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# Succeed at Process Safety

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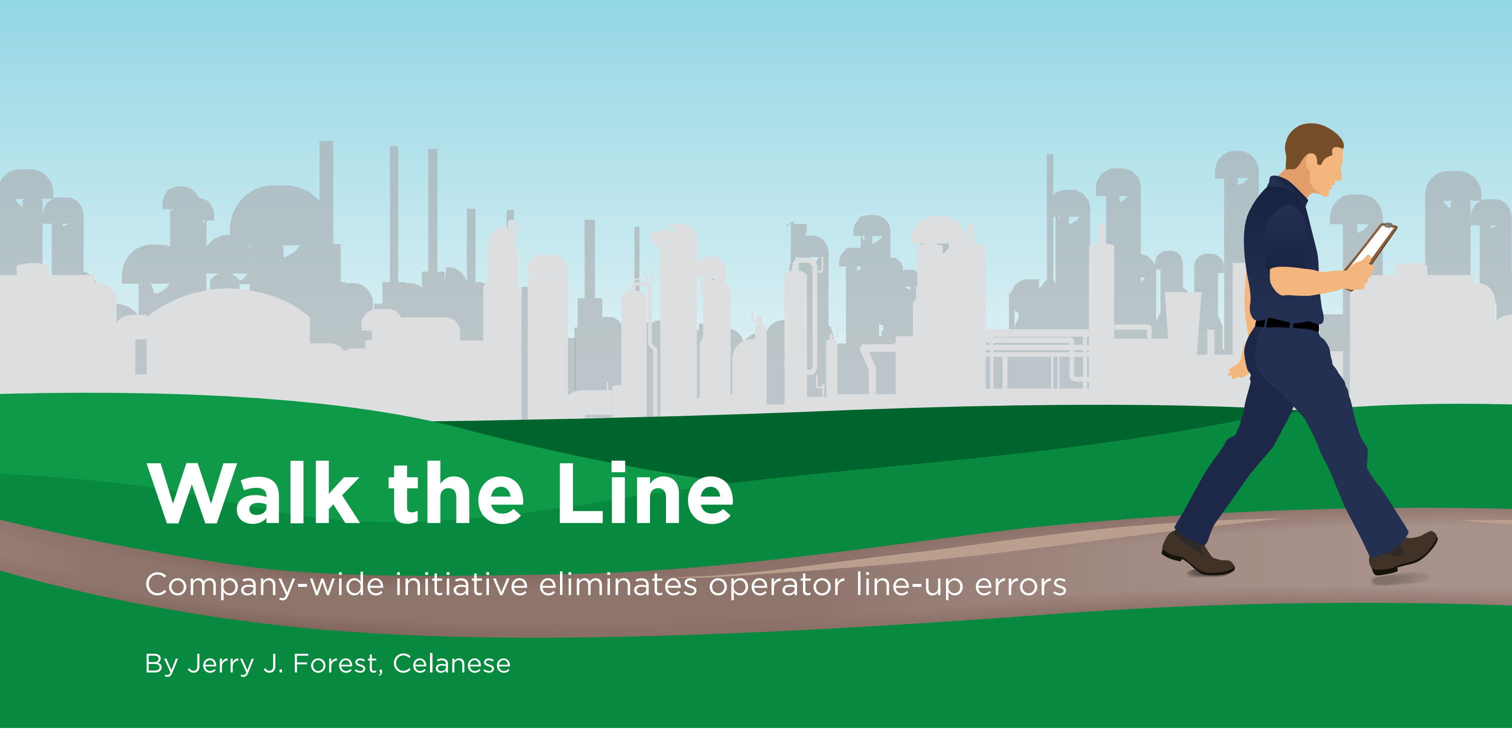
# TABLE OF CONTENTS



## Advertiser Index



# Walk the Line

## Company-wide initiative eliminates operator line-up errors

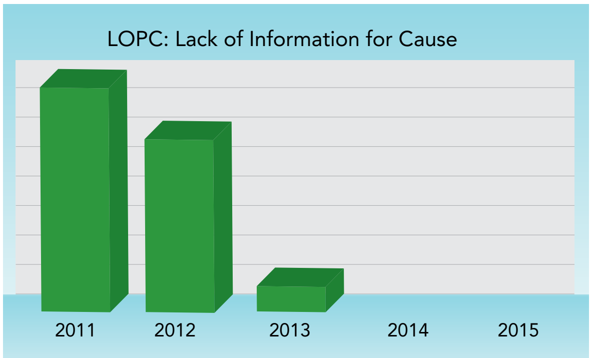
By Jerry J. Forest, Celanese

During an operation to return a filter back to service, a hydrocarbon spill resulted in a reportable quantity release and an API RP-754 Tier 1 process safety incident. The investigation found that the operator neglected to close the downstream bleed valve, causing the release. Corrective action included disciplining the operator.

Does this scenario sound familiar? It likely will. Industry data indicate that greater than 20% of loss of primary containment (LOPC) incidents stem from a few causes: valves left open, open-ended lines on energized pipe and vessels, and line-up errors. More than 10% of these events occur during equipment startup [1].

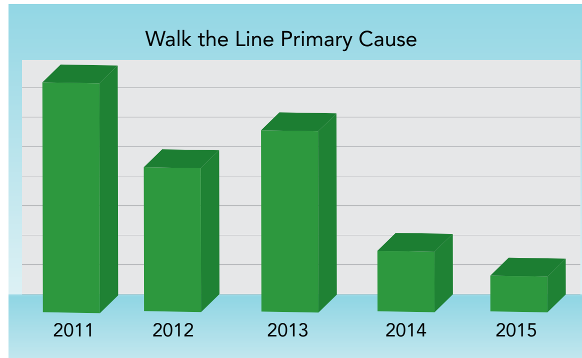
Blaming an operator when line-up errors occur seems easy but doesn't address the underlying problem. We never will eliminate these human-error causes of process safety incidents until we go beyond simply noting "operator left valve open" and answer the question "Why did the operator leave the valve open?"

Analysis of process safety incident data at Celanese indicated that almost half of the incident causes related to conduct of operations — i.e., the management systems in place to ensure operators perform their tasks correctly [2]; a majority of these were line-up errors. The most common operating mode during the incidents is startup or returning equipment to service following maintenance. Recognizing that the most fundamental task operators perform is to line-up equipment, Celanese developed the "Walk the Line" program. It is based on a belief that the operators must know with 100% certainty where energy will flow each time a change is made in the processing unit. The premise of the program is that we can change behavior by providing a




**IMPROVEMENT METRIC**

**Figure 1. The number of incidents without adequate root cause analysis has dropped dramatically.**




**LINE-UP INCIDENTS**

**Figure 2. Walk the Line has significantly cut the number of events caused by line-up errors.**

culture of setting the expectation for accuracy in line-up, and giving operators the tools to ensure accuracy in line-up.

## AN ESSENTIAL FIRST STEP

A pre-condition for Walk the Line is understanding the causes of operator line-up error. This becomes problematic if investigations stop at "operator left valve open" as the cause. As Celanese developed our Walk the Line program, it became clear that we first must improve the quality of our incident investigation process and root cause analysis (RCA). We approached this in two ways. After identifying the line-up error incidents, we asked each site to analyze its near-miss and incident data to the best of its ability to identify why the errors occurred. In addition to this analysis, we completed a global incident investigation management-training program that targeted improving the quality of the application of RCA methodology to give greater consideration to human factor causes. We instituted a practice of reviewing all Tier 1 and Tier 2 RCAs to normalize the quality of cause maps and corrective actions. The metric we chose to measure effectiveness of the training and RCA reviews is "lack of information for cause." Figure 1 shows the improvement trend since these practices were initiated, with 2011 as the base comparison year.

As our RCAs improved, we were able to characterize the causes of line-up errors as: expectation for energy control not set, lack of continuity of operations, and deficiencies with operational readiness. Walk the Line was adopted as a readily recognizable way to raise awareness in these three areas.

Celanese implemented Walk the Line in 2013 and achieved immediate results. Since implementation, LOPC incidents related to operator line-up have fallen 30% per year on average. Figure 2 illustrates these results. The fact some incident causes persist highlights it may take up to five years to effectively ingrain a practice into the culture for lasting change.

## TAILORED IMPLEMENTATION

On reviewing the causal data, it was apparent that each site had unique gaps falling within the three categories. The approach therefore was to focus on culture change at the corporate level, provide the operational discipline tools to address operational continuity, and the operational readiness tools to address the mode of operation where these incidents occur. Sites then implemented the program using the tools applicable to their needs.

*Culture*. The first group of causes centered on the knowledge of an operator's responsibility for energy control. In some instances, a site had failed to formally document its expectations for operator line-up. In other cases, operators had received initial training on proper line-up technique but never any reinforcement of the concept; refresher and on-the-job training ignored the topic.

One way to change this culture is to apply the proper initial training and then follow-up with frequent reinforcement of the expectation that operators must know with 100% certainty where energy will flow each time they make a change to the process. From a corporate perspective, we produced and distributed a number of tools designed to raise the awareness of this expectation. These include:

1. Two-day regional workshop meetings with front-line supervisors that reinforce conduct of operation tools for continuity of operations and operational readiness.

2. Periodic newsletters distributed in native languages across the globe describing Walk the Line expectations and tools.

3. Toolbox presentations of actual incidents caused by line-up errors. These presentations aim to enable front-line supervisors to open dialogs with operators on "what would you do" to prevent the incident. (For details on novel, just-launched interactive safety training tools, see "Achieve Better Safety Training," http://goo.gl/HokrzM.)

4. Standard Walk the Line training packages that can be used as is or modified for a site's individual needs.

5. Short corporate videos that, as part of our process safety lessons learned program, help reinforce the message of Walk the Line.

After three years of raising awareness and setting the expectation, we continue to use terms such as "Walk the Line incident" when describing line-up errors to remind the organization of expectation for energy control.

*Continuity of Operation and Operational Discipline.* In the early phases of Walk the Line, the most common question from operators was "Do we have to physically walk the line each time we make a change?" The answer is, if you don't know with 100% certainty where the material will flow, then yes. However, several tools can help operators grasp the present operating state of a processing unit. Understanding the current line-up and changes to the line-up is one aspect of continuity of operations. The tools are called operational discipline tools because they introduce a discipline to operations that encourages repeatability in results [2].

The operational discipline tools used include: shift instructions, shift notes, expectations of shift relief, shift meetings, and operator evaluation sheets with both informal and formal rounds. Each incorporates the Walk the Line theme through a dedicated section that describes in checklist format common and uncommon situations that give rise to changes in the unit that might lead to a line-up error. Shift supervisors have an opportunity to reinforce the expectation for Walk the Line when they write shift instructions. Highlighting potential line-up issues when discussing the current jobs on shift at the toolbox or shift meeting provides another opportunity. Operators can communicate the changes made on shift by citing them in shift notes, and using these shift notes during shift relief. Each site is expected to define an informal and formal evaluation route and train operators on what to look for during the equipment evaluation. In addition, evaluation round sheets should include location of critical bleeders, valve positions and other critical line-ups so that operators check them each time they make their rounds.

| Operator Shift Notes – Walk the Line Section | Yes √ | No √ | Description of Action Taken on Shift |
|---|---|---|---|
| Abnormal Line-ups | | | |
| Equipment bypassed | | | |
| Equipment out of service | | | |
| Special samples taken | | | |
| Unscheduled equipment outage | | | |
| Tests completed on shift | | | |
| MOCs/PSSRs completed | | | |
| Special operating instructions | | | |
| Abnormal transfers completed | | | |
| Emerging problems/troubleshooting | | | |
| Other situations that change line-up | | | |

**EXAMPLE CHECKLIST**

**Figure 3. This short checklist is used for operator shift notes and shift relief.**

As noted, these tools share a common element — a pre-defined Walk the Line checklist. It must be completed and communicated, regardless of whether a change has been made. This repetition helps build the culture of Walk the Line. Figure 3 shows an example checklist for operator shift notes used during shift relief. This checklist identifies those activities that lead to changes in line-up. These changes are communicated between and among shifts, with confirmation of review required. Operators returning to duty must give positive verification since the last review.

Another class of aids to help operators understand the current operating state of a unit

**CRITICAL BLEED VALVE**

**Figure 4. Bright yellow color alerts staff to importance of this bleed valve.**

involves design tools. For example, a process to identify critical bleeders will highlight those points in the process that must have a bleed valve shut with a plug to prevent an LOPC incident. At Celanese, some sites paint these critical bleeders a recognizable color (Figure 4) and have the operator inspect them during evaluation rounds.

Additional design practices, to name a few, include formal plug and inspection programs, line labeling initiatives, spring loaded valves, and double blocks on some bleeders.

*Operational Readiness*. Experience has taught us that the frequency of incidents is higher during process transitions such as startups. These incidents often result from the physical process conditions not exactly matching those intended for safe operation. Thus, it is important that the process status be verified as safe to start. Operational readiness reviews ensure the process is safe to start by examining issues such as:

- equipment line-up;
- safeguard bypasses restored;
- bleed valves plugged;
- leak tightness;
- pre-startup safety reviews completed; and
- car seals in place.

Such reviews of simple startups may involve only one person walking through the process with a straightforward checklist to verify that nothing has changed and equipment is ready to resume operation. More complex reviews or higher risk startup situations may require different tools.

Operational readiness tools share some common elements such as defining equipment commissioning steps in standard operating procedures (SOPs). Commissioning tools include: process and instrumentation drawings (P&IDs) walk-downs, formal

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"Inspect With Your Mind, Not Just Your Eyes,"
http://goo.gl/eW6YBe

## LEARN MORE ABOUT WALK THE LINE

In 2015, the American Fuel & Petrochemical Manufacturers (AFPM) launched Walk the Line in partnership with member companies as part of the AFPM and American Petroleum Institute (API) Advancing Process Safety Program. Walk the Line is a practices-sharing program designed to help prevent operator line-up errors that cause approximately 20% of all process safety events (according to industry data [1]). This program is successfully raising awareness of operator line-up errors and providing simple solutions to prevent these types of mistakes in the future. Walk the Line materials include "what/if" scenarios, training, conduct of operation practices, operational discipline practices, and operational readiness practices.

For more information, contact AFPM at safetyportal@afpm.org.

pre-startup safety reviews (regardless of whether a change was made), soap testing, checklist SOPs and similar maintenance/operations turnover, and verification after maintenance checks designed to ensure bleeders are closed and line-ups are correct.

A common tool used in industry is independent verification. It often targets some safety devices such as pressure relief devices but also makes sense for critical line-ups. Celanese uses a risk-based ranking criteria to determine if a task should be considered critical. These tasks are performed with a checklist in hand; the operator verifies each step when completed. After the task is finished, another person independently confirms the steps as complete and accurate.

## STEP UP YOUR EFFORTS

Adopt a belief that all process safety incidents are preventable and start with a goal of zero LOPCs caused by operator line-up errors. Of all LOPC incidents, those related to incorrect line-ups and open ends seem easiest to correct. When analyzing incidents, go beyond "operator left valve open" and answer "Why did the operator leave the valve open?"

Recognize which operating discipline and operational readiness tools operators require to understand the current operating state of the processing unit. Set the expectation that an operator must know with 100% certainty where energy will flow each time a change is made to the process. If that person doesn't know with 100% certainty, then walk the line! ■

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2. AIChE Center for Chemical Process Safety, "Conduct of Operations and Operational Discipline," J. Wiley & Sons, Hoboken, N.J. (2011).

# Succeed at Process Safety Management

## Follow ten rules to ensure an effective long-term program

By John S. Bresland, Process Safety, Risk Assessment LLC

Little over a year ago, on August 12, 2015, a catastrophic explosion occurred in Tianjin, China. More than 165 local residents and firefighters died in that explosion. A Chinese state council investigation described it as “an extraordinarily serious production safety accident” caused by ignition of hazardous materials, improperly or illegally stored at the site. I’m reminded of a similar but not so drastic explosion that happened in 1982 in a Philadelphia chemical plant where I was working. By a stroke of great fortune, no employees or community members were seriously injured. I was away from the plant on business on the day of the explosion. When I returned that evening and went out to the scene I was amazed by how a chemical plant designed and built to rigorous standards could be turned into a pile of smoking spaghetti-like steel in a fraction of a second. The subsequent internal investigation taught us a lot about mistakes that we had made.

Many years later, I was appointed by President George W. Bush to be a board member of the United States Chemical Safety Board (CSB). I worked at the CSB from 2002 until 2012, including serving as its chair from 2008 until 2010. During that period, the CSB performed many investigations, including on some of the more infamous incidents, such as the BP Texas City, Texas, refinery explosion and the Imperial Sugar combustible-dust explosion near Savannah, Georgia. Both of those explosions caused many fatalities and injuries but fortunately led to improved safety in the process industries. (See “Chemical Safety Board Opens Up,” http://goo.gl/IrzOu4, for more on the CSB current chair’s aims and plans.)

During my years at the CSB, I learned that three types of process companies exist. I realize that I’m being simplistic here but hear me out.

The first type of company doesn’t understand the hazards of its operations. It lacks suitable process safety programs and suffers serious accidents with dire consequences. We saw a lot of those companies at the CSB.

The second type of company does understand the hazards and the regulations. It has excellent

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safety programs and quality people but still experiences incidents, some minor and some very serious. These incidents (fires and explosions) cause lots of frustration and expense for company management!

The third type of company understands the hazards and the regulations. It has excellent safety programs and quality people. It doesn't have any serious incidents.
Any company in the business of processing hazardous chemicals should strive to become the third type of company.

## TOP TEN RULES

Based on my many years in the chemical industry and my ten years at the CSB, I have developed my "top ten" rules for process safety success. Let me share them:

*1. Leadership (president, chair, board member, plant manager, shift supervisor) must be committed to process safety.* If you are the leader of any type of process company, the safety of your employees and the financial success of your firm depend upon your leadership on process safety. Leaders not only must communicate their passion for process safety but also must establish the right organization and apply the needed resources.

*2. You must get the best possible people in your company, from senior management to the operators in the control rooms of your facilities.* In a perfect world, chemical engineers would oversee the complexities of a plant 24 hours a day. However, many engineers don't aspire to such an operations role and even those that do wouldn't enjoy spending their career working rotating shifts. So, you must mandate a stringent hiring process for control room operators — and for all employees for that matter; training and education opportunities must continue throughout a person's career. Finding and keeping the best people will mean success for your company.

*3. You must ensure equipment reliability through an effective program for mechanical integrity (now more commonly called asset* *integrity).* In today's world, where process plants can operate for 3–4 years or even longer between major turnarounds, the reliability of process equipment is of paramount importance. You must pay attention to everything from piping to valves to control devices to major rotating machinery. To keep the plant running and know that your equipment isn't going to fail, you will need expertise, such as employees who understand corrosion or the complexities of rotating equipment.

*4. Be passionate about taking care of the details.* Large process plants are extremely complicated, containing millions of parts and sophisticated electronic equipment and software. Key equipment should have backups so that a single failure can't cause a shutdown or process incident. A new Boeing 787 airliner contains upwards of about two million parts. Think about the effort needed to ensure that every part is doing its job safely and efficiently. You must apply the same effort in attending to the details in your plant.

*5. Establish, if you haven't already, and carefully track process safety metrics to monitor your operations.* These metrics will educate you on how your plant is operating. You should develop both lagging and leading metrics. Some examples of lagging metrics are the number of reportable incidents and the number of times that a pressure relief valve activates. A leading metric should inform you about activities in your plant that can indicate a trend toward a negative outcome — for example, incomplete action items from investigation reports.

*6. Take the long view on risk.* If an employee alerts you to a problem that only can be resolved by shutting down the process, you must weigh the loss of production from a shutdown and the possibility of a disappointed customer against keeping the process operating until the next scheduled turnaround and risking an incident such as a fire or a chemical spill that may lead to injuries to personnel or damage to the environment. I urge you to take the long-term view and shut down the process today to resolve the problem. By taking the long view, you will incur short-term consequences that soon will be forgotten. On the other hand, an explosion or toxic release, because you delayed taking care of the immediate problem, will cause long-lasting impacts for you and for your company.

*7. Prepare for the possibility of an incident, a fire or an explosion with injuries or off-site impact.* You should ensure you have a first-class emergency response plan and know your local emergency responders. Run drills with them. In addition, maintain a good relationship with local community leaders. Understand that a serious event will turn your business and personal life upside down. Your day-

## REFERENCE

1. Erickson, J., "The Relationship between Corporate Culture and Safety Culture," p. 73 in "Safety Culture and Effective Safety Management," National Safety Council, Itasca, Ill. (2000).

to-day responsibilities of running a process plant will give way to dealing with federal and state regulatory and investigative agencies, lawyers, insurance adjusters, news media and a host of other people with a need to know what happened. Of course, the best way to avoid this is not to have an incident — but planning ahead to prepare for such an emergency can pay huge dividends if one were to occur. Sit down with your leadership team to develop a contingency plan. Then, work with local responders and the community so they can become familiar and train for their role.

*8. Thoroughly investigate all incidents.* Always remember that smaller events often very easily could escalate to catastrophic ones and cause a fatality. You should establish a team that not only is well trained on the techniques of incident investigation but also is charged with finding the real root cause of an event. Too often today, what's described as the root cause actually isn't. Stating "valve failed" or "operator did not check the oxygen level" doesn't address the underlying issues: "Why did the valve fail?" or "Why didn't the operator check the oxygen level?" The most-useful root cause analyses are those that identify a systemic or management issue. (For details on a program one company has successfully used to drive down operator line-up errors, see "Walk the Line," http://goo.gl/vOODKb.)

*9. Don't allow complacency to develop.* When everything is going well, quality is excellent, and your plant has had no environmental incidents, personnel accidents or process safety issues, people tend to get complacent. Strongly combat this inclination. Keep running a "tight ship." Any letup in your resolve to have the best safety program can come back to haunt you with a serious near-miss or an actual incident. As a company leader, it's your responsibility to continually send the message of safe operation and no complacency to all your people. (For more details, see "Stimulate a Sense of Vulnerability," http://goo.gl/tA3ZJP.)

*10. Finally, and maybe most important, you must develop and nurture a strong process safety culture within your company.* Culture basically means "the way we do things around here." Of course, a positive safety culture starts with a positive corporate culture (see: "Process Safety Begins in the Board Room," http://goo.gl/uoPcz8). Employees gauge whether management is just "talking the talk" or really "walking the walk" by its actions: Does management pay attention to safety? Does it ignore the safety suggestions of employees? Does it closely monitor process safety statistics? Does it signal that production is more important than safety? Answer those questions and you'll know how strong or weak your safety culture is. Ensure that in your organization you are doing things the safest way [1]. ■

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# Properly Pump Condensable Vapors

Each system has benefits and limitations as well as special considerations for handling hazards mixtures.

By Phil Vibert, Tuthill Vacuum & Blower Systems

Condensable vapors are the vapor phase of compounds that normally would be in the liquid phase at room temperature and at atmospheric pressure. Examples include water vapors, organic vapors and organic solvent vapors. Organic vapors may include alcohol vapors such as methanol, ethanol, propanol and butanol. Organic solvent vapors can include toluene and xylene.

## VAPOR PRODUCTION

All liquid compounds have a vapor pressure that increases with temperature:

$$Pv = f(T).$$

Reference the Antoine equation describing the relation between vapor pressure and temperature where P is the vapor pressure, T is temperature and A, B and C are component-specific constants:

$$\log (Pv) = A - B/(C + T)$$

As a liquid compound is heated, its temperature and vapor pressure increase. The temperature at which the liquid's vapor pressure is equal to atmospheric pressure (760 torr) is called the liquid's boiling point. Normally, the higher the boiling point, the lower the vapor pressure vs. temperature curve, and the easier it is to condense. The quantity of heat required to convert one unit of mass (normally a lb. or kg) from the liquid phase to the vapor phase is called the liquid's latent heat of vaporization. If the total pressure above a heated liquid is reduced to its vapor pressure, the liquid will boil at the reduced pressure.

This variation of a liquid compound's vapor pressure with temperature and pressure provides a method for separation and transportation of pure compounds from liquid mixtures.

## PUMPING CONDENSABLE VAPOR

Vapor can be condensed by removing the latent heat of vaporization/condensation and normally lowering the vapor temperature. This causes the vapor to change phase back to a liquid. Condensable vapor then can be pumped like a gas by controlling the vapor temperature and pressure.

In a gas and vapor mixture, the vapor will condense when the gas and vapor mixture's temperature is lowered to the temperature that corresponds to the saturated vapor pressure of the condensable vapor that is equal to the partial pressure of the condensable vapor in the mixture:

$$Pv = Ptotal \times MF \text{ of water vapor}$$

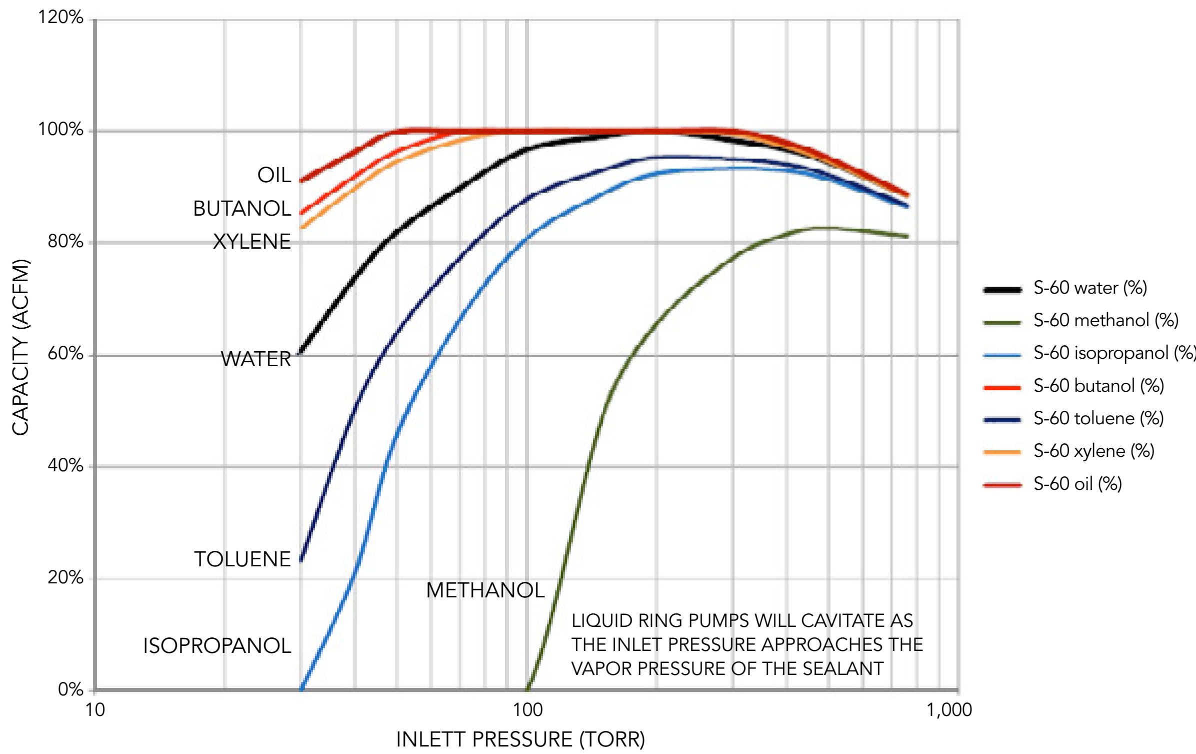
If the gas load is 100% of a condensable vapor, the vapor will condense when the vapor temperature is lowered just below its saturated vapor temperature:

$$Pv = Pv\text{-}sat \approx Ptotal$$

As the vapor's Mole Fraction (MF) decreases, the lower temperature is required to condense the vapor out. Any permanent gas that is present, such as air, will entrain vapor with it and carry the vapor through a condenser, based upon the saturated vapor pressure at the outlet temperature of the condenser:

$$Wv = Wg \times MWv/MWg \times Pv/Pg$$

(Wv and Wg are weight of vapor and of gas, MW is molecular weight, Pv is saturated vapor pressure and Pg = Partial P of gas.)




**LIQUID RING CAPACITY VS. INLET PRESSURE FOR VARIOUS SEALANTS AT 60F**

**Figure 1. Liquid ring pump sealant should be compatible with condensable vapors.**

**BOOSTER/LIQUID RING SYSTEM**

**Figure 2. These systems can pump wet non-condensables.**

## VACUUM PUMP REQUIREMENTS AND TYPES

Vacuum pumps handling condensable vapors have three common features: They do not require internal lubrication, can handle liquid slugs and offer compatible mechanical seals (Figure 1) and elastomers and must offer compatible construction materials for condensable vapor.

Consider these three types of vacuum pumps:

**Liquid Ring Pumps and Booster/Liquid Rings.** Liquid ring pumps and booster/ liquid ring (Figure 2) can pump wet non-

| Advantages | Disadvantages |
|---|---|
| Can perform as both vacuum pump and direct contact condenser | Normally higher operating cost than dry |
| Lower purchase price | Higher power and cooling water consumption |
| Simplicity of rotating parts improves reliability | Larger footprint |
| Low maintenance | Pump performance is limited by vapor pressure of sealant |
| Because of pump simplicity, it can be readily disassembled and reassembled on site by end user | Requires a supply of liquid sealant for makeup or change out |
| Lower operating temperature for thermal sensitive or polymerizable process material | Operation normally results in larger amount of hazardous waste |
| Liquid sealant allows for handling higher temperature inlet gases/vapors | |
| Can ingest liquid from process or condensater from upstream condenser | |
| Less sensitive to process particulate due to larger clearances | |
| Liquid within pump may act as quench to reduce chance of ignition from sparking | |

**LIQUID RING PUMP ADVANTAGES AND DISADVANTAGES**

**Table 1. One plus of liquid ring pumps is their simplicity in areas of parts movement, assembly and maintenance.**

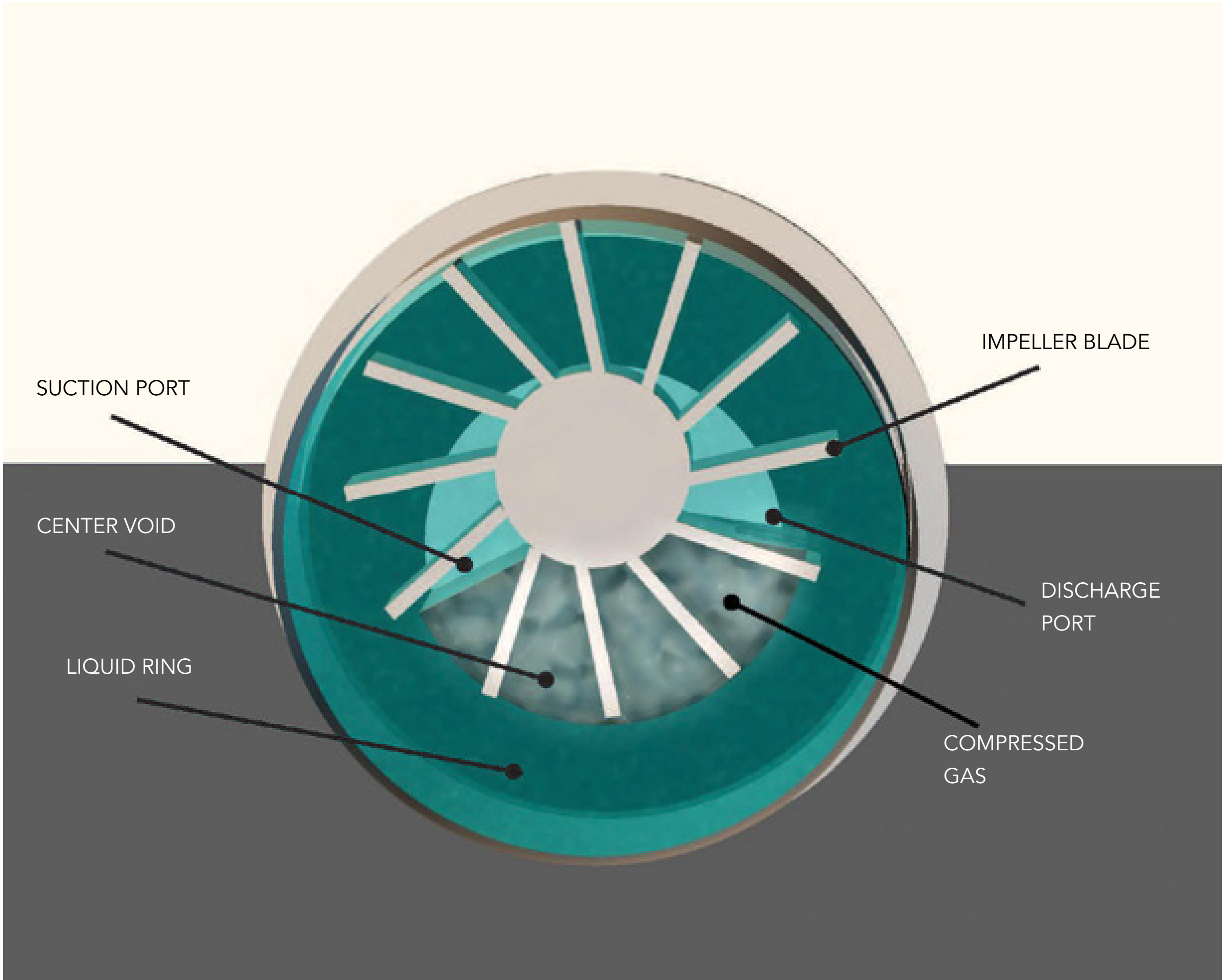
condensables. They are limited by sealant vapor pressure and flow (see Table 1 for more advantage and disadvantages). A liquid ring vacuum pump condenses with direct contact of a sealant ring with vapor (Figure 3).

**Dry Pumps and Booster/Dry Pumps.** Dry pumps and booster/dry pump systems offer a low operating cost with lower BHP and coolant. Their performance is not limited by vapor pressure, and this option can recover solvents without contamination. They are however limited by vapor inlet temperature and auto-ignition temperature (AIT). See Table 2 for more pros and cons of dry pumps.

To compare features of dry vs. liquid pumps, see Table 3.

**Condensers.** Condensers typically offer the lowest capital cost for pumping condensable vapors as either direct-contact or surface condensers. They pump vapor through "change of phase" from vapor to liquid. Condensers are limited by coolant temperature and flow available.

Direct-contact condensers also are known as spray or barometric condensers. Their




**LIQUID RING ILLUSTRATION**

**Figure 3. A liquid ring pump's sealant ring comes in direct contact with the compressed gas.**

advantages include a closer approach temperature = (Tout – tin), lower pressure differential ΔP, normally lower fouling or plugging in dirty processes, normally lower cost and scrub and cool process stream. Their disadvantages include a coolant contacts process that must be compatible, normally greater waste stream from contamination of coolant by process and vacuum level limited by dissolved gas in coolant.

Surface condensers can be shell and tube, plate and tube or finned tube. Their advantages include separation of coolant and condensable; the option for condensation on shell or tube side, the option for horizontal or vertical condenser installation, and a scrub and cool process stream. Their disadvantages include higher approach temperature = (Tout – Tin) so that temperature of condensate/coolant temperature is higher, and greater fouling or plugging in dirty applications.

| Advantages | Disadvantages |
|---|---|
| Lower ultimate pressure and higher capacity at low pressure end for single-stage pump | Higher purchase price |
| Lower power consumption | Higher complexity effects reliability |
| Lower cooling water usage | More difficult to disassemble and reassemble on site by end user |
| Higher discharge temperature helps to keep the process material in the vapor phase while passing through the pump, so it can be either condensed out or sent to a thermal oxidizer | Higher discharge temperature may cause a problem in handling temperature-sensitive compounds that might polymerize, decompose, or have an adverse reaction |
| More compact footprint | Solvent handling limited by auto-ignition temperature of solvent |
| Lower operating temperature for thermal sensitive or polymerizable process material | Operation normally results in larger amount of hazardous waste |
| Can pump high vapor pressure solvents | Limited liquid ingestion |
| Environmentally friendly with less pollution | |

**DRY PUMP ADVANTAGES AND DISADVANTAGES**

**Table 2. Environmental benefits, including low power consumption and lower cooling water usage, are among the advantages of using dry pumps.**

The most commonly used surface condenser is the shell and tube because it offers the best combination of features, including separation of process from coolant but with effective heat transfer, adjustable surface area while maintaining compact heat exchange, lower pressure drop for process and coolant side, pressure integrity and affordable cost in standard materials. The shell and tube condenser offers flexibility for orientation and the process and coolant side, depending upon process conditions such as corrosive fluids, low pressure drop, high or low operating pressure, dirty fluids and cleanability.

## HANDLING HAZARDS

Handling condensable vapors involves some hazards. The vapors can become flammable or explosive, toxic and corrosive. Special process methods and construction materials in pumps can help prevent a hazardous situation.

If flammable, the process needs to avoid air (oxygen) mixtures with flammable gas or vapor. If air is present, avoid the flammable mixture range. For example, methanol has a flammable range of 6–36.5% by volume of methanol vapor in atmospheric air. Lessen hazard risks by reducing air in-leakage, using inert gas purges and possibly requiring the

| Feature | Dry Vacuum Pumps | Liquid Ring Vacuum Pumps |
|---|---|---|
| Liquid within Pumping Chamber | No liquid required | Liquid required for sealing and cooling |
| Clearances | Smaller clearances required to reduce gas slip-page | Clearances can be larger since liquid is sealed |
| Rotational Speed (RPM) | Normally higher to reduce effect of higher gas slip on performance | Normally lower since gas slippage is less and drag of the liquid increases HP |
| Ultimate Pressure | More dependent upon RPM and clearances | More dependent upon liquid properties such as vapor pressure and gas solubility and liquid temperature |
| Discharge Gas Temperature | Normally elevated since no liquid is present to help cool it | Normally lower since the liquid acts as a cooling agent |

**DRY VS. LIQUID RING PUMPS**

**Table 3. This table compares various attributes and restrictions of both dry vacuum and liquid ring vacuum pumps.**

use of explosion-proof motors and electricals.

If toxic, the process should contain fluids that could contaminate the process. This can be done with the use of mechanical seals, or even double mechanical seals, and the option for a gasketed pump and a full sealant recovery (FSR) system.

If corrosive, the process should try to keep anhydrous by avoiding contact with moisture. This includes avoiding moisture in the air (humidity) as well as air bleeds. Inert gas purges should be used with auto-start/-stop and seal purge if necessary. Use more resistant metallurgy and protective coating such as PTFE or bi-protect. Because many applications pumping condensable vapors involve organic solvents, the vacuum pumps must be able to handle some solvent carryover. This dictates a pump that does not require lubrication of its rotary internals such as a liquid ring, a dry pump or a booster/liquid ring or booster/dry pump system. The pump should have a resistant mechanical seal or gasket elastomers such as Teflon encapsulated, Kalrez or Simriz. The pump needs to recover solvents with minimal contamination for reuse, reprocessing or disposal. The pump also should have resistant metallurgy (SST) or coating (PTEE or bi-protect).

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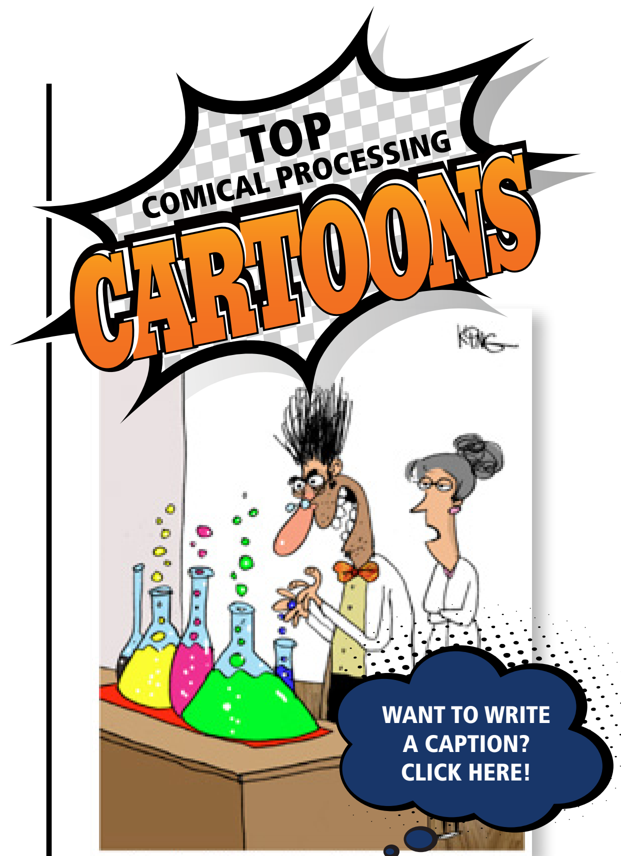


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