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Use Elegant Design to Bolster Inherent Safety

Embrace a variety of strategies that can eliminate hazards from operations

By Kelly K. Keim, chief process safety engineer for ExxonMobil Research and Engineering and Scott W. Ostrowski senior process safety engineering associate for ExxonMobil Research and Engineering

Trevor Kletz was able to simplify the concept of inherent safety in such a way that everyone "gets it." His mantra "What you don't have can't leak" is so clear and powerful that it has grabbed the attention of all stakeholders, including owner/operators, labor, community members and regulators, who have an interest in safer processing facilities of all types. It expresses a vision that we all seek, one where no harm comes from the operation of process facilities that manufacture the materials that make our lives better every day.

Of course, the concept of inherent safety goes beyond simply not having materials that potentially could damage the pipes, vessels and equipment that make up manufacturing facilities. We must understand all the ways those materials can be involved in incidents that harm people, the environment and our facilities. Without a thorough understanding of those scenarios and how they can occur, we can't properly evaluate the risks posed by different technological approaches and effectively apply inherently safer technologies.

For example, the lower annual corrosion rate of a stainless alloy compared to carbon steel in some processes may seem compelling. However, chloride exposure may cause stress corrosion cracking in the alloy; this damage is difficult to detect before a catastrophic component failure occurs. So, in fact, the inherently safer option may be to use carbon steel while implementing a strong inspection and replacement program that manages the hazard of corrosion effectively.

FUNDAMENTAL STRATEGIES

Kletz in his groundbreaking 1984 paper [1] described four basic strategies for achieving inherently safer processes:

- intensification;
- substitution;
- attenuation; and
- limitation of effects.

In its 2007 book, “Inherently Safer Chemical Processes: A Life Cycle Approach” [2], the Center for Chemical Process Safety translated those terms into simpler ones readily understood by a wider audience than just safety professionals:

- substitute — replace a material with a less hazardous one;
- minimize — reduce the quantities of hazardous substances;
- moderate — use less hazardous conditions, a less hazardous form of a material or facilities
  that minimize the impact of a release of hazardous material or energy; and
- simplify — design facilities that eliminate unnecessary complexity and make operating errors less likely, and that accommodate errors that occur.

Let’s consider their application to the use of a chlorine cylinder:

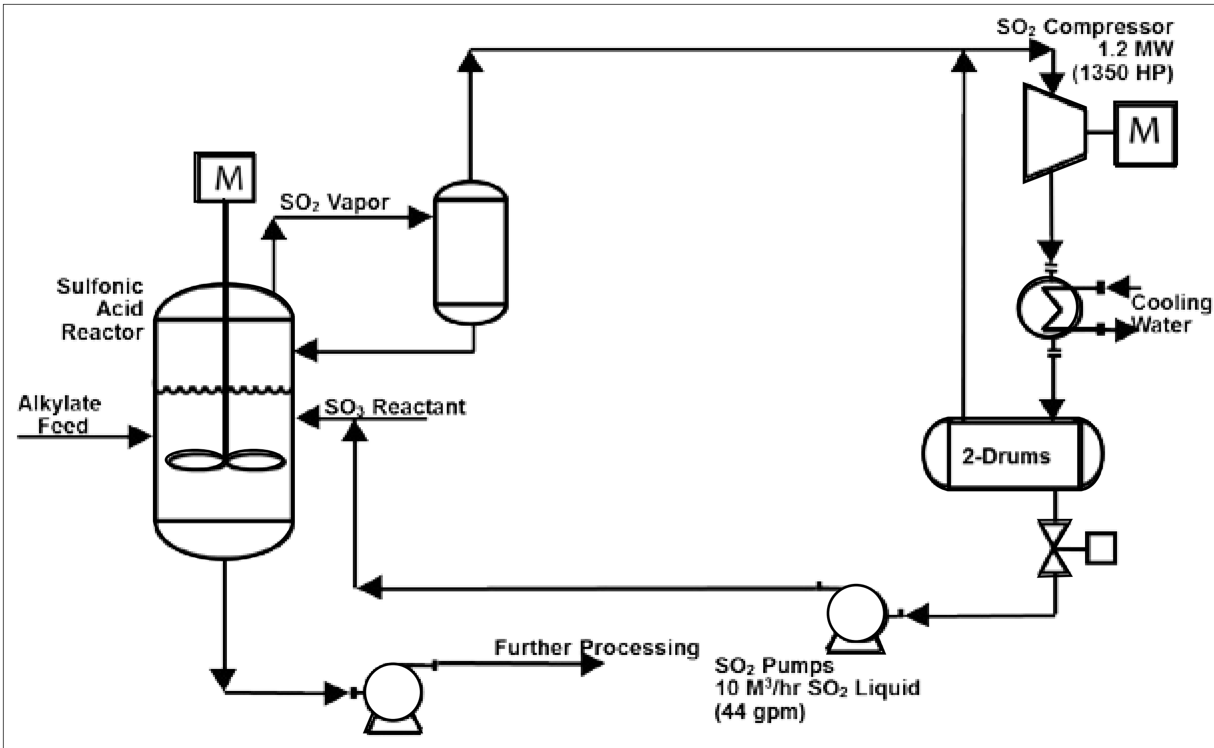
- substitute — change from chlorine to a bromine tablet;
- minimize — keep only one cylinder on the site;
- moderate — connect a vacuum inductor to the cylinder; and
- simplify — adopt a distinct design with unique connections for chlorine hoses.

Other strategies can complement these simple ones. Here, we introduce the phrase “elegant design” to represent the selection of process technology, equipment, design or layout that makes higher-potential-consequence scenarios non-credible. Elegant design may take advantage of a number of Kletz’s strategies — and may even go beyond them to achieve risk reduction, minimization, or elimination.

Simply put, the concept of inherently safer design is: “What can’t happen can’t happen.”

Any number of design features can contribute to preventing something from happening. Substitution and some elegant design solutions can provide absolute certainty against an occurrence. Minimization, moderation and other elegant designs can afford a reasonable certainty. Instructions and procedures can help but offer the least degree of certainty. All are desirable steps toward a safer processing facility.

Every strategy doesn’t have to result in the complete elimination of the hazard or risk scenario. When we can make an incorrect action or assembly impossible (or at least very difficult) or design to accommodate the error without harm, we use the term “mistake proofing.” Where doable at a reasonable cost,



SULFONIC ACID PLANT

Figure 1. Traditional design includes a compressor and knockout drum.

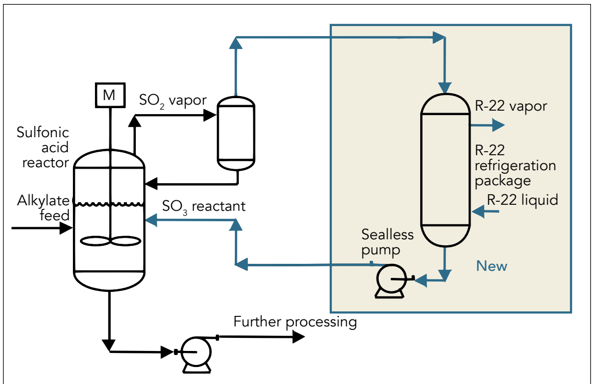
this may be an attractive strategy because it rarely introduces alternative scenarios. For our chlorine cylinder example, mistake proofing might include using unique connections for the hoses.

In contrast, mistake tolerant systems provide timely feedback when a mistake happens, the means (either before or after loss of containment) to correct the error before an undesirable outcome occurs, or, if not corrected, reduced consequences from the mistake. For the chlorine cylinder, a mistake tolerant strategy might involve isolating chlorine inside buildings that have a chlorine vapor recovery system.

APPLYING THE STRATEGIES

To illustrate the application of inherent safety strategies, let's look at several real-world situations: sulfonic acid plant design, aluminum chloride ($AlCl_3$) handling, a utility station and an electrical switchgear.

Sulfonic acid plant design. Reacting sulfur trioxide (SO_3) dissolved in sulfur dioxide (SO_2) with an alkylate feed produces sulfonic acid. This is an exothermic reaction that boils off SO_2 as its primary means of heat removal. The SO_2 performs the role of mutual solvent to allow intimate contacting between alkylate and SO_3, which otherwise would only react at their mutual surface. All of the materials are



SAFER SET-UP

Figure 2. Modified design requires less inventory of SO2 and eliminates equipment that could leak toxic material.

flammable. The SO_2 and SO_3 are both inhalation toxics.

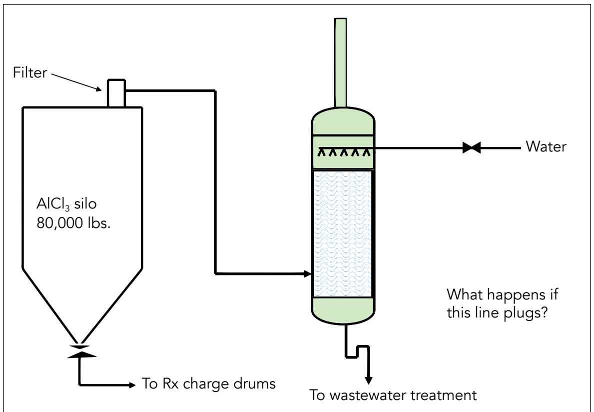
The heat of reaction boils the SO_2 and SO_3 from the reactor. In the traditional plant design (Figure 1), two drums collect the boiled-off vapor and allow the return of SO_3 and any knocked-out liquid to the reactor. A compressor and cooling water exchanger provide cooled, liquefied SO_2 for recycling to the reactor.

Following inherently safer design principles, the process was modified to eliminate the compressor and collector drums and replace the standard pumps with seal-less ones (Figure 2). This very significantly reduced the inventory of SO_2 required to operate the process and removed two pieces of rotating equipment, each of which had the potential to leak toxic material to the air. In addition, because a Freon refrigerant is used, the bulk of the SO_2 now is at a temperature not far from its boiling point, which minimizes vaporization in the event of a leak. However, these process safety improvements were achieved by using an ozone reactive material rather than cooling water.

The minimization and moderation strategies enhanced process safety — but opportunities exist to make the process even more inherently safe:

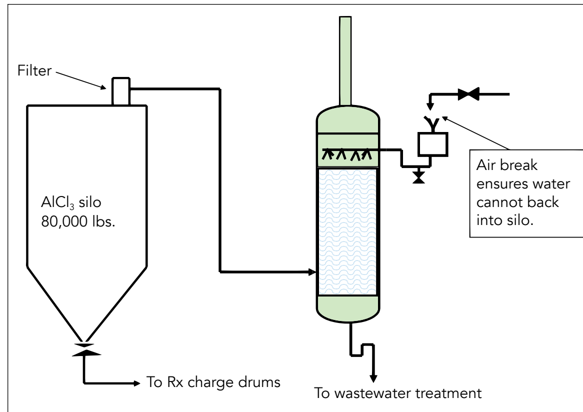
- Use the cooling exchanger as knockout pot and provide for gravity drain of cooled SO_2 back to the reactor, eliminating the pump. (This requires relocation of the SO_3 injection point.)
- Find a safer solvent than SO_2. In addition, even greater inherent safety may be possible by avoiding the process altogether, such as by switching to sulfonic acid alternatives that are made via inherently safer processes.

Aluminum chloride handling, part 1. Figure 3 depicts part of a process that uses $AlCl_3$ as an ionic polymerization catalyst. $AlCl_3$ is a powder that reacts violently with water to form toxic hydrogen chloride (HCl) gas and aluminum hydroxide ($Al(OH)_3$). Its contact with skin results in burns. Low-pressure nitrogen is used to unload $AlCl_3$ from delivery trucks and transport the material to smaller vessels from which it is conveyed into the reactor. The AlCl3 is a very fine powder, some of which will travel with the nitrogen. All conveying nitrogen is returned to a silo that can contain as much as 80,000 lb of $AlCl_3$. It then passes



ALUMINUM CHLORIDE SILO WITH SCRUBBER

Figure 3. Plugging of line could lead to water getting into the silo — causing an exothermic reaction that creates HCl.



ELEGANT DESIGN

Figure 4. In the event of drain-line plugging, water will overflow at the air break rather than back up into the silo.

through a filter that returns most of the $AlCl_3$ to the silo. What passes through the filter is scrubbed from the nitrogen in a packed tower where water is sprinkled down through the bed as the nitrogen rises and is released from an elevated vent stack. The slightly acidic water drops through a “p-trap” and then goes to the wastewater sewer.

This is a fairly simple process — but what happens if the p-trap plugs? Water will flood the scrubbing tower and back up in the line towards the silo. Because the top of the vent from the scrubber is considerably higher than the filter on top of the silo, the water eventually will reach the silo, resulting in a highly exothermic reaction and generation of HCl gas that can’t be contained within the silo.

The normal way to address this issue would have been to install level sensors in the packed tower with alarms and automated trip of the scrubbing water. An elegant and inherently safer design was to provide an air break in the water to the scrubbing tower (Figure 4). The top of the funnel is at an elevation considerably lower than that of the filter — thus, if a plug occurs in the drain line, the water runs out the top of the funnel. Little-to-no pressure head was required to get the water through the distributor inside the tower.

This modification was far less costly than installing the safety critical devices first considered.

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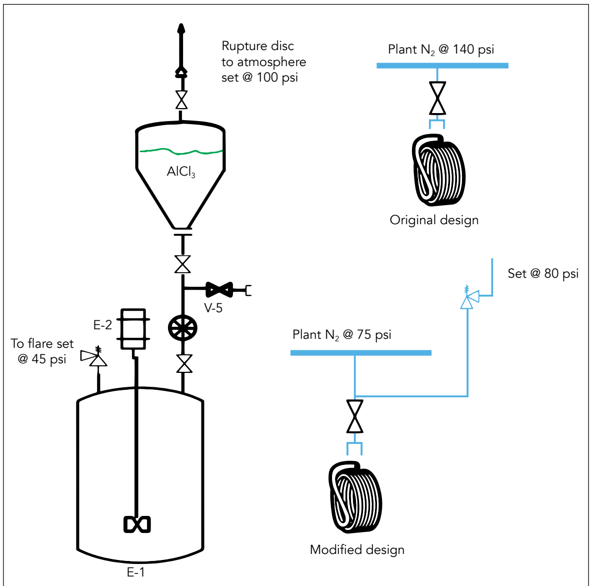


HANDLING PLUGGING

Figure 5. Original design had nitrogen at 140 psi, which posed risk of blowing rupture disk if operator used nitrogen to remove plug; changing to lower nitrogen pressure reduced risk.

It's difficult to put this inherent safety strategy into any of the four basic ones. It's simply an elegant design solution that works to make the scenario of water backing into the silo non-credible.

Aluminum chloride handling, part 2. Figure 5 shows the situation that existed at the reactor in the same plant with the $AlCl_3$ silo. The $AlCl_3$ passes at a controlled rate through a rotary feeder into the reactor. The $AlCl_3$ has a tendency to plug the standpipe between the feeder and the reactor. An operator's natural inclination is to blow the plug free and into the reactor using 140-psi nitrogen available close by. Fortunately, there's never enough catalyst in the standpipe to cause a runaway reaction.

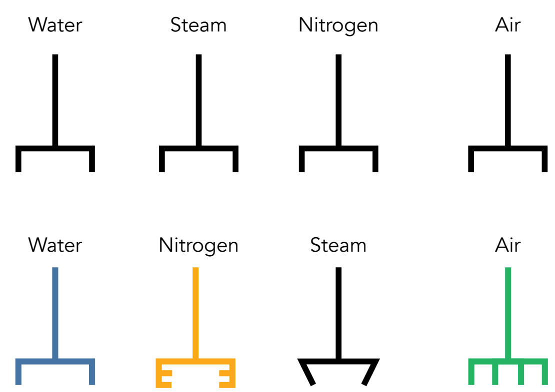
What can go wrong in this situation? If the valve between the bleeder where the nitrogen is injected and the day pot is left open or leaks, the nitrogen overpressures the day pot, blowing the rupture disk and sending fine $AlCl_3$ powder over several acres.

To make the situation more mistake tolerant, the nitrogen source within a hose length of the bleeder was reduced in pressure to 75 psi, well below the set pressure of the rupture disc on the $AlCl_3$ day pot. To prevent an operator from being tempted to adjust the pressure of that regulated nitrogen, a safety valve that relieves to an elevated location limits the pressure.

This didn't prevent one ambitious operator from stringing two nitrogen hoses together to bring 140-psi nitrogen to the day pot after working unsuccessfully for several hours to remove a clogged drop line using the 75-psi source.

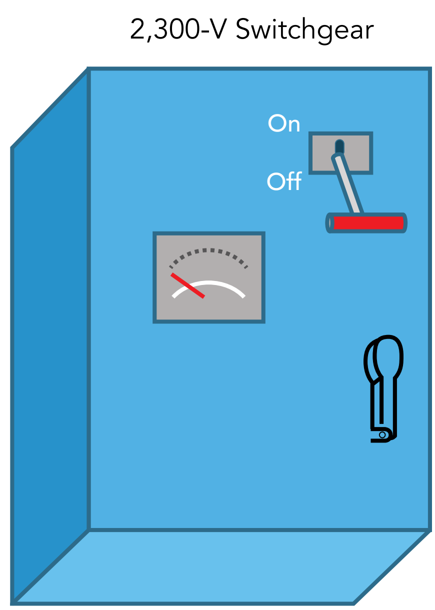
Utility station. The use of a hose connected to a utility station is one of the most common ways that operators interact with process facilities. Figure 6 depicts a typical set-up for a utility station near the point of use that provides water, steam, nitrogen and air.

What could go wrong here? How could this set-up be improved?
In the modified utility station design, each



UTILITY STATION

Figure 6. Use of similar types of connections makes it easy to connect a hose to the wrong utility; opting for distinct connections and color-coding makes hookup mistakes unlikely.



ELECTRICAL SWITCHGEAR

Figure 7. Operators mistakenly presume the lockout lock should go through hasp on cabinet door handle; sawing off the hasp eliminated the problem.

utility was given a different type of connection. Each line not only was labeled but also color coded in a fashion that allowed even those suffering from color blindness to distinguish the utility based on the line's lightness or darkness. The distinct connector and color of each hose made mismatching, and therefore mistaking, the utility being connected to the process very unlikely. In addition, the arrangement of the utility station was modified to separate the air and nitrogen supply to provide one more barrier to mistakenly using nitrogen to drive a tool in a confined space.

It remains possible for some ambitious soul to prepare a crossover connection by appropriating the right set of fittings. Therefore, you must carefully control these utility station fittings.

This is an application of the mistake proofing form of inherently safer design.

Electrical switchgear. Figure 7 depicts an electrical switchgear in 2,300-V service. It serves as the primary electrical disconnect and lockout point for isolating a large pump when it needs service.

Where does the lock go to ensure that the equipment can't be re-energized while repairs are being made? There is a hasp conveniently placed in plain view on the handle that opens the cabinet door. However, the lock actually should go through a little tab above the disconnect switch that can be pulled out when

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2. Center for Chemical Process Safety, "Inherently Safer Chemical Processes: A Life Cycle Approach," 2nd ed., Wiley, Hoboken, N.J. (2010).

the switch is in the off position.

You could try training your personnel on the proper location for the lock. You could put a sign on the cabinet to indicate where the lock goes. Then you could realize operators will hang the lock in the wrong location before they look for a sign that would tell them the right location — and put another sign on the wrong location that says: "Lockout lock does not go here!" However, eventually even that sign becomes just background noise.

We tried all these things before happening upon a solution that worked — cutting off the hasp on the door handle!

An operator knows a lock must be placed on the switchgear. Now, if the operator forgets exactly where the lock should go, the person will think about it and either come up with the right — and only — solution or ask. The possibility of making a mistake no longer exists.

Is this an inherently safer switchgear? Yes. Does it fall into one of the four basic inherent safety strategies? Not really, although it may be a form of mistake proofing.

THE KEY TO SUCCESS

Application of inherent safety principles is just one aspect of making safety second nature. For each situation, other approaches may be equally effective as the basic four and may be economically feasible when none of the four are. Moreover, it's important to realize that mandating the use of inherent safety is like placing signs throughout the workplace that say: "Be Safe." Each has little benefit until you have translated the mindset into practical application.

You achieve expertise in the practical application of inherent safety principles through the diligent and repeated search for and application of inherently safer solutions. This experience is what makes a safety engineer effective and a process plant a safer place to earn a living. You train your brain to spot applications for solutions you've seen before and you apply principles you've used before to solve new problems. The end result is a mindset that makes safety second nature. ■

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Refinery Tackles Water Issues

Skid-mounted treatment unit improves water quality and cuts costs

By Mike Jenkins, Progressive Water Treatment

The oil and gas (O&G) industry requires massive amounts of water — the water/oil ratio averages 8:1. Currently, American O&G operations consume 82 billion bbl of water (1,300 times San Francisco's annual use) and produce more than 2.5 billion bbl of wastewater each year. Now, as in industry more broadly, O&G companies are placing increasing priority on water management and are beginning to look for advanced wastewater-treatment technology to address operational and economic challenges.

Across the U.S., several key factors impact upgrades:

Aging infrastructure and tougher regulations. Without proper infrastructure, industries can't perform efficiently at scale. The U.S. Environmental Protection Agency (EPA) estimates the country requires an additional $500-billion investment in water infrastructure. Also, environmental concerns are spurring stricter water-disposal regulations to protect natural resources — and, consequently, intensifying the stress on already complicated water-treatment protocols. EPA standards now place the burden of wastewater treatment on businesses rather than local utilities. Numerous facilities now find their existing wastewater-treatment systems can't keep pace with today's regulations. As water use is more heavily tracked and increasingly strict wastewater regulations are imposed on O&G facilities, many operators are looking to update treatment systems.

Regional water shortages. Extreme drought also is affecting industrial (and residential) water use in a variety of areas across the country, especially California, where new standards are cropping up to better manage water across the value chain. For example, California Senate Bill 1281, passed in 2015, requires all O&G operators to provide a monthly water-use statement to the state board for approval. As legislation continues to tighten, operators, still dealing with trimmed budgets because of recent low oil prices, are seeking an environmentally friendly water-treatment alternative that won't break the bank.

Lack of in-house resources. Purchasing a water-treatment facility or equipment requires a substantial investment of time and resources. Yet, in general, refineries now lack dedicated in-house water managers. Nevertheless, the companies must find the resources to complete water analyses, technology evaluation, scope development, vendor assessment, capital budgeting, and proposal requests and evaluation. In addition, they must perform final design work, equipment fabrication, environmental permitting, field installation and process optimization. By partnering with external experts who engineer, install and operate water equipment and services, facility personnel can better focus their resources on their core business. Outsourcing can help take care of all the tasks related to water treatment in a comparatively short time span. Moreover, the specialists can pinpoint how to maximize onsite treatment, minimizing logistics costs associated with central treatment and disposal.

ONE REFINERY'S RESPONSE

A leading oil refinery in East Texas exemplifies an industrial facility that needed a water infrastructure upgrade. Its aging ion-exchange system had become inefficient and costly to maintain. The system generated waste every two days, and chemical and treatment costs were high. The plant also desired higher-quality water to feed its high-pressure boilers. Besides addressing these concerns, the refinery had to comply with Texas' strict suspended- and dissolved-solids quality requirements for boiler feed water. So, in December 2015, the refinery decided it was time to update the site's water treatment.

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The municipal water fed into the refinery didn't meet regulations for maximum contaminant levels and, thus, required pretreatment for use in the boiler system. This refinery's boiler-feed ion-exchange system required regular regeneration, causing a significant drain on revenue. Not only that, operators had to constantly manage the waste generated from the boiler feed system. The wastewater had to be treated with heavy chemicals before it could be disposed of with the rest of the plant waste. According to analysts at Jefferies & Co., the cost to a site of an industrial water-management process averages $9–$26/bbl of water.

To address these three key concerns, refinery managers outsourced the facility's new boiler-feed system to Progressive Water Treatment (PWT), a McKinney, Texas-based water services company. To replace the outdated system, PWT designed and installed a large yet compact skid with its reverse osmosis (RO)technology that is engineered to comply with regulations, reduce chemical costs and require less overall maintenance.

ENGINEERING CHALLENGES

The site posed space constraints. Installing the treatment system in a hazardous area would double or triple the $1-million+ capital cost for the project. So, instead, PWT designed a system consisting of three complete 250-gpm reverse-osmosis units mounted on one 8- × 23- × 13.5-ft painted steel skid. This enabled the unit to fit in a non-hazardous location in the heart of the plant, thus saving on capital costs for a new building and associated engineering and design labor. Additional process equipment included ion exchange water softeners, multimedia filtration, RO chemical feed systems, and a membrane clean-in-place skid to clean the RO membranes in situ. Thanks to creative engineering, the system has the ability to reuse 100% of the RO wastewater onsite, and offers the option of utilizing the reverse-osmosis reject water as feed for the cooling towers and the reverse-osmosis product as boiler feed water, to improve efficiency and reduce boiler-feed-water costs. PWT manufactured all the equipment involved in the upgrade. To save on capital cost, PWT took advantage of some existing equipment, such as tanks and chemical pumps. The safe and user-friendly system features a programmable logic controller and human machine interface for completely automated control. The skids are easy to access for any necessary repairs and require little manpower to operate, further reducing maintenance and operational costs for the refinery.

Installed in December 2015, the system should enable the refinery to reduce supply costs, improve operating efficiency, decrease maintenance costs, as well as supply consistent high-quality boiler feed water. ■

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Minimize Oil and Gas Refinery Downtime

Coordinate shutdown and turnaround logistics with operational planning tools

By Patrick Zirnhelt, IFS North America

Shutdowns and turnarounds are a necessity in the refining industry. They are huge, expensive undertakings, affecting hundreds of processes and thousands of people both inside and outside the refinery walls. Careful planning, organization and adaptation are key to ensuring success.

THE TICKING CLOCK

Shutdowns and turnarounds are not new for refineries in the oil and gas sector, but the bottom line remains the same—an inefficient turnaround means dollars lost. One plant estimated the cost of a shutdown at $10 million per day.

The recent fall in oil prices has increased pressure for refineries to find cost savings, rendering project management around shutdowns and turnarounds critical to bottom-line success.

The moment operations cease, time becomes money. The end goal is, of course, to get operations up and running in the shortest possible time, but with health and safety standards intact.

Most savings can be found by driving efficiency, but real efficiencies can be achieved only by careful asset and workforce management at all stages of what is a complex and continuous process. The enterprise resource planning (ERP) or enterprise asset management (EAM) system must be agile and flexible enough to deal with these complexities to achieve efficiencies.

ESTABLISHING A SINGLE POINT OF TRUTH

No one-size-fits-all plan exists to facilitate a shutdown or turnaround. Planning is a dynamic event. It's a continuous task that requires rethinking and rescheduling, even after the process has begun.

The planning problem begins with the complex nature of oil and gas refineries — more specifically, the vast amount of data streams being fed into the ERP or EAM system. These data streams can come from various platforms such as Microsoft Excel spreadsheets, database programs or third-party software.

To control the overall shutdown and turnaround process, many refineries also run a number of separate IT systems that are not integrated or aligned. This makes it difficult to control and report on project deliverables — from engineering specifications to commissioning, all of which must include health and safety and risk perspectives.

Establishing an overall "single point of truth" to plan a shutdown or turnaround becomes challenging when data exists in varying formats and comes from different IT systems. This disjointed data feedback can derail planning efforts, resulting in a longer lead time ahead of any shutdown and turnaround. ERP and EAM systems must be able to integrate all this data to provide the information necessary to plan effectively and accommodate complexities.

WORKFORCE LOGISTICS

One such complexity is workforce scheduling and management. Planning shutdowns and turnarounds requires coordinating thousands of people inside and outside refinery walls. This includes arranging for external contractors who come with their own work schedule requirements and roadmaps. These external requirements can affect the refinery's internal staff.

Refinery planners need to project how many people are required to complete a shutdown and turnaround in a set-time period, but this depends on many workforce factors that range from suitability to availability. They need to consolidate data from contractors, multiple systems and applications to get an accurate, single point of truth. This data can be fed into the project program, further consolidating progress, cost and changes to measure against an execution plan.

THE PRESSURE COOKER EFFECT

The scope of a shutdown and turnaround can become stressed in the window before execution because demands may conflict as everyone tries to optimize that time period. Many subcontractors and refinery personnel want to maximize the window of opportunity and are working to tight deadlines. However, they have different agendas, which can create a pressure cooker situation. Using appropriate software can minimize conflicts and help to release that pressure.

A POSSIBLE PANDORA'S BOX

In a shutdown and turnaround, organizations are working in a timebox, so planners determine the time frame in which to complete the work. To optimize execution, they synchronize the material, work orders and resources ahead of time and update them as necessary after the process has begun. For example, personnel may have a work order to perform maintenance on a particular piece of machinery. The long lead times required result from the machine's complexity, so from a material point of view all possible parts and new equipment need to be procured beforehand.

During the shutdown and turnaround's execution, organizations risk opening Pandora's box on a piece of equipment. Unforeseen machinery problems can arise that require further engineering expertise or even new health and safety considerations. This generates subsequent work orders that need to be scheduled, resulting in shutdown and turnaround process repercussions.

The complexity of all this revised data being fed back and forth between fragmented IT systems makes it difficult to provide a planner with a real-time point of truth during execution.

All these factors carry the threat of extremely high revenue loss resulting from inefficiency during the time the refinery spends offstream. Add to this third-party contractors who may introduce their own roadmaps and systems, not aligned with the refinery planner's, and integrating these fragmented systems can become complex and costly.

CURRENT IT SYSTEM LIMITATIONS

Some refineries are integrating third-party tools and existing ERP and EAM software to plan shutdown and turnarounds, while other organizations are using simple project planning tools.

The issue with these tools is that they are static project planning tools — long lists that can become outdated before they are used. Unanticipated problems routinely are found during machinery maintenance, for example, causing delays and requiring new calculations to the planner's original schedule. Starting with an incorrect picture of the shutdown's planning stages will exacerbate its execution as problems arise and plans deviate.

The maintenance plan might be located in a Microsoft Excel or Primavera document, while purchasing orders and inventory are handled in the ERP system. Companies now are relying on printouts and planners' brain power to coordinate changes, paving the way for potential errors and delays.

Nothing is definite in the lead-up to and execution of a shutdown or turnaround. Basic project planning tools or integrations struggle to cope with this changing environment once begun, leading to inefficiency and dollars lost.

The project execution method with integrated third-party systems can be cumbersome and document-driven and does not take advantage of newer, database-driven techniques and data-sharing. It provides no real tool to synchronize project work and pre- and post-maintenance work.

Refinery planners need a system that supports them during both the planning and execution phase of a shutdown or turnaround. These systems need the agility to adapt and replan to minimize downtime caused by unexpected changes to the existing schedule.

OPERATIONAL PLANNING TOOLS

Operational planning tools have been developed specifically to assist companies in optimizing shutdown and turnaround processes by helping to bridge the planning and execution stages.

These tools analyze key variables such as equipment structure; work orders; preventive maintenance plans; and the availability of staff, materials and tools to produce an optimal plan for a shutdown or turnaround. When linked with other applications, the tools may identify potentially critical situations requiring action and enable planners to produce work orders that can be executed immediately with the resources available.

They may visualize planned downtime together with planned maintenance and allow for the sourcing of staff, materials and equipment necessary for specialized maintenance activities well-ahead of execution.

Minimizing Downtime Ups Profitability
Planners carry out their jobs in a pressurized and dynamic environment. Profitability depends on minimizing downtime — outages need to be as brief as possible and managed carefully.

These tools help to enhance the planning and execution process by uniting all the variables into a single system, making it easier to respond to changes in the shutdown or turnaround process and to identify potential roadblocks.

INCREASED “WRENCH TIME”

Operators aspire to high levels of “wrench time,” the amount of time that maintenance personnel spend carrying out maintenance tasks as opposed to chasing materials and equipment. It’s not uncommon for personnel to be issued with a work order, only to find that the materials needed are not in stock or on-site. Operational planning tools help to ensure that work orders are not issued without the necessary materials and resources at hand, enabling maintenance engineers to complete their assigned tasks.

Increased wrench time means more proactive and efficient maintenance during day-to-day refinery operations, which can translate into engineers spending less time turning around equipment. Keeping equipment well-maintained during operations limits the time refineries spend offstream.

REFINING FUTURE SHUTDOWNS AND TURNAROUNDS

Falling oil prices require oil and gas companies to increase efficiency, reduce operation costs and maintain quality services. Savings must be found by optimizing existing processes, particularly the costly offstream period associated with a shutdown and turnaround.

A new generation of software that bridges both planning and execution, that integrates planning and asset management and that gathers variables into a single solution makes it easier for planners to manage and adapt in a dynamic execution environment.

Such software allows planners to respond to changing maintenance tasks in real-time, working around delays or faulty parts. It can save refineries money by streamlining a shutdown and turnaround, enabling operations to begin again as quickly as possible.

Looking further forward, this new breed of integrated software will enable a more proactive approach to maintenance while refineries are operational—reducing the amount of maintenance required during the shutdown and turnaround process in the long term.

All this feeds back into increased wrench time and greater efficiency. Getting operations back up to speed as quickly as possible is paramount. Refinery planners need software that supports them before, during and after a shutdown or turnaround so they don’t have to face that costly bill of $10 million a day.

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Carefully Choose Gasket Material

High temperatures, exposure to moisture and other factors can lead to leakage.

By Warren H. Hall, Garlock Sealing Technologies

The advent of hydrofracturing, or fracking technology, for drilling natural gas and crude oil in the United States has had a significant impact on chemical companies' profitability. Access to inexpensive natural gas has enabled companies to improve their positioning on the cost curve for the production of ethylene, propylene, methanol and other base chemicals.

Access to inexpensive natural gas provides two fundamental advantages to chemical companies: inexpensive raw materials and inexpensive energy. Both of these advantages translate into the ability to potentially produce high-volume petrochemicals at worldwide competitive costs.

IMPROVING DOWNSTREAM MARKETS

Chemical engineers know that increasing the temperature in reactors generally increases the rate of reaction as described by the Arrhenius equation. In addition, distillation and other separation processes can produce higher purity products economically as reflux ratios are increased. As impurities are reduced in high-volume petrochemicals, more process options become available to downstream customers, potentially resulting in better products and new markets. Both of these process improvements require either higher process temperatures or more heat from the utilities, which likewise can require higher temperatures in these areas.

Access to relatively inexpensive feedstocks along with affordable energy enable chemical companies to produce both commodity and specialty chemicals profitably. Affordable energy allows process temperatures to be raised to accelerate reaction and production rates and increase purity. For instance, ethane cracking typically takes place at temperatures in excess of 800°C (1,472°F).

COMPLICATIONS FROM RISING TEMPERATURES

As the process temperature rises, options for gasket materials become limited. PTFE materials are good from cryogenic conditions to 260°C (500°F), hardly a high temperature. A number of graphite and carbon fiber-based gaskets extend the range to 540°C (1,004°F) on excursions, but on a continuous basis 340°C (644°F) is recommended. In addition, graphite-based materials oxidize over time, which will result in gasket failure. If only steam service is being considered, some graphite-based products are appropriate up to 677°C (1,250°F).

The challenge becomes how to seal flanges at temperatures approaching 1,000°C (1,832°F).

Gasket materials that can be used in this temperature range have been available for some time. Unfortunately, the number of companies offering such products is limited. In addition, these products have some shortcomings, notably the tendencies to deteriorate when exposed to moisture and to leak at low temperatures under conditions of thermal cycling.

HIGH-TEMPERATURE GASKET

Figure 1. This vermiculite-based gasket has experienced extended exposure to water.

EXPOSURE TO MOISTURE

Figure 1 shows a vermiculite-based, spiral-wound high-temperature gasket exposed to water for 4.5 hours.

The high-temperature sealing materials in these gaskets are hygroscopic, meaning they absorb moisture. Over time, this exposure causes the sealing element to deteriorate. Usually, engineers will note there is no water in their process media.

However, many chemical and petrochemical plants are located in humid environments such as the Gulf Coast of the United States. Gaskets stored in locations without climate control can be exposed to moisture. Many maintenance shops, trailers and shipping containers are not dry environments, a problem repeatedly reported on the Gulf Coast.

Gasket materials also can be inadvertently exposed to water that is not supposed to be in the media. Often this occurs with tube leaks in heat exchangers when steam or cooling water on the utility side leaks into the media side. Eventually these leaks are detected, and the equipment is shut down for repair.

When the piping system reaches ambient temperature and stresses on the flanges change, the gasket can be exposed to the media. Depending on the hydrocarbon-water system in the media, the gasket material can be exposed to water at the low or high spots in the blocked-off process equipment. If it deteriorates, a new leak will occur in the piping system after maintenance has been performed and the process is brought back on stream. Note for this to occur, the gasket must be in an uncompressed state.

Gaskets also can be exposed to water when equipment is isolated, flushed with water and steam-cleaned to remove all traces of hydrocarbon. In the process of isolating the equipment, crews sometimes loosen a flange and slip a blank into it. The gasket may or may not be under compression as it is steamed. If it begins to deteriorate in these conditions, a leak will occur upon restart.

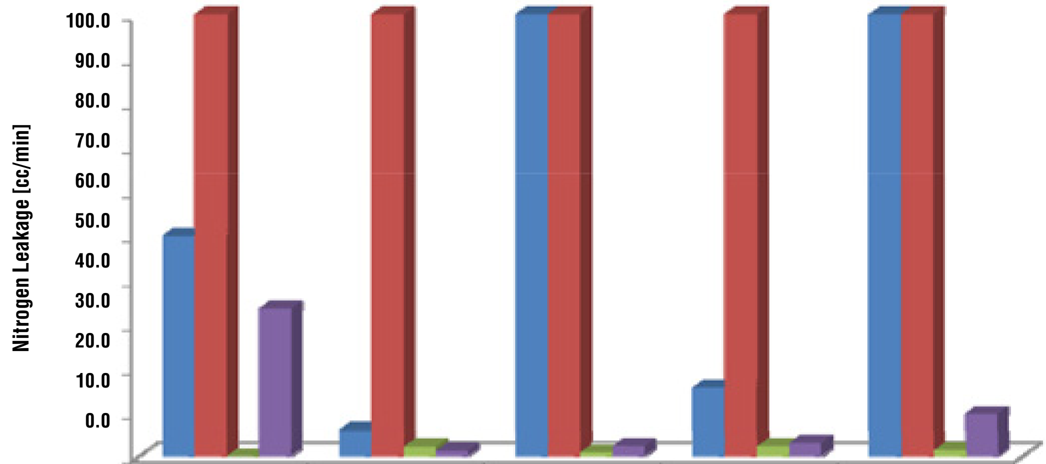
THERMAL CYCLING

Conventional high-temperature gaskets also have limitations under conditions of thermal cycling in batch-processing applications. The piping systems of reactors, separation equipment and utilities are exposed to temperature fluctuations, usually from ambient to high and back, but some processes can cycle through low temperatures, as well. Mica-based gaskets in a typical 3-in., 300-lb. flange can leak considerably when cooled to ambient conditions, even though they had been sealing effectively at 1,000°C (1,832°F). This also can relate to the water exposure previously described.

Rare is the continuous chemical process that is brought up to temperature where it remains. Eventually the equipment must be taken out of service for maintenance or due to a process upset. A gasket that seals properly at the operating temperature but leaks as it is brought down to ambient poses several problems. If the media is a hydrocarbon, the leakage can result in an amount sufficient to support combustion. Also undesirable is a hydrocarbon leak that poses environmental or health hazards.

RELEASE FROM FLANGES

Finally, many gaskets are subject to flange removal problems. When a piping system



	Leakage@ Ambient	Leakage @ 1,000°F	Ambient (cool down)	Leakage @ 1,000°F	Ambient (cool down)
Mica	50.0	5.8	100.0	15.3	100.0
Ceramic	100.0	100.0	100.0	100.0	100.0
Therma-Pur Faced	0.004	2.2	0.9	2.3	1.3
Heat Shield	33.4	1.263	2.312	3.046	9.41

LEAKAGE VS. THERMAL CYCLING

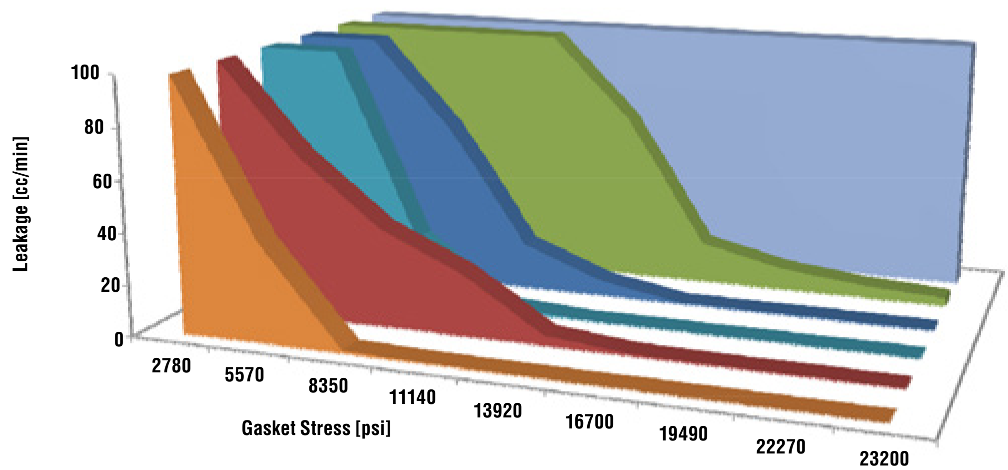
Figure 2. As piping systems undergo thermal cycling, different materials are prone to leakage.

is installed, it usually is simple to slip the correct gasket in between the flanges, install the bolts and tighten and torque the assembly as required. However, when removing the gasket, it may have a tendency to adhere to the flange faces. It is strongly recommended that gaskets not be reused, so flange surfaces need to be cleaned for the new gasket to seal properly. In plant environments, this often leads to the use of solvents or scraping the flanges. This is made even harder on short pipe runs or large-diameter pipe where it is difficult to get the proper tool on the face of the flange. Using the wrong tool or method can damage the flange face, incurring the expense and inconvenience of repair.

A GASKET MATERIAL OPTION

In response to chemical plant operators' desires to run at extreme temperatures and the limitations of existing gasket products, we developed a new proprietary material that releases more easily from flanges to facilitate maintenance. This material is hydrophobic, meaning it does not absorb water. It also resists leakage as piping systems undergo thermal cycling. This is depicted in Figure 2.

In addition, it requires less stress to prevent



	2,780	5,570	8,350	11,140	13,920	16,700	19,490	22,270	23,200
Standard Graphite	100.000	39.050	0.896	0.206	0.106	0.033	0.024	0.015	0.008
Faced Therma-Pur	100.000	64.100	38.830	24.350	3.866	0.707	0.313	0.281	0.091
Heatshield	100.000	100.000	26.150	2.250	0.101	0.047	0.027	0.024	0.018
Therma-Pur SW	100.000	100.000	65.240	18.250	5.880	0.328	0.310	0.294	0.105
Mica	100.000	100.000	100.000	100.000	67.450	16.200	8.650	4.900	3.000
Ceramic	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

LEAKAGE VS. GASKET STRESS

Figure 3. The stress required to minimize leakage should be taken into account when choosing a gasket material.

leakage in comparison to the alternative materials in Figure 3.

GASKET SELECTION CONSIDERATIONS

Many elements should be reviewed when selecting gaskets for high-temperature applications. Practical consideration needs to be given to moisture resistance, whether or not water is specified in the media. Thermal cycling needs to be taken into account especially for batch processes and temperature swing absorbers, but it also is a factor in continuous processes as they are brought into and out of service. Finally, the stress required to minimize leakage also should be taken into account. ■

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Take a Closer Look at Above-Grade Pump Stations

Technology offers safer, more-efficient wastewater and stormwater pumping

By Don Aholt., M.S., Smith & Loveless Inc.

The context of today's industrial plant and facility operations dictates promoting worker safety, improving operational efficiency and reliability, and incorporating green practices—all of which translates to reducing costs. These demands are even making their way through to the "back of the plant" in the environmental management process.

CPI plants and refineries generate large volumes of wastewater and environmental runoffs as part of daily operations. The wastewater and environmental runoff are collected in sumps, in-ground pits or reservoirs, typically ranging in depths from three to 20 feet. When liquid levels within the sumps reach designated limits, the wastewater is transferred to storage, treatment or disposal.

For larger sump applications (minimum flows from 50 gpm and sumps with depths of at least 6 ft), complete pump stations (or lift stations) are generally applied for conveyance around the facility to the treatment system or discharge point. These pumping systems can take different forms, based on the type of pump employed and the relative positioning of the system's mechanical equipment. Most wastewater pumps are centrifugal, but can vary from conventional and chopper submersible pump systems (wet-pit) to above-grade, prime-assisted mechanisms. Each system type brings specific characteristics that have to be weighed by facility designers and managers, in the context of worker safety, operational efficiency and cost minimization.

OPERATOR SAFETY FOR INDUSTRIAL PUMP STATIONS

In wastewater and storm water pumping, the major hazard (aside from the obvious combination of electricity and water-handling systems) is exposure to designated confined spaces, which in these cases would be the sumps and any associated below-grade pump valve-vault (Figure 1). These spaces require very deliberate maintenance safety procedures, proper training and additional personnel and gear to maintain proper safety protocol and prevent worker injury. Some facilities may choose to bring in outside service groups to maintain these systems, but this strategy can drive up operating costs while still requiring some risk management of onsite personnel. Because the service life of most industrial wastewater submersible pumps spans one to three years (or longer with frequent rebuilds or replacement), industry is looking to other, safer alternatives for wastewater and stormwater pumping.

CONFINED SPACE

Figure 1. Suction pipes and float switches lead to an above-pumping station. With this arrangement, no pumps, mechanical equipment or electrical components exist in the sump, thereby eliminating the need for humans to enter the confined space for operation and maintenance.

It figures that if confined space hazards can be eliminated, then safety and ease of maintenance can be significantly improved and costs can be eliminated. That's why above-grade, prime-assisted pump stations are an emerging technology in refineries and processing plants. These systems positioned above the sump allow operations professionals to immediately access all of the pumping system's mechanical and electrical components, thereby eliminating the need for confined-space entry, and also the costs of manpower and related maintenance, paperwork and labor costs. This has been demonstrated in the municipal collection system market, where it has been documented repeatedly that above-grade pump stations reduce operation, maintenance and parts by more than 50 percent when compared to confined-space submersible pumping stations.

PRIMING FROM ABOVE

Naturally, placing the pumping system above the sump, pit or wet well with the pump rotating assemblies above the sump liquid level — rather than submerging with submersible pumps — requires priming assistance. The liquid has to be lifted from the sump in order to "prime the pump" and commence safe pumping. There are two

SELF-PRIMING PUMP STATION

Figure 2. Using duplex horizontal end-suction pumps that prime with internal recirculation, this particular station includes VFDs and is accessible on each side through multiple hatches.

VACUUM PRIMED PUMP STATION

Figure 3. This system features two vertical close-coupled centrifugal pumps. Access to the station equipment is gained through a easy-lift tip-up hood enclosure, while the pumps can be pulled within minutes with the removal of just four bolts near the volute casing.

general ways that this occurs in centrifugal pump design: fluid suction-lift achieved with self-priming pumps and fluid suction-lift achieved with vacuum-priming.

Self-priming pumps (Figure 2) are typically horizontal end-suction centrifugal pumps that “self-prime” by using internal recirculation within the pump to draw the liquid. After water fills the volute, the pump’s impeller will turn in a counterclockwise rotation. The initial prime of the pump is directed through an ever-increasing water channel into a discharge chamber inside the volute casing. There, the water and air separate. The heavy water falls back down into a recirculation port while the air is evacuated. While water recirculation occurs inside the casing and air is being released, low pressure is created at the eye of the pump impeller. The higher atmospheric pressure differential forces the sump liquid to rise up the suction pipe and pushes all of the air ahead of it into the volute casing where it is handled through the recirculation process. As the water arrives, the pump goes into complete operation. Overall, the priming stage can take several minutes from the beginning before full pumping commences.

Vacuum primed pumping systems (Figure 3) differ significantly from self-priming type pumps. First, where horizontally-configured self-priming pumps are designed to prime and pump, vacuum primed pumps are vertical, close-coupled pumps with oversized pump shafts and bearings. Rather than priming itself, these pumps rely upon a simple, ancillary priming system, comprising three basic components: a prime sensor, a solenoid valve and a separate 1/8 hp vacuum pump. When the liquid level rises in the sump and tilts the low-level displacement switch or transducer, the vacuum pump is activated to lift the liquid into the volute casing. The vacuum pump turns off when the prime sensor senses sufficient liquid in the volute. The centrifugal pump activates once primed and commences pumping. From a totally non-primed condition, the system primes the pump within 60 seconds under standard rated conditions. Once the centrifugal pump is primed, it is designed to stay primed indefinitely.

Despite being separate from the actual centrifugal pump and requiring a separate vacuum pump, the vacuum priming process is generally more efficient than self-priming because the self-priming pump motor must generate the priming action. For example, a 15 hp self-priming pump may utilize 5 hp simply for the priming cycle compared to just 1/8 hp of the vacuum pump. Thus, the need for self-primers to both prime and pump increases the energy required to prime while lowering the overall operating efficiency. Compared to vacuum-primed pumps, the overall difference in wire-to-water efficiency can be as much as 20–25%, which can mean hundreds to thousands of dollars per pump station in annual savings when compared side-by-side.

In evaluation for prime-assisted pumping systems for wastewater and stormwater, whether vacuum-primed or self-priming, there are several things to consider: pump efficiency/power costs, operator safety, operation and maintenance time and cost including downtime, equipment durability, ease of access to pump internals. When undertaking an evaluation, planners should consider and explore answers to these questions:

1. Pump Efficiency/ Power Costs. At normal operating conditions, what are the differences in wire-to-water efficiencies for the particular application between a self-priming pump and vacuum-primed pump? How much does that translate into annual power costs? Evaluating the application's design points along the particular pump's published pump curves can provide the data for calculating the pump efficiency and resulting power requirements in a given period of time. Improving pump efficiency can help lead to energy credits and LEED certifications for new construction.

2. Priming System Nuances. What are the components that comprise the system's priming scheme? What are events that can prevent normal priming? How will typical priming time affect the sump/wet well size? For example, if one system takes several more minutes to prime than another, it can affect the sump volume capacity. It would need to be sized correctly to prevent potential overflows during heavy surges in flow.

3. Maintenance. What are the wearing parts that will have to be eventually replaced (at what costs)? Are there shims, v-belts (belt-drives), or wear plates that have to be adjusted? Seal maintenance: Does the pump require fresh-water or oil-filled seals (that require periodic checking and filling)? How many different kinds of valves are required for each system? When performing maintenance on these kinds of pumps, how easy is it to gain access to the volute and seal? These are important questions for assessing long-term operation and management and lifecycle costs. Obviously, maintaining fewer wearing parts lowers labor time and associated costs. The better pumping system manufacturers will be able to provide real data on parts and maintenance labor.

4. Operator Safety. What operator safety concerns apply beyond typical electrical shut-off procedures? For example, when accessing the volute, are there any issues with potential spillage or steaming concerns (generated from recirculation)? Specifiers and decision-makers should understand the differences in vertical and horizontal pump construction as it relates to maintenance. Overall, because confined-space requirements are eliminated, prime-assisted pump stations and systems do provide the safest approaches to wastewater and stormwater pumping systems for flows of at least 50 gpm compared to conventional submersible and chopper pumps.

5. Footprint. Because prime-assisted pump stations and systems are above-grade, all of the equipment will be housed on a skid or steel base with different types of enclosure designs. Obviously the location of the sump must be able to provide the vertical or horizontal access space to access the equipment. That said, there are no confined space entry requirements and valve-vaults to consider.

The key for today's industrial pump stations centers on reducing hazards, maintenance and labor time, and overall costs. Taking the pumps out of the sump presents a cost-saving solution that safely addresses confined space restrictions while improving the operating efficiency and maintenance cost. The need to prime these above-grade systems represents a slight trade-off to the hidden submersible, but the safety and ease of maintenance benefits are clear. As above-grade pump stations continue to expand into refineries and processing plants, decision makers should see that there are two primary types, which starts with how they are primed and how the pump is constructed. Understanding these differences will aid in planning wastewater and stormwater pumping projects in line with reliability, safety and an improved bottom-line.

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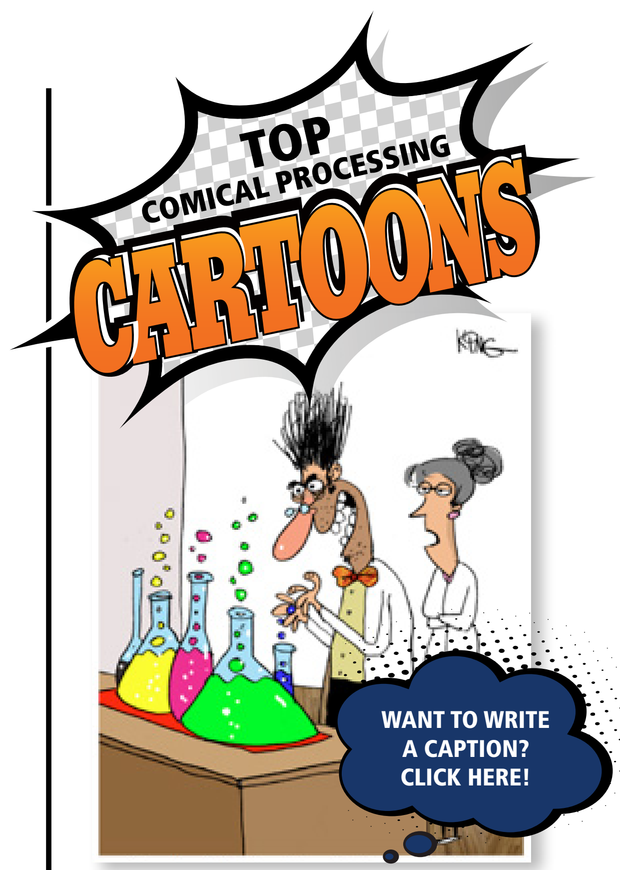

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