoint.
3. Look at the slurry entering the conveyor. See if you can lower its moisture content.
4. Corrosion of carbon steel is caused by prolonged contact with moist/wet air. Protecting the exposed parts of the conveyor with paint is an option. Paint vendors can help in selecting optimum paint type and coating requirements.
5. Dry air causes static in winter. Possible fixes include:
   - better housekeeping — sweeping dust from the floor;
   - mopping the floor (a wet floor will help reduce static buildup); and
   - providing grounding at relevant locations.

GC Shah, consultant,
Houston

GET RID OF THE MOISTURE

How you deal with vapor during a drying operation can decide whether you are successful or not. Clearly, you have a problem separating the steam from the powder. All the problems mentioned lead back to this issue. The first indication you were in trouble is that you went after the symptoms (e.g., via bangers on the product bins) not the cause of the problem.

Let's consider these options to reduce downtime:

1. Are you running above capacity? Find out the capacity of the blowers, belts, etc., so you can estimate the maximum capacity of the process. My bet is that you are operating above maximum.

2. Now that you've collected data, consider adding dryers to the intakes of Blowers 1 and 3. Drive the wet bulb temperature below 0°F if you can. Then, add a heat exchanger to Blower 3 if it won't affect product quality.
3. Increase the size of Blower 1 to accommodate a higher air flow. This probably won't work for Blower 3 because of the risk of lifting some of the dust.
4. Look for tramp air in your system. It's always there but tighter seals can make a world of difference.
5. Increase the steam flow to the ejector.
6. Dehumidify the room.

Once you have the moisture under control, you'll introduce a new problem you didn't have before: dust. It is critical to address this, especially in the winter when static electricity is high.

Because clumps of wet product didn't pose as serious a fire risk as dust, you now must do some crucial work. Start by determining the velocity needed to lift the dust; vendors can help if you send a dust sample. Next, look at the area of the intakes. Then, with velocity and area, you can determine the volume flow needed by the dust collection blowers.

With the process in control, this would be a good time to tune it. Look at dispersion in the weir feeding the first belt. Is slurry dispersed evenly over the belt? Is there foaming? Lumps? You'll also want to see if distribution is even over the second belt. You may find you must replace some equipment once you optimize the weir distributor, guides, belt membrane and sprays.

By reducing moisture, the rappers on the product bins will be needed less often and will be more effective in handling the buildup. It would be a good idea to clean the bins thoroughly to remove past clots caused by moisture buildup.

Your work in optimization only really begins once you address these basic problems.

Dirk Willard, consultant,
Wooster, Ohio

SEPTEMBER'S **PUZZLER**

Our pumps use API Plan 53 for sealing. We're having problems with our seal pots: high consumption of very expensive oil, and contamination of the oil in the pot (see Figure 1).

Our young inspector brought this to my attention. He wants to bring in the pump salesperson but I doubt that person has the technical expertise we need. I can't get any help at all from the company that sold us the seal pot or the seals; the salesman familiar with our product suggested a steam seal but that's not our corporate policy. We have trouble maintaining pressure at our air compressors, especially with the use of pneumatic pumps all over the plant. I have seen the psi at the air tank drop to the low 70s; the tank is located 500-ft away from the seal pot. I want to send the sample to a laboratory for analysis because I think it's the seal.

SEAL POT PROBLEM

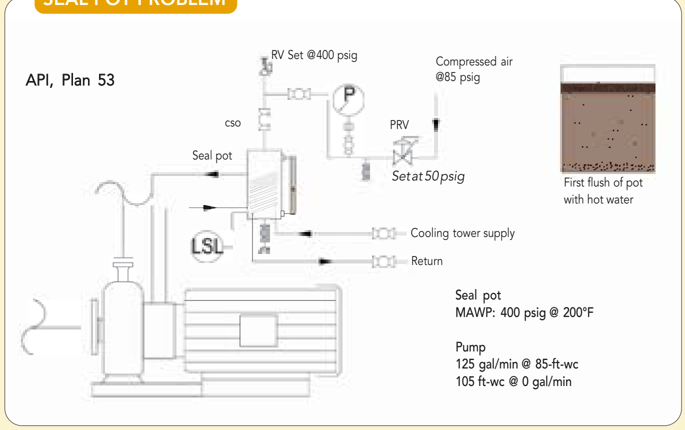

Figure 1. High oil consumption as well as contamination afflict operation.

The inspector wants to test the cooling water coil. He thinks it might be leaking into the seal pot. The water is from a cooling tower.

What is the cause of the high consumption of oil? Is there any solution besides continuing to go through $10/gal oil? Are there any tests we should run?

Send us your comments, suggestions or solutions for this question by August 12, 2022. We'll include as many of them as possible in the September 2022 issue and all on ChemicalProcessing.com. Send visuals — a sketch is fine. E-mail us at ProcessPuzzler@putman.net or mail to Process Puzzler, *Chemical Processing*, 1501 E. Woodfield Rd., Suite 400N, Schaumburg, IL 60173. Fax: (630) 467-1120. Please include your name, title, location and company affiliation in the response.

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

Don't Push Piping Flow Too High

Understanding velocity limits to prevent erosion and corrosion is crucial

Velocity limits tend to be service specific.

THE QUEST to squeeze out more capacity from a plant may surface even before initial construction is finished. Assessing the maximum additional flow through piping requires special care.

Initial sizing usually is based on balancing constraints including minimum velocity needed, economic pressure drop, and maximum allowable velocity. Because pipes only come in standardized sizes, the chosen pipe often may boast ample extra capacity. Except for special cases, the cost of pressure drop rather than a maximum velocity limit generally sets pipe sizes in new plants. Common exceptions where maximum velocity limits may take precedence include caustic (4 ft/s), concentrated sulfuric acid (4 ft/s), and aqueous alkanolamine solutions (10 ft/s).

Some combination of erosion, corrosion, erosion/corrosion, vibration, static electricity or hydraulic hammer may call for setting velocity limits. These tend to be service specific. So, what general approach makes sense to determine these limits?

Let's look particularly at erosion in systems. High velocity can damage the piping surface and, ultimately, lead to piping failure, which usually results from some combination of erosion and corrosion. High velocity damages a surface film; the damaged surface film exposes the base piping material and the pipe corrodes. As long as velocity remains high, deterioration continues and can rapidly damage pipe.

Ideally, true single-phase fluid flow should have only minimal erosion rates. Problems tend to occur when two-phase flow hits the surface. Two-phase flow can involve solids entrained by gas or liquid or liquids entrained by gas. In any case, getting past the problem that erosion or erosion/corrosion limits are very system specific still is difficult.

Nevertheless, some guidelines can help. These are not meant to substitute for experience or reduce the requirement to monitor process piping for damage from high velocity flows. Moreover, they demand verification by field observation and data for your specific system.

Recommended Practice 14E ("Recommended Practice for Design and Installation of Offshore Production Platform Piping Systems") of the American Petroleum Institute (API), Washington, D.C., exemplifies the most common approach to determine a maximum velocity allowed based on erosion or erosion/corrosion. This sets a velocity threshold of:

$$V_e = c/(\rho^{1/2})$$

where V_e is the velocity in ft/s above which erosion may occur, c is a constant that varies with the system and materials, and ρ is flowing density in lb/ft^3 assuming no-slip in mixed-phase flow. Different organizations recommend using c valves ranging from 100 to 160 for continuous flow with carbon steel and up to 200 for corrosion-resistant alloys, with allowable values for intermittent services generally 25% higher.

However, an extensive dispute exists about the reliability of this evaluation. Some argue the equation lacks theoretical justification and simply is an empirical correlation. Yet, little published data support either the form of the equation or the c values often used. So, if you opt for this equation, it is important to understand the assumptions involved.

First, the use was intended for gas/oil/water systems with no solids present. Solids can increase erosion rates dramatically. Second, passing the threshold does not imply a specific erosion rate or defined pipe life. Third, no allowance is made for pipe bends, diameter changes, or other fittings, although changes in pipe geometry clearly are linked to many erosion problems. Fourth, the equation gives a higher "threshold'" velocity for lower mixed-phase density. A lot of experience directly contradicts this. Indeed, much data support the idea that lower bulk densities increase erosion rates in two-phase flow due to local variations in flow patterns.

Some alternative evaluation methods for maximum line velocity exist. However, they all generally suffer from a lack of justifiable data behind them and problems with how to account for flow density.

One alternative is based on the velocity. This is equivalent to making the erosion limit proportional to the momentum of the flowing liquid (rather than its kinetic energy as in API RP 14E):

$$\rho V_e/9{,}272 \le k$$

where k is 4 for 6-in. and larger pipes, 3.5 for 4-in. pipes, and 3.0 for 3-in. pipes.

Another alternative is:

$$\rho V_e^3 \le 45{,}000$$

However, the justification for this form is unclear as now the velocity is a cubic function.

Regardless of the approach you use, always remember, if high velocity is a concern, monitoring of piping thickness is essential and you need system experience to truly understand the actual erosion behavior. ●

ANDREW SLOLEY, Contributing Editor
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Metering Pump Provides Accurate Dosing

The MDR Range progressive cavity pump is a metering pump that can withstand harsh chemicals. Due to an external general-arrangement seal and engineered composite seal housing, lantern, and rotating unit, the only metallic part in contact with the conveyed product is the rotor. This design allows for broad chemical compatibility, increased performance, and decreased maintenance, says the company.

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SMRs Pose Waste Handling Issues

Study reveals small modular reactors produce more nuclear waste than traditional ones

It's not a conclusion the U.K. nuclear industry likely will welcome.

THE PUSH for nuclear power, especially using small modular reactors (SMRs), is snowballing in Europe as countries rush to find replacements for Russian gas.

The European Commission's contribution is to label both nuclear and gas as sustainable forms of energy. However, critics have dismissed this decision both as greenwashing, and a threat to the European Union's aim to become climate neutral by 2050. So, the European Commission has been emphasizing its decision comes with certain provisos. Gas plants would only be considered green if, by 2035, they switched to fuels such as biomass or hydrogen produced with renewable energy. Nuclear power plants would be deemed green only if sites safely manage the disposal of their radioactive waste.

This safe disposal is the focus of new research from the Center for International Security and Cooperation (CISC) at Stanford University, Stanford, Calif.

In a recent article in the *Proceedings of the National Academy of Sciences*, CISC affiliate Lindsay M. Krall and colleagues make a detailed assessment of SMRs' impact on the management and disposal of nuclear waste relative to that generated by larger commercial reactors of traditional design. They conclude that existing strategies aren't designed to cope with the waste from SMR-based nuclear fuel cycles.

The proposed SMRs have purported cost and safety advantages over existing gigawatt-scale light water reactors (LWRs) but few studies have assessed their implications for the back end of the nuclear fuel cycle, note the authors.

They point out often-used simple metrics, such as mass or total radiotoxicity, suggest advanced reactors will generate "less" spent nuclear fuel (SNF) or high-level waste (HLW) than a gigawatt-scale pressurized water reactor (PWR) — the prevalent type of commercial reactor.

As an example, the authors cite research suggesting advanced reactors will reduce the mass and long-lived radioactivity of HLW by 94% and ≈80%, respectively. "These bulk metrics, however, offer little insight into the resources that will be required to store, package, and dispose of HLW," they stress.

To rectify this, Krall's team used design and fuel cycle specifications from license and patent applications to compare three SMR designs — ones using water, sodium or molten salt as the primary coolant — to an 1,100-MWelec PWR in terms of the energy-equivalent volume, (radio-)chemistry, decay heat, and fissile isotope composition of (notional) high-, intermediate-, and low-level waste streams.

This research reveals all three designs generate more waste per-unit-of-power-produced than a typical gigawatt-scale PWR. For instance, SNF alone was projected to increase by a factor of up to 5.5. Neutron reflectors or chemically reactive fuels and coolants in SMR designs contribute to the excess waste.

"That said, volume is not the most important evaluation metric; rather, geologic repository performance is driven by the decay heat power and the (radio-)chemistry of SNF, for which SMRs provide no benefit," explain the authors.

Specifically, they find SMRs will not reduce generation of certain fission products which are important dose contributors for most repository designs. In addition, SMR spent fuel will contain relatively high concentrations of fissile nuclides that will demand novel approaches to evaluating criticality during storage and disposal.

"Since waste stream properties are influenced by neutron leakage, a basic physical process that is enhanced in small reactor cores, SMRs will exacerbate the challenges of nuclear waste management and disposal," they conclude.

It's not a conclusion the U.K. nuclear industry, which is leading the European push for SMRs, likely will welcome.

Rolls-Royce, Derby, U.K., hopes its 470-MW SMR technology will become the backbone of a new nuclear energy industry there. According to a recent article in *The Guardian*, the company already has started building parts for its SMRs in anticipation of regulatory approval by 2024 and grid connection in 2029.

Nuclear Waste Services (NWS), Didcot, Oxford, U.K., the U.K. government's integrated nuclear waste management organization, currently is pursuing a long-term strategy to encourage communities to consider building geological disposal facilities (GDFs) in their local areas. So keen is NWS to find hosts that up to £1 million/yr (≈$1.22 million/yr) in funding is available to local communities who engage in discussions about hosting a GDF. ●

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