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# Forensic Investigations of Propane-Related Food Truck Incidents

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## Abstract

*The proliferation of propane-fueled food trucks and concession trailers over the last decade has led to a fast-growing industry. As with many nascent industries, accidents accompany the surge in growth, and the food truck industry is no exception. Numerous propane-related fires, flash fires, and explosions have resulted in property damage, business interruption, injury, and death. Conducting a proper investigation of a food truck incident is essential in determining the origin/cause and ultimately assigning liability and preventing recurrences. This paper discusses the food truck industry as well as the design, construction, and layout of the trucks. It provides an overview of the gas systems installed in the vehicles — from the cylinder or tank to the appliances, properties of propane, and relevant codes and standards applicable to food trucks that utilize propane. Finally, an outline of the proper methodology to use when investigating a food truck incident is provided, and a food truck explosion case study is presented.*

## Keywords

Food truck, concession trailer, design, layout, codes, standards, fire, flash fire, explosion, propane, gas system, appliances, accident investigation, methodology, BLEVE, forensic engineering

## Introduction

Food trucks and concession trailers (hereafter collectively referred to as "food trucks") are mobile commercial kitchens. As such, they have similar cooking equipment and systems to those found in restaurants. However, they also have unique components like engines and on-board generators. The potential incidents that can occur with a mobile kitchen are like those historically encountered in a commercial restaurant kitchen. Examples include fires (electric, solid-fuel, cooking, self-heating, etc.), carbon monoxide poisoning (appliance, generator, etc.), and flash fires/explosions (gas leak). While it is acknowledged there are many different types of incidents that can occur with food trucks, this paper will focus on propane-related fires, flash fires, and explosions.

## The Industry

The mobile food industry is nothing new, considering it has been a part of U.S. history in many different configurations for years. Some historical examples include pushcarts in New York City (circa 1691), chuckwagons and railway dining cars in the 1800s, field kitchens for military personnel in the early 1900s, ice cream trucks in the 1950s, and present-day mobile food trucks and carts[1]. Recent statistics indicate that more than 26,000 food truck businesses exist in the U.S. market, employing more than 32,000 people. In addition, the food truck business has been prospering, showing a revenue growth rate of 7.5% since 2016[2].

Amid the Covid-19 pandemic, many food trucks and carts experienced a depletion of foot traffic in their regular operating business districts. This caused operators to become innovative and change their focus to essential businesses, residential neighborhoods, and, in some instances, hospitals and factories[2]. As Covid-19 restrictions ease, gatherings such as the one shown in **Figure 1** will return, thereby reinforcing the need for safe design, construction, and operation of food trucks/mobile cooking operations.

## Food Trucks

Although there are many different mobile commercial kitchens driving down the road and/or parked on streets and in parking lots on any given day, most trucks have a similar design, construction, layout, and gas system installed in them.

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**Figure 1**
Example of tightly packed food trucks at a food truck fair in Minneapolis in 2012[3].

*A. Design and Construction*

Food trucks and trailers are found in many configurations and designs, including repurposed portable trailers, converted and repurposed trucks, and newly constructed trucks/trailers. In many circumstances, the construction of the food truck was performed by well-trained professionals, displaying pride, craftsmanship, and purpose in their product.

Many of the trucks have the functionality and configuration of an actual mobile commercial kitchen, utilizing stainless steel surfaces and purposeful safety components. It is not uncommon for these units to come with design drawings and operators' manuals that encompass safety and training requirements/recommendations. Other food trucks are often repurposed bread trucks or homemade conversion units that incorporate large quantities of aluminum diamond plate walls and display minimum efforts with regard to craftsmanship, safety, and code compliance.

*B. Layout*

An example of the typical layout of a food truck is illustrated in **Figure 2**. Components common to most food trucks include: the cylinder housing; generator and external power hookup; air conditioner; service counter and window; preparation area(s); sink(s); refrigerator and freezer; cooking line; hood and restaurant hood fire suppression system; and cab.

*C. Gas Systems*

Food truck gas systems generally contain a tank or cylinder(s), hoses, regulator(s), gas piping, manifolds, appliance shutoff valves, flexible connectors, appliances, and automatic fuel shutoff valve. The system starts with the container storing the propane (either a motor vehicle tank or portable cylinder). The motor vehicle tanks are designed, fabricated, tested, and marked or stamped in accordance with the regulations of the American Society of Mechanical Engineers (ASME) Code, Section VIII, Rules for the Construction of Unfired Pressure Vessels[5].

The motor vehicle tank will contain a metal nameplate, indicating the manufacturer, serial number, year of manufacture, maximum allowable working pressure (MAWP), tank capacity (in gallons), and year of manufacture, among other things. The appurtenances on a motor vehicle tank include the vapor shutoff valve, fixed maximum liquid level gauge (also known as a spitter valve), float gauge, filler valve (which incorporates an overfilling prevention device or OPD), and pressure relief valve. The fixed maximum

**Figure 2**
Images of the typical interior layout of a food truck (www.United-Food-Truck.com)[4].

liquid level gauge is used to fill the tank by volume. Typical motor vehicle tanks used on trucks have a capacity ranging from 30 gallons to 60 gallons, and they are most often mounted to the underside of the truck frame.

By far, portable cylinders are the most common container used on food trucks. These are designed, fabricated, tested, and marked or stamped in accordance with the United States Department of Transportation (DOT)[6]. Cylinders manufactured prior to 1967 may have been fabricated to the requirements of the Interstate Commerce Commission (ICC) Rules for Construction of Unfired Pressure Vessels[7].

The manufacturer, serial number, year of manufacturer, DOT cylinder specification (e.g., details of cylinder construction), water capacity (in pounds), and tare weight (in pounds) are stamped into the cylinder collar. All cylinders (whether DOT or ICC) are typically required to be requalified within 12 years after the date of manufacture. Three methods are used to requalify cylinders, each of which have different periods until the next requalification time: volumetric expansion (12 years); proof pressure (seven years); and external visual inspection (five years).

The collar will have stamped into it the retester identification number (RIN or entity that performed the requalification), requalification method used (S for proof pressure or E for external visual inspection), and requalification date. Alternatively, a sticker containing the same information may be found affixed to the collar instead of stamping. Unless a cylinder is correctly requalified, DOT rules do not allow it to be filled or transported.

The appurtenances on a cylinder include the vapor shutoff valve, fixed maximum liquid level gauge, and pressure relief valve. Cylinders with capacities of 4 pounds to 40 pounds should also be equipped with an OPD. The tare weight and water capacity weight stamped into the collar are used to fill the cylinder by weight (i.e., using a scale), and the fixed maximum liquid level gauge is used to fill the cylinder by volume. Typical sizes of cylinders used on trucks include 20-pound, 33-pound, 40-pound, and 100-pound. Cylinders can be mounted in open air configurations on the back of a truck or (in the case of food trailers) mounted on the tongue. On some food trucks, the propane cylinders are contained in compartments built into the side or attached to the rear of the vehicle.

The pressure relief valve protects the tank/cylinder from rupturing due to excessive internal pressure. Two possible causes of excessive internal pressure include external heat from a fire, heat-producing appliance, or sunlight (i.e., high vapor pressure) or a liquid-full condition associated with an overfill (i.e., hydrostatic pressure).

Since the vapor pressure inside the container is too high for use by the gas appliances inside the truck, system regulation is required to reduce the pressure to a usable level. For propane appliances, this is approximately 13 inches water column (in. wc) or approximately ½ pound per square inch gauge (PSIG).

Regulation is accomplished through a regulator, either a single integral twin-stage regulator or the combination of two regulators, a first stage and a second stage (i.e., a two-stage system). An integral twin-stage regulator is comprised of two stages in one device. The container pressure is reduced to 13 in. wc. Some integral twin stage regulator models, referred to as "automatic changeover regulators," are connected between two cylinders and designed to automatically switch from the active cylinder (determined by the position of the changeover lever on the regulator) to the reserve cylinder when pressure decreases to a level indicative of the primary cylinder going empty. The changeover regulator is installed near the two cylinders on the outside of the truck.

A true two-stage system uses two separate regulators to decrease gas supply pressure going into the food truck to 13 in. wc. The first-stage regulator connected to the cylinder or tank decreases the pressure to 10 PSIG, and the second-stage regulator (typically found some distance downstream from the cylinder/tank) drops the pressure from 10 PSIG to a usable pressure of 13 in. wc. The two regulators can be connected using a hose, black iron pipe, or copper tubing. Both regulators are installed on the exterior of the truck. If, under the rare situation the second stage regulator is installed inside the food truck, the regulator vent opening should be piped to the outside of the truck, as the vent serves as the discharge port for the regulator's built-in internal relief valve, which protects the appliances from the potential damaging effects of high gas pressure should the regulator malfunction.

From the final point of system pressure regulation (i.e., the outlet of the integral twin-stage regulator or second-stage regulator), black iron, copper, and/or non-metallic tubing or hose is used to provide gas to the interior of the food truck. Typically, the first device encountered inside the truck is the automatic fuel shutoff valve, which is part of the restaurant hood fire suppression system. The automatic fuel shutoff valve is designed to close automatically in the case of a fire on the cooking line or by manual operation via a pull station. When activated, the shutoff valve closes, thereby preventing propane fuel flowing to the cooking line and removing it as a potential fuel source for the fire.

A gas manifold with individual appliance shutoff valves is usually located downstream of the automatic fuel shutoff valve. The shutoff valve and manifold are connected using lines constructed of black iron pipe, copper tubing, or corrugated stainless steel tubing (CSST). The lines provide gas to the appliances. Valves connected to the manifold, which is normally constructed out of black iron, are used to isolate (i.e., stop the flow of gas to) individual appliances. The appliances can be connected to the manifold using steel flexible gas connectors or copper tubing.

Common appliances found on food truck cooking lines include commercial fryers, cook-top ranges, griddles, charbroilers, ovens, warming tables, and/or salamanders. These individual appliances may have their own gas valves, which provide additional gas pressure regulation and temperature control. The reader is encouraged to obtain the manufacturer's information for the specific appliances found in the food truck of interest.

## Propane Properties

Propane is a viable fuel source because it burns readily and can be liquified at relatively low pressures, making for easy bulk transport. The specific gravity of propane liquid at 60°F is 0.504 (about 50% lighter than water), which equates to a density of 4.2 pounds/gallon. The specific gravity of propane vapor at 60°F is 1.50 (about 50% heavier than air), which equates to a density of 0.115 pounds/ft$^3$. Thus, propane gas is often described as being heavier than air, and it tends to sink[8].

From the two densities, the expansion of one gallon of liquid to vapor at atmospheric pressure can be determined. One gallon of liquid propane will generate approximately 36.4 ft$^3$ of vapor/gas at sea level atmospheric pressure or 14.7 pounds per square inch absolute (PSIA). The flammable range for propane is 2.15% to 9.60% by volume in air, and the heating value is 2500 Btu/ft$^3$ of gas. As a comparison, natural gas has a flammable range of 5% to 15% and a heating value of 1,000 Btu/ft$^3$.

The propane stored in a container is present in two distinct phases in equilibrium with one another — a liquid phase and a vapor phase in the headspace (e.g., ullage). **Figure 3** shows the saturated vapor pressure versus liquid temperature relationship for pure propane; the pressure of the vapor in the headspace is determined by the liquid temperature, and the liquid temperature is typically driven by the ambient temperature and radiant sun exposure[9]. As the liquid temperature increases, there is an accompanying increase in pressure. Conversely, as the liquid temperature decreases, there is an accompanying decrease in pressure. As long as there is a vapor space above the liquid, the vapor pressure-temperature relationship depicted in **Figure 3** will be followed. Under normal operating conditions, the vapor pressure inside a container will not reach the set point of a tank or cylinder relief valve (312 PSIG for ASME tanks and 375 PSIG for DOT cylinders, respectively). However, if heat from an outside source (e.g., operating appliance, generator, external fire, etc.) impinges on a tank or cylinder, the liquid temperature and consequently pressure can potentially increase sufficiently to cause the relief valve to function.

Liquid propane in a container expands with an increase in temperature, thereby decreasing the headspace volume. Cylinders and tanks are typically only filled to 80% to prevent them from becoming liquid-full due to anticipated atmospheric temperature changes — the concern being, if a container was to become liquid-full, the pressure generated by the incompressible liquid propane is significant enough to cause rupture if not relieved. Additionally, if pressures reach the set point of the relief valve (and the relief valve opens), then the release of vapor or liquid propane could pose a fire/explosion risk in the presence of an ignition source.

## Codes and Standards

Prior to 2017, there were references published in

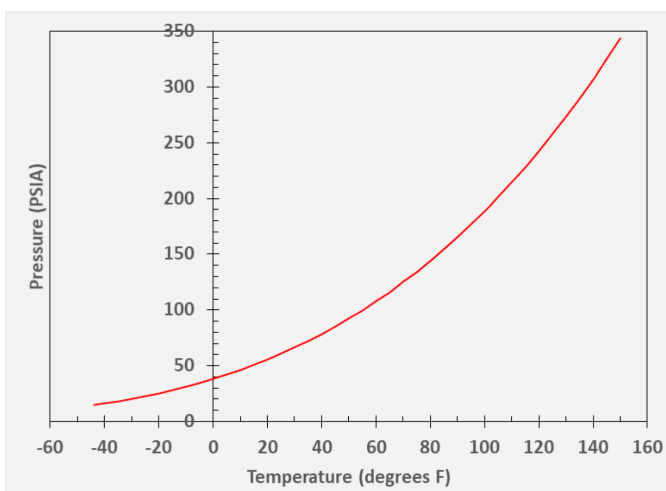


**Figure 3**
Saturated vapor pressure versus temperature relationship for pure propane.

multiple codes for the design, construction, and operation of food trucks, including the following examples:

- National Fire Protection Association (NFPA) 1, *Fire Code*, for licensing, emergency equipment access, public seating requirements, and portable power supply placement[10].
- NFPA 58, *Liquefied Petroleum Gas Code*, for cylinder and tank requirements, documented leak test requirements on gas connections, closure of gas supply valves when not in use, accessible gas supply valves, upright and secured propane containers, and appropriately installed flexible gas connectors[8].
- NFPA 70, *National Electrical Code*, for the appropriate installation of electrical systems[11].
- NFPA 96, *Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations*, for refueling operations, location of portable power sources, gas detection system installation, proper appliance operation and ventilation, and approved fire extinguishing systems[12].

The dearth of specific and centralized code requirements for mobile kitchen construction and operation has caused many jurisdictions to create their own regulations. Jurisdictions are adopting excerpts from NFPA 58, NFPA 96, and NFPA 1192, *Standard on Recreational Vehicles*[13]. NFPA 1192 regulates recreational vehicles that contain cooking appliances. However, the scope of this standard is not applicable to mobile kitchens that contain commercial appliances, ventilation systems, and fire prevention systems. Some jurisdictions (like the state of Indiana) have chosen to not inspect a food truck because it is a vehicle, while others (like the city of Chicago) have adopted specific requirements, such as always having an employee present on the vehicle who is trained by the fire department in handling and exchanging propane tanks.

In June 2017, the NFPA 96 Technical Committee added a normative annex section on mobile and temporary cooking operations. This annex section consolidated extracts from the requirements of NFPA 1, NFPA 58, and NFPA 70 as well as applicable chapters from NFPA 96 in an effort to provide the user with common requirements. While this annex section is written in mandatory language, it is not enforceable, unless adopted by the local jurisdiction[14]. In 2018, NFPA 1 added Section 50.7, a new enforceable section that is applicable to Mobile and Temporary Cooking Operations[15]. These two additions to the current NFPA codes added clarity to the requirements for jurisdictional authorities and food truck builders — whether commercial or homemade.

In 2020, NFPA compiled a Food Truck Safety Fact Sheet that references Code sections for each applicable requirement[16]. The compilation of this resource added clarity and guidance for the Authority Having Jurisdictions (AHJs), commercial truck builders, and the homemade food truck builders.

In 2021, a proposal was submitted to the NFPA 58 Technical Committee to compile Mobile and Temporary Cooking Operations requirements within NFPA 58. At the time of publication of this paper, the proposal is currently under review.

Several jurisdictions have adopted the NFPA family of codes, while others have adopted the International family of codes. The current consolidation of excerpts from the NFPA codes found in NFPA 1 and NFPA 96 may not be readily available or enforceable in jurisdictions that have adopted the International code family. One specific code that is common by reference to the International and NFPA code families is NFPA 58, the *Liquefied Petroleum Gas Code.* A new proposed chapter has been submitted to the NFPA 58 Technical Committee for review. This proposed new chapter has consolidated the code references similar to NFPA 1 and NFPA 96. This new proposal, if adopted, can potentially become an important avenue of information that adds consistency for jurisdictions and truck builders toward the safety in the food truck industry. The need to reference different code books to fully understand the design, construction, and operational requirements pertaining to the various components of a food truck will remain a necessity for truck builders and jurisdictional authorities.

## Accident Investigation Methodology

The investigation of a food truck incident is similar to that of a structure fire, flash fire, or explosion investigation where a propane system may be involved. The ultimate goal of the investigation is to determine where the incident originated, what caused the incident, and, where applicable, assign responsibility. The general process entails: A) pre-investigation activities, such as reviewing public entity reports and witness statements; B) examining and documenting the truck and surrounding location, explosion/fire damage, and gas system; C) examining and documenting the gas system components and layout; D) testing the gas system for leaks and obtaining propane samples; E) analyzing the fill history and weather data; and F) researching the applicable codes and regulations. These steps are discussed in more detail in the sections that follow. It should be noted, however, that the sections below are not intended to be a definitive guide on conducting these investigations. Instead, they should be viewed as a starting point for an investigator to understand the basic concepts and methodology involved.

*A. Pre-Investigation*

Although not exhaustive, **Figure 4** is a detailed list of items an investigator should consider collecting, identifying, and gathering prior to and/or during the initial documentation phase of the investigation. Many of these items are similar to those collected during a typical fire or explosion investigation, but the list also includes data specific to food truck/propane incidents.

*B. Overall Documentation: Truck and Surrounding Location*

As with any fire or explosion scene, the investigator should document the overall condition of the scene in a systematic fashion, typically starting from areas of least damage and progressing to the areas of greatest damage. In incidents involving food trucks, that typically entails a thorough examination of the area immediately surrounding the food truck, the exterior of the truck, the interior cooking spaces, and the driver's compartment.

Investigators should conduct a thorough canvas of the immediate area to identify and collect any surveillance

| Item | Details |
|---|---|
| Witness Statements, Interviews, and Media | Social media — GoFundMe, Twitter, Facebook, Instagram, Snapchat, etc. |
| | Electronic media (videos and photography) per local news media and/or witnesses |
| | Surveillance videos |
| Public Entity Reports and Data | National Fire Information Reporting System (NFIRS) incident reports |
| | State and local public authority investigation reports — police department, fire department, sheriff's department, Department of Transportation, Bureau of Alcohol, Tobacco, and Firearms, Occupational Safety and Health Administration, LP gas inspector |
| | Medical records — EMT/emergency room notes and reports |
| | Interviews/statements provided by first responders |
| | Post-incident testing conducted by the gas utility and/or public agencies (including leak testing of the subject gas system) |
| Subject Food Truck Data/History | Owner's name and contact information |
| | Purchased new vs. converted/remodeled |
| | Chassis manufacturer — make, model, year, VIN |
| | Kitchen design and build company |
| | Design drawings |
| | Service, maintenance, and inspection records — truck, gas system, and restaurant hood system |
| | Pre- and post-incident photographs (food truck, design/build company web sites, social media, etc.) |
| | Recent modifications/changes and operating history |
| Historical Weather Records | The day of the incident and weeks prior to the incident |
| Propane Fill Records | Most recent prior to the incident and as many as possible preceding the most recent |

**Figure 4**
Pre-investigation guide checklist.

media. This includes surveillance footage captured by adjacent food trucks, businesses, and residential security/doorbell cameras. For systems that are not cloud-based (e.g., systems using a digital video recorder or DVR, the footage should be preserved immediately post-incident to ensure it is not overwritten or lost.

A detailed examination of the subject food truck is critical. Investigators should specifically document and photograph the overall condition of both the driver's and kitchen compartments. Specific attention should be given to the fuel-gas system, appliances, hood and restaurant hood fire suppression system, generator, engine compartment, electrical system, and any other safety systems.

Further, the overall scene documentation of both the food truck and surrounding area should include any relevant explosion, overpressure, and thermal damage. Specifically, explosion damage to the truck, propane tank/cylinders, gas piping and appliances, nearby structures, and vehicles (as well as thermal damage to the inside and outside of the truck, occupants, customers, pedestrians, and passengers in vehicles) should all be documented and photographed.

A detailed survey/laser mapping of any debris fields should be considered to memorialize the position of evidence relative to original locations. Investigators should prepare both comprehensive scene diagrams and detailed diagrams of the subject food truck. **Figure 5** is a list of data investigators should attempt to include on the respective diagrams.

*C. Gas System Components and Layout*

In the event of an explosion or suspected fuel-gas related incident, a detailed examination and thorough testing of the fuel gas system are necessary. In particular, the investigator should document the information and/or components in the system, as listed in **Figure 6**.

*D. Leak Testing and Propane Samples*

When possible, a leak test of the fuel-gas system using propane, nitrogen, or air should be performed in situ to verify system integrity and quantify any potential leaks that may exist. System integrity testing of the fuel-gas system is typically divided into two parts. The first is the gas distribution system, which includes supply regulators, piping/tubing, and flexible connectors that connect to the appliances. The second is testing/examination of the respective appliances, including their individual regulators and associated gas controls/safety valves. Supply

| Item | Details |
|---|---|
| Overall Scene Diagram | Location of subject truck relative to surrounding structures and/or other permanent landmarks |
| | Overlay diagram with satellite/drone imagery |
| | Clearances to adjacent buildings, structures, vehicles, food trucks, public seating areas, and any combustible materials |
| | Location/position of fire/explosion debris and other critical evidence relative to the incident |
| | Surveillance video camera locations |
| Food Truck Diagram | Location/routing of fuel-gas system (propane tank/cylinders, gas piping, hoses, regulators, manifolds, shutoff valves, flexible connectors, etc.) |
| | Appliances and cooking line (manufacturer data tags, date codes, position of control knobs/settings, location, etc.) |
| | Position of valves, switches, and other pertinent controls |
| | Fire suppression and kitchen hood system (automatic fuel shutoff valve position and cable, nozzle location and aim, location and condition of fusible links and cables, overall cleanliness of system, expellant cartridge condition, cylinder charge level, evidence of system deployment, etc.) |
| | Fire extinguishers (type, service/inspection tag, fill level, pin position) |
| | Electrical system (switches, receptacles, breakers, fuses, controls) |
| | Ventilation/HVAC systems, size and location of windows, doors, and any openings |

**Figure 5**
Truck and surrounding location checklist.

| Item | Details |
|---|---|
| Cylinder(s) | Collar information (date, water capacity, tare weight), requalification stamp, visual condition, ICC vs. DOT, cylinder valve (make, model, date), position of cylinder valve, weight |
| Tank | Nameplate and appurtenances information (auto-stop fill valve, fixed maximum liquid level gauge, float gauge, pressure relief valve, and vapor valve), position of vapor valve, volume of fuel in tank |
| Tank/cylinder installation | Shielded by enclosure or direct sunlight impingement, isolated from the interior, nearby heat sources (e.g., generator, appliance, truck engine exhaust, etc.) |
| Regulator or regulators | Type (integral twin stage, integral twin stage with automatic change-over, two stage system), date codes, model numbers, serial numbers, vent condition and point of discharge, installation orientation and location |
| Gas piping/hoses from tank/cylinders to automatic fuel shutoff valve and manifold | Type, size, lengths, etc. |
| Automatic fuel shutoff valve | Confirm existence, document state (i.e., open or closed), location in gas system |
| Manifold and valves | Valve positions and associated appliances |
| Gas piping to appliances | Type, size, lengths, etc. |
| Appliances | Type, nameplate data (usage rates Btu/h, model and serial numbers), location, knob and valve positions, power switch (on or off), plugged in or not, settings |
| Accessory cylinders | Location (inside or outside food truck), type (one pound, 20-pound, etc.), condition (separate or connected to a portable heater), position of cylinder valve, heater settings, hose connected between heater and cylinder, weight of cylinders |

**Figure 6**
Gas system components and layout checklist.

regulators should be tested and checked for proper operation, including measuring both lockup (i.e., pressure output under "no flow" conditions) and flow pressures under various loads. Investigators should document any condition that would cause the regulator(s) to malfunction.

If leaks are discovered during the system integrity testing, the location of the leaks should be identified and the size of each quantified using flowmeters and pressure gauges/manometers. This quantitative data can be of particular importance for conducting future consumption analysis and energy calculations — and for overall causation theory determination.

*E. Fill History and Weather Data*

Determine when and where the food truck propane cylinders/tank were filled, and document the findings as listed in **Figure 7**.

| Item | Details |
|---|---|
| Dispensing station | Pump and scales |
| Fill method | Weight, volume, weight/volume, company procedures, training |
| Dispenser operation | Confirm the accuracy of the dispenser pump and scale |
| Fill ticket | Obtain and review the fill ticket for the subject truck containers and compare the size of the containers to the amount of propane dispensed |
| Ambient temperature | At the time of the fill, between fill and accident, at time of accident |

**Figure 7**
Fill history and weather data checklist.

*F. Regulations*

A review of the codes and standards applicable to the incident is an important step in the overall investigation. This review can identify construction or operational practices that may have contributed to the incident.

## Case Study

An explosion and subsequent fireball erupted from a food truck while it was parked and operating on a street in an eastern U.S. city. At the time of the incident, the owner was at the rear of the food truck near the door between the two propane cylinders, a second individual was inside the food truck seasoning chicken, and a third was in the front of the food truck next to a fourth individual. A fifth individual was sitting in a chair on the sidewalk outside the food truck, and two others were driving by in a vehicle. The owner and the third individual died, 13 others (including the two individuals in the front of the food truck, the individual in the chair, and the two individuals in the vehicle) were injured, and the food truck and nearby items were damaged.

A joint investigation into the cause of the explosion (that spanned approximately four years) was conducted by several public entities and other potentially interested parties. The truck and other artifacts had been collected and moved from their post-incident locations by the public entities prior to these writers being engaged to investigate the accident. As such, the public entity reports and photographs had to be relied upon for some of the analysis. Further, the Federal DOT significantly limited access to the cylinders, rubber hoses, changeover regulator, and copper tubing from the food truck gas system. The authors were not given the opportunity to examine those artifacts and had to rely on the photographs taken by others. Presented below is a summary of the investigation and ultimate findings.

*A. Pre-Investigation*

The owner purchased a used food truck (first food truck) on Craigslist. The owner acquired the truck about 1.5 years prior to operating it for approximately six months. The first food truck had only one 100-pound propane cylinder that fueled the gas appliances.

Two years after purchasing the first food truck, the owner purchased an empty, used truck on Craigslist (the food truck subsequently involved in the explosion). The owner of the truck then contracted a separate entity to design and build a kitchen inside the truck. The owner started operating the subject food truck seven days a week at the location where the incident occurred — approximately two months prior to the explosion (see **Figure 8**).


**Figure 8**
Location where the food truck was being operated at the time of the incident
(see red box; street and business names redacted). North is at the top of the image.

The subject food truck came with two propane cylinders. A nearby dispenser would not fill them for an undetermined reason. Consequently, the truck was initially operated using only the single cylinder until a customer gave the owner a second cylinder about a week and a half later. Both were filled at the nearby dispenser the day the owner was given the second cylinder. From that point forward, both cylinders were used on the food truck. The left cylinder was the one brought over from the first food truck, and the right cylinder was the one given to the owner by the customer. The cylinders were routinely filled at the nearby dispenser and sometimes at a second dispensing location.

A customer complained to the owner about an odor of propane around the end of the first month of operation, and the valve on the cylinder from the first food truck was reportedly replaced by the entity that designed/built the kitchen. Odor complaints ceased after the valve was replaced.

The last documented fill of the two propane cylinders occurred in the morning two days prior to the incident at the nearby dispenser. No fill ticket or receipt was available detailing the total gallons added to the two cylinders. After the cylinders were filled, the owner installed them on the food truck and operated the truck. There was conflicting testimony as to whether the food truck was operated the day prior to the accident. However, when in operation over the three-day period leading up to the incident, only the right cylinder was in use.

In the early evening on the day of the incident, the left cylinder ruptured, and the propane vapor was subsequently ignited, resulting in a large fireball. A security camera at a nearby business captured the explosion. **Figure 9** shows

**Figure 9**
Images of the explosion taken from the video captured by a nearby security camera.

**Figure 10**
Images of the rear of the food truck post-incident. The left cabinet and cylinder were missing.

**Figure 11**
Pre-incident images of the rear of the food truck and the left and right propane cylinder cabinets.

images taken from the video (approximately 25 frames per second) at different times. The first sign of the white cloud associated with propane is visible in Frame 1. The white cloud increases in size in Frames 2 through 7. Ignition is first observed in Frame 8, and the fireball expands in Frames 9 through 11. Smoke without fire is seen in Frame 12.

*B. Overall Documentation*

**Figure 10** shows the back of the food truck post-incident; the left cabinet and cylinder were both missing, but the right cylinder was still intact (and in place) inside the right cabinet. The right cylinder valve was closed after the incident by the fire department. As a comparison, pre-incident images of the food truck are illustrated in **Figure 11**.

Various pieces of the back of the food truck were identified in the debris field, which was dispersed rearward away from the back of the truck. **Figure 12** shows the

| Artifact Description | Approx. Distance (ft) |
|---|---|
| Diamond plate bumper cover | 0 |
| Flexible tubing, ~24 inches in length | 32 |
| Left cylinder cabinet remnants | 42 |
| Lid of left cylinder cabinet | 56 |
| Section of copper tubing and tee fitting | 66 |
| Left cylinder cabinet remnants and changeover regulator | 84 |
| Left cylinder | 105 |
| Door of left cylinder cabinet | 120 |
| Padlock | 122 |

**Figure 12**
As-found location of artifacts in the debris field as measured from the rear of the food truck.


**Figure 13**
The front (left), driver (middle), and passenger (right) sides of the food truck.

distance each artifact was found as measured from the rear of the food truck. The diamond plate bumper cover was found underneath the rear bumper. The cover over the portable tent structure to the right or south of the food truck was consumed by the fireball.

The post-incident appearance of the food truck is illustrated in **Figure 13**. The windshield was missing from its frame. The truck was equipped with a generator located inside a cabinet near the back on the driver's side. Metal on the front and rear sides of the generator cabinet were pushed to the front. The exterior diamond plate on the rear of the truck, which formed the back wall of the left cabinet, had a dent or impact mark about 2 feet 10 inches above the bumper. Reconstruction of the left cabinet, which was framed using square metal tubing covered with diamond plate, is shown in **Figure 14**. The exterior diamond plate on the rear wall of the truck enclosed the back of the cylinder cabinet. The cabinet exhibited signs of forces from the inside acting in an outward direction.

*C. Gas System Components and Layout*

The subject food truck was equipped with six propane-fired appliances fueled by the two 100-pound propane cylinders. The left and right cylinders were originally located inside of bottomless diamond plate metal cabinets — one on either side of the rear door above the bumper cover/step, as illustrated in **Figure 11**.

The following observations were made with regard to the left cylinder (see **Figure 15**):

1. The cylinder had ruptured;

2. There was no evidence of cylinder failure related to corrosion or fatigue;

3. Based on the model number, the cylinder valve was not manufactured with a relief valve and was meant to be used with a separate relief valve;

4. There was no separate relief valve;

5. A plug was threaded into the gauge tap opposite the POL (Prest-O-Lite) connection;

6. The cylinder valve did not have a fixed maximum liquid level gauge; and

7. The cylinder valve was in the closed position.

The following observations were made relative to the right cylinder (see right image in **Figure 10**):

1. The cylinder was intact;

2. The cylinder valve had a relief valve;

3. The cylinder valve did not have a fixed maximum liquid level gauge; and

4. The cylinder valve was in the closed position. It was learned through discovery that the fire department closed the valve after the incident.

The information displayed on each cylinder and cylinder valve is delineated in **Figure 16**. The left and right cylinders were manufactured in November 1948 and September 1985, respectively, and were qualified for service for 12 years past their dates of manufacture. The left cylinder required requalification in November 1960. However, the cylinder was never requalified. The right cylinder was requalified in February 1995 (i.e., 2 95 in 2 95s) and was good for seven years or until February 2004 (the "s" in the requalification stamping "2 95s" signifies it was requalified using the hydrostatic pressure proof

**Figure 14**
Reconstruction of the left cabinet.

test). The cylinder was never requalified after February of 1995.

The "W.C. 239" indicates each cylinder could hold a total of 239 pounds of water or 28.7 gallons at a temperature of 60°F when 100% full. Therefore, if properly filled with propane to 80%, each cylinder would hold 22.9 gallons.

Rubber hoses had been used to connect the cylinder service valves and the two inlets to a low-pressure two-stage automatic changeover regulator. The regulator was housed in the left cabinet above the cylinder, and the ⅜-inch hose from the right cylinder was routed to the regulator through the bumper cover via notches below the cabinets. Three-eighths-inch copper tubing was connected between the outlet of the regulator and a ½-inch steel tee. The tee was attached to a ½-inch 90-degree elbow near the bottom of the left cabinet via a ½-inch short nipple. The 90-degree elbow was connected to a ½-inch steel line that penetrated the rear wall and supplied gas to five appliances on the left side of the food truck. The other end of the tee supplied gas to the only appliance on the right side of the truck via ¼-inch copper tubing that penetrated the rear wall of the food truck inside the right cylinder cabinet. Like the rubber hoses, the ¼-inch copper line was routed to the right-side appliance through the bumper cover.

**Figure 15**
Left cylinder. The cylinder was ruptured, and the cylinder valve had no relief valve or fixed maximum liquid level gauge.

| Cylinder | Cylinder Information | Valve Information |
|---|---|---|
| Left | PST, D-3090, ICC-4BA240-717, W.C. 239#, 11-48 | 3329, 5112 |
| Right | J536298, DOT 4BW240, W.C. 239, T.W. 74, D.T. 9.0, 9-85, 2 95s, B154 | 3250A |

**Figure 16**
Cylinder and cylinder valve information.

As shown in **Figure 17** prior to the incident, the five gas-fired appliances on the left side of the food truck (from rear-to-front) consisted of a deep fat fryer (1), flat-top griddle (2), charbroiler (3), vertical broiler (4), and range (5). A refrigerator and freezer were adjacent to and forward of the range. An exhaust hood and fan were installed above the five appliances. The exhaust hood did not have a restaurant hood fire suppression system or automatic fuel shutoff valve. A steam table (6) was located on the right side at the rear.

Propane gas was supplied to the five appliances on the left side via a ½-inch steel line. The steel line was located against the left wall below the appliances, and branched off to feed two manifolds, both of which were below the metal counter supporting the flat top griddle, charbroiler, and vertical broiler, as depicted in the top image of **Figure 18**. The first manifold was just forward of the deep fat fryer and below the flat-top griddle, as seen in the bottom left image of **Figure 18**. The manifold, which consisted of two appliance shutoff valves and three ½-inch flexible gas connectors, provided gas to the deep fat fryer (1, driver's side line), charbroiler (3, middle line), and flat top griddle (2, passenger's side line). The deep fat fryer did not have an appliance shutoff valve. The second manifold was just to the rear of the range, as shown in the bottom right image of **Figure 18**. The manifold, which consisted of two appliance shutoff valves and two ½-inch flexible connectors, provided gas to the vertical broiler (4, horizontal line) and range (5, vertical line). Propane gas was supplied to the steam table safety valve through ¼-inch copper tubing. The steam table did not have an appliance shutoff valve.

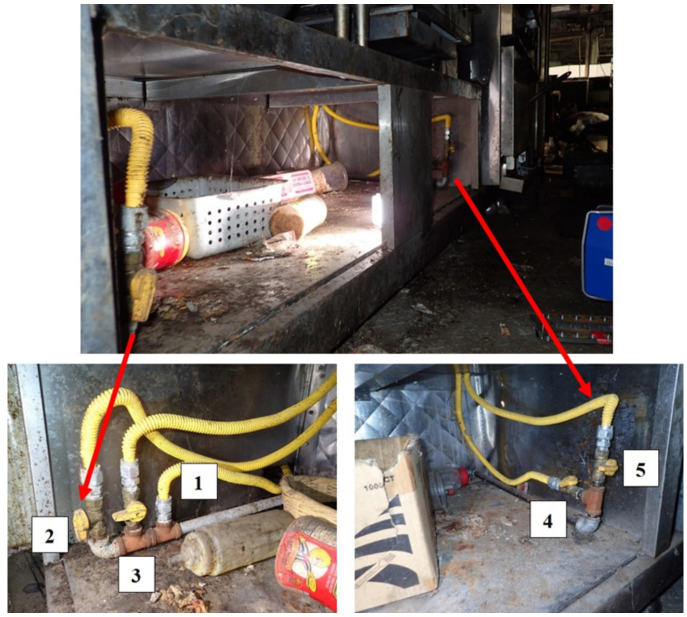


**Figure 18**
The images show the as-found positions of the manifold valves after the incident.

All the gas system components (rubber hoses, regulator, and copper tubing) between the cylinders and where the piping connected to or penetrated into the rear of the food truck were accounted for during the investigation. No relief valve external to the left cylinder was noted. Several fractures and separations were observed in the rubber hoses, regulator, and copper tubing.

The four manifold valves supplying gas to the appliances on the left side were found in the following positions (see **Figure 18**): flat top griddle (2) open, charbroiler (3) closed, vertical broiler (4) closed, and range (5) closed.


**Figure 17**
Six gas appliances inside the food truck.

The five appliances on the left side and the one appliance on the right side of the food truck after the explosion are shown in **Figure 19**. The appliance information and as-found valve positions for each appliance are detailed in **Figure 20** (the valves for each appliance were assigned a number). For example, the left valve on the griddle was labeled as “2L,” the left rear valve on the cooktop of the range was labeled “5LR,” and the oven control was labeled “5O.”

*D. Leak Testing*

The food truck gas system was leak tested using a setup consisting of a nitrogen cylinder, cylinder regulator with a pressure gauge ($P_1$), flow meters (F), a regulator, and manometers upstream ($P_2$) and downstream ($P_3$) of the bank of flow meters. The leak test setup was connected to the elbow to test the gas piping and appliances on the left side, and then to the ¼-inch copper tubing to test the steam table on the right side. The results of the leak tests are summarized in **Figure 21**.

Some flow was measured through the standing pilots of a few of the appliances, but no leaks were detected in the gas system.

*E. Fill History and Weather Data*

The cylinders were filled 10 separate times at the two dispensers. **Figure 22** summarizes the time of fill, gallons added, and final percent full for each fill. Both cylinders were filled during the two 50-gallon fills and one 49.1-gallon fill. As can be seen in the third column of the table in **Figure 22**, the cylinders were historically overfilled (i.e., filled beyond 80%). The final percent full calculation assumed the cylinders were empty prior to filling (the start volumes during each fill were unknown), the 49.1 gallons and 50 gallons were divided equally into the two cylinders, and the cylinders had capacities of 28.7 gallons when completely 100% full.


**Figure 19**
Post-explosion images of the six gas appliances inside the food truck, which included a deep fat fryer (1), griddle (2), charbroiler, (3), vertical broiler (4), range (5), and steam table (6).

| Appliance | Information | Valve Positions |
|---|---|---|
| Deep fat fryer (1) | Gross input 90,000 BTU/hr, gas type prop | Control valve knob ON, safety OFF, thermostat set at 400°F |
| Flat top griddle (2) | Input 20,000 BTU/hr, 5.9kW | Left valve (2L) ON and right valve (2R) OFF, standing pilots |
| Charbroiler (3) | Input 30,000 BTU/hr, 8.8kW | Left valve (3L) and right valve (3R) OFF, standing pilots |
| Vertical broiler (4) | Gas LP, 20,000 BTU/hr | Rotisserie switch OFF, thermostat valve PARTIALLY OPEN |
| Range (5) | Oven 35,000 BTU/hr, oven top 32,000 BTU/hr | Left front (5LF), left rear (5LR), right front (5RF), right rear (5RR), and oven (5O) valves OFF, oven safety OFF, standing pilots |
| Steam table (6) | Not available | Thermostat valve handle vertical or OFF, safety OFF |

**Figure 20**
Appliance information and as-found valve positions for each appliance.

Video from a security camera at the dispenser where the cylinders were filled two days prior to the incident showed the scale was not used to fill the cylinders (i.e., the cylinders were not filled by weight). The ambient temperature at the time of filling was about 77°F, and the ambient temperature when the incident occurred was about 90°F.

| $P_1$ (PSIG) | $P_2$ ("WC) | $P_3$ ("WC) | F (CFH) | Comment |
|---|---|---|---|---|
| ~10 | 14.3 | 14.3 | 0 | Test setup connected to the elbow, 14.3 in. WC on water manometer as a check, pressure holding with valve downstream of second stage regulator and valve at outlet of test rig closed |
| 60 | 14.3 | 14.3 | 0 | Increased $P_1$ into service regulator |
| 55 | 14.0 | 13.5 | 10 | 5-50 CFH FM,[a] as-found condition |
| 55 | 12.0 | 11.2 | 9.5 | Adjusted second stage regulator so that $P_3$ ~ 11" WC per the protocol |
| 55 | 12.0 | 11.3 | 9.5 | Closed valve 3L (charbroiler) |
| 60 | 12.5 | 12.5 | NM[b] | Closed valve 2L (flat top griddle) |
| 60 | 12.5 | 12.0 | 0.2 | 0.1-1.0 CFH FM |
| 60 | 12.5 | 12.5 | NM | Closed manual valve 2 |
| 60 | 12.5 | 12.5 | NM | 0.05-0.5 CFH FM |
| 60 | 12.5 | 12.5 | NM | Opened manual valve 3, 5-50 CFH FM |
| 60 | 12.5 | 12.5 | NM | 0.05-0.5 CFH FM |
| 55 | 11.8 | 11.4 | 16.5 | Rotated 3R CCW 90° so knob vertical, 5-50 CFH FM |
| 60 | 12.5 | 12.5 | NM | Closed valve 3R (charbroiler) and manual valve 3, opened manual valve 4 |
| 60 | 12.5 | 12.5 | NM | 0.05-0.5 CFH FM |
| 55 | 12.4 | 11.5 | >0.5 | Closed manual valve 4, opened manual valve 5 |
| 60 | 12.4 | 11.5 | 1.5 | 0.05-5.0 CFH FM |
| 60 | 12.5 | 12.5 | NM | Test setup 2 connected to the 1/4-inch tubing to warming table on the right side of the truck, as-found condition of steam table (6), 0.5-5.0 CFH FM |
| 60 | 12.5 | 12.5 | NM | 0.05-0.5 CFH FM |
| | | | | a = flow meter, b = not measurable |

**Figure 21**
Results of the leak tests.

| Days Prior to Incident | Gallons | Percent Full |
|---|---|---|
| 108 | 27.7 | 97 |
| 83 | 25 | 87 |
| 78 | 26 | 91 |
| 74 | 25 | 87 |
| 66 | 25 | 87 |
| 47 | 50 | 87 |
| 25 | 50 | 87 |
| 17 | 25 | 87 |
| 12 | 49.1 | 86 |
| 2 | No record | - |

**Figure 22**
Summary of the time of fill, total gallons added to the cylinder(s), and final percent full for each fill.

*F. Regulations*

Based on the requirements of NFPA 58: 1) the left and right 100-pound cylinders were out of requalification by 66 years and 19 years, respectively; 2) the left cylinder should have been equipped with a pressure relief valve, either as part of the cylinder valve or as a separate add-on appurtenance; and 3) the left and right cylinders should have had fixed maximum liquid level gauges so they could be accurately filled to 80% by volume[8].

*G. Analysis and Findings*

The main goal of an explosion origin and cause investigation is to scientifically determine the origin, point of origin, first fuel ignited, oxidizer, ignition source, and cause of the incident. Related to the origin, the security video and still images taken from the video (**Figure 9**) clearly show the explosion and subsequent fireball originating proximate to the rear of the food truck. More specifically, they show the first appearance of a white cloud consistent with the release of liquid propane near the left cylinder cabinet, the white cloud significantly increasing in size, the appearance of projectiles from the left side of the truck, ignition of the propane vapors, expansion of the fireball, and complete consumption of the propane vapors. In addition to the video and images, the following observations support the point of origin of the explosion originating at the left cylinder:

- Physical damage to and displacement of the left cabinet, rear door, and bumper cover.
- Damage to the wall behind the left cylinder cabinet.
- Appearance (i.e., ruptured/split open) and displacement of the left cylinder.
- Damage to and displacement of the propane regulator, hoses, tubing, and fittings.
- Damage to the generator cabinet walls.
- Relative lack of damage to the right cylinder cabinet and right cylinder.

The explosion with the left cylinder can be classified as mechanical, which is defined as, “A mechanical explosion is the rupture of a closed container, cylinder, tank, boiler, or similar storage vessel resulting in the release of pressurized gas or vapor. The pressure within the confining container, structure, or vessel is not due to a chemical reaction or change in chemical composition of the substances in the container[17].”

Once the mechanical explosion occurred, the contents of the left propane cylinder were released. The white cloud observed in the video and still images after rupture of the cylinder and prior to ignition is likely a combination of moisture (e.g., water vapor or humidity) in the air condensing as the liquid propane near the moisture vaporizes and an aerosol of liquid propane droplets. The propane vapors were the first fuel ignited after the left cylinder ruptured. As in most fuel-air combustion events, the oxidizer was the oxygen in the air (20.9% v/v) that mixed with the flammable propane vapors. The exact ignition source for the combustion event was not determined, but there were many competent ignition sources on the food truck including, but not limited to, open flames from standing pilots and burners, hot surfaces, and contacts/switches in electrical equipment.

Ultimately, the incident was caused by rupturing of the left cylinder. The cylinder ruptured because the internal pressure exceeded the strength of the cylindrical vessel. The cause of the excessive internal pressure merits further discussion.

As previously noted, cylinders are required to have a fixed maximum liquid level gauge (bleeder valve or spitter valve) if they are to be filled by volume, and they are required to have a relief valve. The bleeder valve is used to correctly fill a cylinder to 80% when filling by volume. It provides the filler with a visual cue (i.e., the release of white liquid) when the liquid level inside the cylinder reaches 80%. The 20% vapor space is necessary to allow for expansion of the liquid as the ambient temperature and ultimately liquid temperature increase. This prevents a cylinder from reaching a liquid-full condition from expected ambient temperature changes.

To demonstrate the magnitude of the temperature change required to cause a properly filled cylinder to become liquid-full, consider a cylinder properly filled with propane initially at 75°F would need to be heated to about 175°F (a differential of approximately 100°F) to make it liquid-full, which is not a realistic situation under normal ambient conditions. As the initial fill level of a cylinder increases, the temperature change needed to reach the liquid-full state decreases. For the same cylinder initially filled to 95% with 75°F propane, a temperature change of only about 27°F (final liquid temperature of about 102°F) is required to make it liquid full[8].

The left cylinder had a water capacity (W.C.) equal to 239 pounds, which means it had a total volume of 28.7 gallons and could be correctly filled with 100 pounds or 22.9 gallons (80% of 28.7 gallons) of propane at 60°F. The left cylinder did not have a fixed maximum liquid level gauge as part of its cylinder valve, nor was one provided separately as an add-on appurtenance. Under this condition, it would be difficult to properly fill it to only 80% without weighing the cylinder to determine the amount of propane to add — that is to say, determining the amount of propane to put in the left cylinder without weighing it would amount to guessing.

The vapor pressure inside a cylinder under typical ambient temperature conditions is not high enough to cause failure. As an example, the vapor pressure of commercial grade propane inside a cylinder with liquid at 105°F and 130°F is 218 PSIG and 300 PSIG, respectively[8]. Based on historical weather data, the ambient temperature at the time of the incident was about 90°F. If the liquid propane temperature was between 105°F and 130°F because of solar gain and/or external heating sources (e.g., food truck appliances and/or generator), the pressure inside the cylinder should only have reached between 218 PSIG and 300 PSIG.

The left cylinder had a service pressure of 240 PSIG, as indicated by the "240" in ICC-4BA240-717 stamping. The cylinder was likely manufactured with a safety factor of about four, which means it would not fail until about 960 PSIG or significantly above the expected vapor pressure inside the cylinder. On the other hand, as previously discussed, the pressures that can be generated by an incompressible fluid like propane in a liquid-full condition are significant[18].

**Figure 23**, which was created using NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP), illustrates the pressure versus temperature relationship for pure propane under two different scenarios[9]. The solid red line in **Figure 23** depicts the scenario where a cylinder is filled to 80% at 75°F, allowing 20% vapor headspace. The liquid propane is allowed to expand into the headspace of the cylinder and maintain the saturated vapor pressure versus temperature relationship. On the other hand, the dashed blue line in **Figure 23** depicts the scenario where a cylinder is filled to 95% at 75°F, leaving only 5% vapor headspace. The propane is allowed to expand until the 5% vapor headspace becomes occupied by the liquid, which occurs at about 102°F (a temperature differential of 27°F). At that point, the pressure inside the cylinder rapidly increases with an increase in temperature due to the hydrostatic condition (Note: This assumes constant volume — i.e., no expansion of the cylinder).

In the unusual situations where the vapor pressure is abnormally high (e.g., in a fire condition) or the cylinder becomes liquid full (e.g., overfill), the relief valve is designed to release the excess pressure at a specified setting, typically 375 PSIG, or well below the failure point of the vessel. However, the left cylinder did not have a pressure relief valve, either as part of the cylinder valve or as a separate add-on appurtenance. The lack of bleeder and relief valves on the left cylinder contributed to the incident, as outlined in the following causation scenario:

1. The cylinder was filled without the use of a fixed maximum liquid level gauge or a scale.
2. The cylinder was overfilled.
3. The temperature of the liquid propane inside the cylinder increased due to an increase in the ambient temperature, solar radiation, and/or external heating sources, which caused the cylinder to become liquid-full.
4. The internal pressure increased to the point of vessel failure because the cylinder was not equipped with a pressure relief valve.
5. Once the cylinder began to fail, the sudden reduction to ambient pressure resulted in rapid flashing of the liquid propane to vapor, splitting open of the cylinder, and projecting the cylinder across

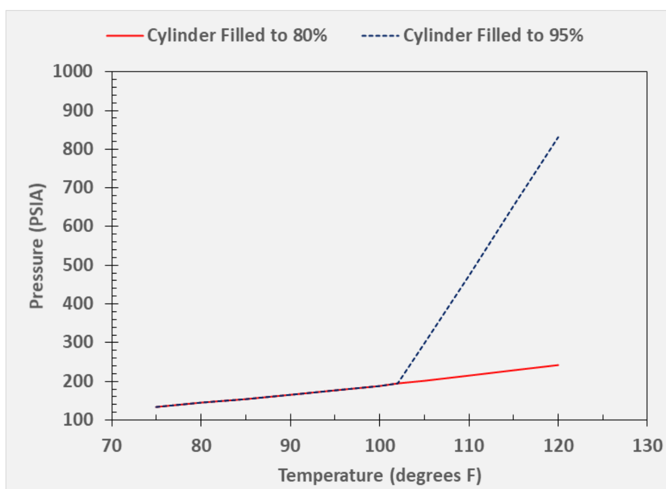


**Figure 23**
Pressure versus temperature relationship for pure propane under two different scenarios.

and down the street.

Item 5 in the causation scenario is often associated with the term BLEVE, which is an acronym for boiling-liquid-expanding-vapor explosion and is a subset of mechanical explosions. There are many definitions for BLEVE such as, "A BLEVE is an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure[19]." In this case, the normal boiling point for propane is -44°F.

Most theories related to BLEVEs consider the superheat limit temperature when defining a BLEVE[19]. For propane, the superheat limit is generally regarded to be 127°F (53°C). If the liquid propane in a cylinder is at or above the superheat limit temperature and the pressure is suddenly reduced to atmospheric, the bulk of the liquid will rapidly and violently flash to vapor, creating a blast wave[19]. The temperature of the liquid propane in the left cylinder may not have achieved or exceeded the superheat limit temperature, and the mechanical explosion may not have technically been a BLEVE. However, the end result was more or less the same. As stated in Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs by the CCPS[19]:

*A theory that adequately explains all BLEVE phenomena has not yet been developed. Reid's (1979, 1980) theory seems to be a good approach to explain the strong blast waves that may be generated. But even when a liquid's temperature is below the superheat limit, the liquid may "flash" within seconds after depressurization, resulting in a blast wave, a fireball, and fragmentation.*

Neither the right or left 100-pound propane cylinders should have been filled by the dispenser for the following reasons:

1. The left and right cylinders were 66 years and 19 years past their requalification dates, respectively.
2. The left cylinder did not have a spitter valve, eliminating the ability to accurately fill the cylinder by volume.
3. The left cylinder did not have a relief valve to protect it from the possibility of overpressurization.
4. The right cylinder did not have a spitter valve, eliminating the ability to accurately fill the cylinder by volume.

Even though the cylinders should not have been filled for the above listed reasons, the cylinders could have been properly filled using the weight method using a scale. The dispenser, however, did not fill these cylinders using the weight method. Ultimately, it was determined that the left cylinder was overfilled, and the overfill was the proximate cause of the explosion.

## Conclusions

Correctly and scientifically investigating an incident is essential in determining root cause and ultimately preventing recurrence. Following the systematic approach outlined in this paper (and illustrated in the case study) will give the investigator the best chance of success for determining the cause of an accident, which will advance industry safety.

As the food truck industry continues to grow, the expectation is accidents associated with food trucks utilizing propane systems will continue to occur on a similar or more frequent basis. Educating the food truck designers, builders, and owners on propane use and handling, developing food truck-specific codes and standards, and consistently implementing and enforcing those codes and standards will help decrease the frequency of accidents.

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