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# Deflated—Victims of vacuum

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**Abstract**

Atmospheric pressure combined with a partial vacuum within chemical plant or refinery tanks can result in some ego-deflating moments. This article will review three catastrophic vessel failures in detail and touch on several other incidents. A 4000-gal acid tank was destroyed by a siphoning action; a well maintained tank truck was destroyed during a routine delivery; and a large, brand new refinery mega-vessel collapsed as the steam within it condensed. Seasoned engineers are aware of the frail nature of tanks and provide safeguards or procedures to limit damages. The purpose of this paper is to ensure this new generation of chemical plant/refinery employees understand the problems of the past and take the necessary precautions to guard against tank damages created by partial vacuum conditions.


*Keywords:* Case histories; Process safety; Tank accidents; Vacuum incidents; Vessel failures

## 1. Introduction

> "It should not be necessary for each generation to rediscover principles of process safety which the generation before discovered. We must learn from the experience of others rather than learn the hard way. We must pass on to the next generation a record of what we have learned." Those are the words of wisdom from Mr. Jesse C Ducommun as an introductory quote in each of the excellent "BP Sharing the Experience Booklets" [1].

About three decades ago, Dr. Trevor Kletz wrote an article predicting the near term future. He simply stated, "The collapse of atmospheric storage tanks has been a frequent occurrence in almost every company, and more will be sucked in during the coming year" [2]. Over the years, our tank design and operations have drastically improved and the occurrences seem less frequent.

Today's article includes a case of an atmospheric tank collapse and the destruction of a transportation pressure vessel on a truck and a mega-sized refinery pressure vessel. Please be sure to share this article with less experienced members of your team.

## 2. An acid storage tank destroyed in seconds, but it is remembered for years

### 2.1. Background

Despite the fact that I have used this case history as a teaching example of the frail nature of tanks for a number of years, I still find it difficult to visualize such unexpected destruction resulting from an overflow siphoning action.

A chemical plant complex on the U.S. Gulf Coast used large volumes of brackish water from an adjacent river for once-through cooling. At the outfall the cooling water co-mingled with process sewer water and the company was concerned about the possibility of pH excursions in the effluent. A process engineer developed a plan, which included the installation of a light-weight fiberglass tank to store and meter out hydrochloric acid to maintain proper effluent pH. The design package and controls was made so that a regulated amount of acid was available to neutralize small amounts of caustic soda to form a more environmentally acceptable table salt [3].

A nominal 4000 gal "off-the-shelve" fiberglass tank about 8 feet in diameter and 8 feet high was selected to receive, store and distribute the acid. During normal operations the vessel would receive acid via an in-plant pipeline. It was also equipped to receive acid via tank trucks (see Fig. 1).

This atmospheric closed top tank was manufactured with two top nozzles. The smaller of the top nozzles was connected to allow truck unloading and the larger (6 in.) diameter piping

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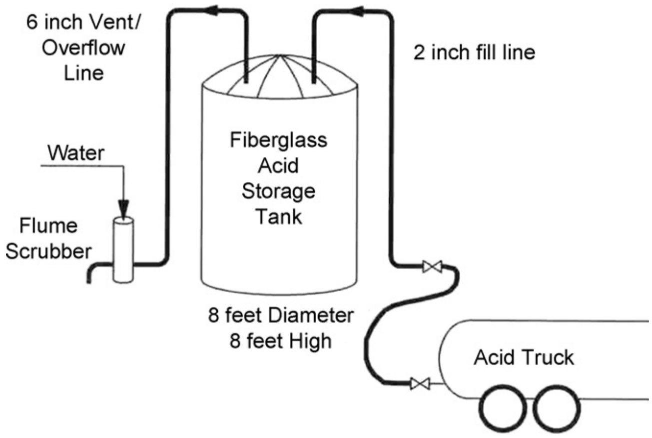


Fig. 1. Siphon action destroys small acid storage tank.

served as a vent. The tank vent was routed to a small vent scrubber that used a trickle of water to eliminate acid fumes given off during the filling operation or from thermal breathing during the day.

### 2.2. Not a good day

Initially, the system operated successfully. About a year after the system was in service, circumstances required that the tank be filled via tank trucks instead of being supplied by the usual pipeline from another area of the complex. Over time, several tank trucks were received. On one of the deliveries as the tank truck emptied, the level in the storage tank rose high in the tank. Acid started to overflow through the 6-in. line into the scrubber and to the ground.

The alert truck driver quickly responded, just as you or I would do. He abruptly shut the quarter turn delivery valve on his tank. Unexpectedly, the partial vacuum created by the siphoning action of the overflowing acid, exceeded the tank's vacuum rating. The small storage tank was totally destroyed. Who would have thought a little siphoning action could ruin the equipment?

The design did not have a vacuum breaker, because such systems were not perfected to be fume free at that time for these low-pressure tank applications. After this incident a similar storage tank was installed. However the connecting piping system was redesigned. An overflow line was built into the upper portion of the vertical cylinder and the vent continued to be from the top. The system has worked successfully since that incident.

## 3. The catastrophic collapse of a perfectly good tank truck

### 3.1. All is routine

A well-maintained truck arrived at a plant site for a routine delivery and was inadvertently destroyed within an hour. A tank truck catastrophically collapsed as the truck driver was unloading an oily hazardous material. Not a drop of hazardous fluid touched the ground. The assistant trucking terminal manager who responded described this incident as the worst tank truck vessel collapse that he had witnessed in the his 25 years of service [4].

The tank truck appeared to be very well maintained prior to the incident. The 6300 gal tank had a nameplate design of 30 psig and was frequently used in this service and making a routine delivery.

The truck arrived about 9:00 a.m. and was driven to the proper unloading station. The 3-in. delivery hose was connected to an unloading pump and lined up to the correct receiving tank by the chemical process operator. A 3/4 in. nitrogen hose was connected to a manifold on a wheel fender just forward of the right side rear wheels on the trailer (see Fig. 2).

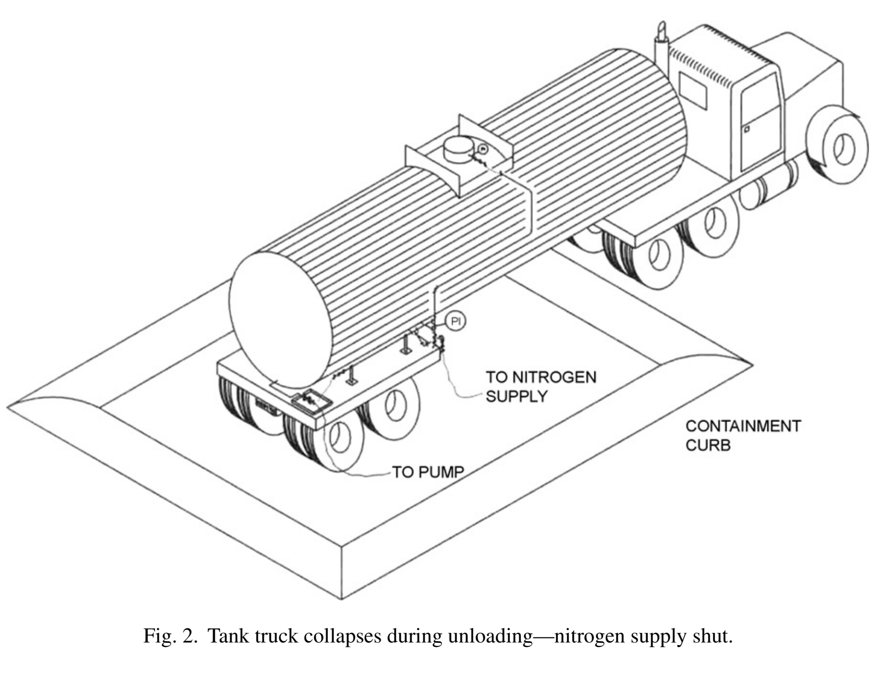


Fig. 2. Tank truck collapses during unloading—nitrogen supply shut.

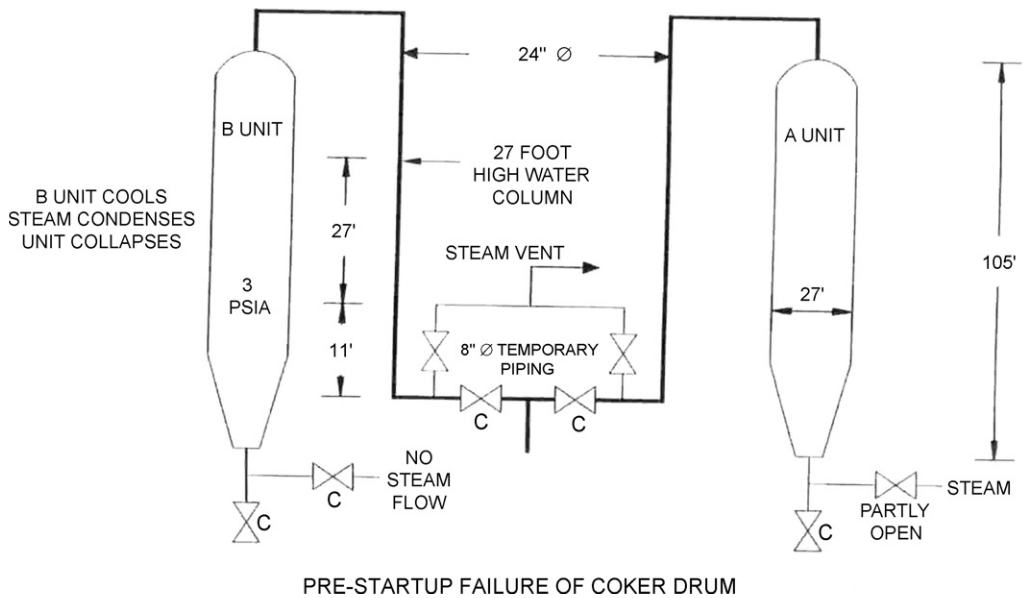


Fig. 3. Pre-start up steam testing causes collapse of coker drum.

Next, the operator opened the 3/4-in. nitrogen valves that were both upstream and downstream of the pressure regulator to nitrogen pad the truck. The operator then read the fender mounted pressure gage which read the expected 20 psig. Then she opened the proper liquid delivery valves and started the centrifugal unloading pump.

The delivery appeared to be routine as the unloading activity continued and the truck driver stayed with the truck as procedures require.

### 3.2. Collapse occurs

People in the area reported hearing a loud rumbling about 10:05 a.m. The tank truck catastrophically collapsed. The noise and the unusual situation attracted a number of the supervisors, technical and other employees who quickly arrived on the scene. No one was injured. There were no leaks or sprays of hazardous materials and no damage to the receiving plant.

An investigating team was immediately assembled to determine the root causes before the truck was moved. Investigating engineers determined that the nitrogen was opened to the hose connected to the tank trailer manifold on the right rear wheel fender, but there was a failure to open the valve atop the truck. The valve on top of the truck had a handle wheel that was circular and a tubing modification that allowed the introduction of nitrogen without the necessity of climbing the ladder to the loading/unloading dome. The handle was also loose on this quarter turn valve and the driver misunderstood the position of the valve.

The investigating team also observed a device that appeared to be a combination safety relief valve and a vacuum breaker. The information on this chrome-plated instrument read "Press 26,700CFM @ 32.5 psig," "VAC Relief 1750 @ 1 psig. Despite the nameplate on this protective device, the trailer was not able to deal with a vacuum.

## 4. Steam condensers within a mega-vessel and the vessel is destroyed

### 4.1. Gigantic vessels installed

A U.S. Gulf Coast petroleum refinery was in the final phases of increasing its petroleum coke production. It has been said that the corporate owner of this refinery had to drop its plans for a festive formal publicity announcement of the startup when one of the four gigantic vessels was destroyed. Four new large coker drums were designed, fabricated, installed, and were being readied for service [4].

One of these vessels became a victim of vacuum despite its gigantic size and apparent strength. These vessels were 27 feet in diameter and had an overall height of 105 feet. These mega-vessels had a dome shaped top and a cone shaped lower section. The wall thickness of the lower section was 0.836 in. The vessel internal design pressure was for 55 psig, but the unit was not designed for a full vacuum.

### 4.2. Pre-operational testing wrecks equipment

As part of the pre-operations process, steam was introduced into the equipment. They tested the coker with up to 50 psig steam. The procedure is used to check for any leaks and to displace any oxygen prior to startup. Prior to the test, a temporary 8-in. piping modification was constructed to release the steam of this pre-start up activity. As Fig. 3 shows, the "A Unit" and the "B Unit" shared a common vent line to the atmosphere. Unfortunately the design of the 8-in. vent piping modification was flawed. The temporary vent piping contained a loop (or trap) that could collect water as the steam condensed.

Steam was introduced to the "B Unit" first. At the conclusion of the test, steam was vented through the temporary 8-in. vent piping. The gross failure occurred about 4 days later (see Fig. 3).

An eyewitness in the operators' shelter heard what sounded to him as a muffled explosion and ran to the back door expecting to see fire or smoke. Fortunately there was no fire to be seen, but the collapsed coker drum was very easily observed. Another witness said the coker was destroyed in such a manner that it appeared to be crushed like an aluminum beer can, being squeezed in the middle.

As the coker collapsed, it tore away from levels of decking and the structure that supported it. The vessel was so damaged that it was impractical to salvage.

The investigation revealed that the "A Unit" was steamed-out just after the steam was shut off to the "B Unit". The steam in the "B Unit" continued to condense as the unit cooled while steam continued into the "A Unit" for two additional days.

There was not any direct measurement of negative pressure on the "B Unit" drum because the range of the pressure transmitter was 0–60 psig. Therefore, the instrumentation could not indicate the negative pressure and warn of potential vacuum related problems.

Investigators carefully studied the collapse. Evidence indicated that the steam condensate from the A Coker filled a 27-foot vertical section of line on the "B Unit" prior to the collapse. The height of the water column is based upon thermodynamic properties of steam and the fact that the internal temperature of the "B Unit" was 144 °F. This means that the "B Unit" was inadvertently experiencing an internal pressure of 3 psia. The vessels were not designed for full vacuum conditions.

The investigation team made two major recommendations. They recommended that the vent line be modified to eliminate any possible trap. The team also recommended that a low-pressure alarm be engineered and installed to alert the control room operator of low-pressure conditions within the coker drums.

### *4.3. Can your tanks handle full vacuum?*

Hopefully this paper is an eye-opener for the newer members of the chemical and petro-chemical industries. The destructive forces created by vacuum can be memorable if our vessels are not designed for vacuum conditions and they are deflated. And for the other members of our industry, it can serve as a reminder that we need to review existing vacuum protection thoroughly and be sure it is proof-tested as required. We must also ensure that that any alterations or modifications are properly evaluated and approved for service, prior to startup.

### *4.4. Great sources of practical awareness/training material*

If you have a need to train individuals on the frailty of storage tanks or other practical within-in-the-fence process safety topics, consider the *BP Sharing the Experience* booklets. These superb booklets cover fundamentals and are backed up by numerous case histories of hard-learned lessons. There are more than 12 booklets in the series with titles that include: "Hazards of Trapped Pressure and Vacuum", "Hazards of Water", "Safe Tank Farms and (Un) loading Operations." These booklets are now being distributed by the Institution of Chemical Engineers via their website. Currently a description of the series can be found and the booklets can be purchased at: http://www.icheme.org/publications/books/newtitles and http://www.icheme.org/shop booklets.

### *4.5. Need more examples of bad things happening in our industry?*

Another superb source of case histories and other practical information on process safety can be found at http://www.aiche.org/ccps/safetybeacon.html. The Center of Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers has developed a one-page, easy-to-understand monthly messages for manufacturing personnel. The publication is called the Process Safety Beacon.

If you would like more examples of bad things happening to good vessels, as well as a range of other hard earned lessons, consider subscribing to the Process Safety Beacon. The "Beacon" is a product of the American Institute of Chemical Engineers' Center of Chemical Process Safety's (CCPS) "Beacon".

The February 2002 Process Safety Beacon could be considered an abstract of this article. The Beacon's headline read "*A little "nothing" can be deflating! VACUUM is a powerful force!*" This Beacon summarizes the common causes of vacuum damage to tanks to include:

- The vessel has insufficient strength to withstand a vacuum...
- Vacuum is created when liquid is transferred from a vessel or when hot vapor condenses, neither of which is replaced by air/nitrogen or other non-condensable material, and
- A vacuum relief system is not present or is not functioning properly.

The CCPS has developed the "Beacon" and aimed it to deliver process safety messages to plant operators and other manufacturing personnel. The topics covered include the breadth of process safety issues. Most issues present a real-life accident, and describe the lessons learned and practical means to prevent a similar accident in your plant.

If you are interested in learning more, go to the website: http://www.aiche.org/ccps/safetybeacon.html for a free subscription.

The first Beacon was published and distributed by e-mail on November 2001 and has continued on a monthly basis. Mr. Adrian Sepeda has been coordinating and nurturing this effort for the past few years. Currently there are about 3000 individuals directly receiving the English version, 300 people receiving the Spanish version, over 200 receiving the French version, over a 150 individuals receiving the Portuguese and German translations. It is also distributed in the Arabic, Chinese, Dutch, Hebrew, Hindi and Italian languages.

## References

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