Physical and Chemical Properties of Propane
OBJECTIVES

1) List the two major flammable gases used in the Liquefied Petroleum Gases (LPG) industry.
2) Describe the two primary reasons for odorizing propane.
3) Identify five basic characteristics of LP-Gases.
4) Describe the following physical properties of propane and explain their significance in the risk assessment process at a propane incident:
   - Specific gravity
   - Vapor density
   - Boiling point
   - Expansion ratio
   - Vapor pressure
5) Describe the following chemical properties of propane and explain their significance in the risk assessment process at a propane incident:
   - Flammable limits
   - Ignition temperature
   - Combustion characteristics
6) Describe the three basic ways propane behaves when stored in a closed container.
7) Describe the relationship between heat, temperature, and boiling point as it relates to the storage of propane in a closed container.
8) List the basic products of incomplete combustion of propane.
9) List the five primary signs and symptoms of carbon monoxide poisoning.
10) Describe the basic hazards of aldehydes as they relate to incomplete combustion of propane.

ABBREVIATIONS AND ACRONYMS

ASHRAE  American Society of Heating, Refrigeration, and Air Conditioning Engineers
BTU  British Thermal Unit
BTU/ft³  British Thermal Unit per Cubic Foot
CO  Carbon Monoxide
ft³  Cubic Feet
LFL  Lower Flammable Limit
LPG  Liquefied Petroleum Gases
NFPA  National Fire Protection Association
OSHA  Occupational Safety and Health Administration
ppb  Parts per Billion
TLV/TWA  Threshold Limit Value—Time Weighted Average
UFL  Upper Flammable Limit
PROCESSING AND REFINING LP-GASES

Propane belongs to a family of chemical compounds known as hydrocarbons. This means they are made up of hydrogen and carbon atoms only. When looking at their chemical structure, propane is classified as a straight-chain hydrocarbon that belongs to a chemical class known as the alkanes (NOTE: All hydrocarbons in the alkane series end in ane). Commonly known alkane hydrocarbons include methane (CH\textsubscript{4}) (the primary component of natural gas), ethane (C\textsubscript{2}H\textsubscript{6}), propane (C\textsubscript{3}H\textsubscript{8}), and butane (C\textsubscript{4}H\textsubscript{10}). Of these hydrocarbons, propane, butane, and their isomers are classified as LP-gases (liquefied petroleum gases).

Propane and butane are normally found with crude oil or natural gas. About 30% of the propane and butane produced today is extracted with and refined from crude oil, while the other 70% is processed from natural gas.

**Crude Oil Extraction and Refining**—LP-gases are processed from crude oil by heating the crude oil until it begins to boil. Boiling crude oil produces many different gaseous hydrocarbons, including propane and butane. These different gases are captured under pressure and slowly cooled. Depending on their boiling point, each of the gases will condense into a liquid, one at a time, as the temperature drops below the boiling point of each gas. Both propane and butane are captured in this manner and then stored as a liquid under pressure.

**Natural Gas Processing**—LP-gases are extracted from natural gas in several different ways. When natural gas is removed from a gas pocket, it is normally referred to as a “wet” gas. The term wet means that the gas is a mixture of hydrocarbon gases and, in some cases, liquids. Once removed from the ground, the different gases and liquids are separated, processed, and refined. Among the gases and liquids removed are methane (chief component of “natural gas” used in appliances), propane, butane, and, in many cases, natural gasolines (pentane, heptane, etc.).

The two primary sources for LP-gases are quite different. However, once refined, there is little difference between the LP-gases processed from crude oil and those processed from “wet” natural gas liquids.

**LP-GAS BLENDS**

In addition to the basic differences between propane and butane, there are different types or blends that are used in the LP-gas industry. These blends are processed to meet the different needs of the many LP-gas customers. The four major blends are:

**Commercial Propane**—A type of LP-gas that consists mainly of propane and propylene (a straight-chained hydrocarbon with a double chemical bond similar to propane).

**HD5 Propane**—A type of LP-gas that consists mainly of propane with a maximum of 5% propylene.

**Commercial Butane**—A type of LP-gas that consists mainly of butane and butylene (a straight-chained hydrocarbon with a double chemical bond similar to butane).

**Butane/Propane Blends**—A mixture of both butane and propane. The blend is given in percentages, indicating the proportion of each LP-gas in the blend. A typical blend is 60/40, indicating that it is a mixture of 60% butane and 40% propane.
LP-GAS PHYSICAL AND CHEMICAL PROPERTIES

To mount a safe and effective response to a propane incident, responders must understand (1) how the product will behave (i.e., its physical properties) and (2) how it can harm (i.e., its chemical properties). These properties are critical elements in the risk assessment process and in developing an incident action plan to control and mitigate the incident. Physical and chemical terms covered in this section may be referenced from either the Material Safety Data Sheet (MSDS) or from emergency response guidebooks.

PHYSICAL PROPERTIES

Physical properties provide information on the behavior of a material. These properties or characteristics can be observed or measured, and provide responders with knowledge of how LP-gases will behave both within and after being released from its container.

Key physical properties common to all LP-gases include:

- They are tasteless, colorless, and usually odorless.
- LP-gases are capable of being either a liquid or gas. However, under ambient conditions, propane will be a gas.
- Most LP-gases can be stored and transported as liquids under pressure and can easily vaporize into gas under the proper conditions.
- Under normal outdoor temperatures liquid LP-gases expand rapidly into gas. One cubic foot of liquid propane will boil off and produce 270 cubic feet of propane vapor.

LP-gases will expand when heat is applied. If stored inside a container, this expansion will increase the volume of the liquid and the pressure inside the container. LP-gases are not toxic, but they present possible inhalation hazards. If released in a confined space, propane can displace oxygen and act as a simple asphyxiant.

SPECIFIC GRAVITY AND VAPOR DENSITY

An important characteristic of propane gas is its weight and how it compares with the weights of other liquids and gases. One of the most common ways of making such a comparison is the physical property known as specific gravity.

SPECIFIC GRAVITY OF LIQUIDS

The specific gravity of a liquid is the comparison of the weight of a given volume of one liquid at a certain temperature with the weight of the same volume of water at the same temperature. For example, if the specific gravity of a liquid at 60°F (15.6°C) is 3.0, then a given volume of that liquid at 60°F (15.6°C) is three-times as heavy as the same volume of water at 60°F (15.6°C).

In the case of propane liquid, the average specific gravity is 0.504 at 60°F (15.6°C). (See Table 2-1.) This means that propane liquid is a little more than one-half the weight of water at 60°F (15.6°C). It is necessary to know and to understand the meaning of specific gravity of propane liquid (a) when the propane is delivered to the plant, and (b) when propane liquid is used in filling operations.
When propane is delivered to the plant, the specific gravity of propane liquid is normally marked on the bill of lading. Since different liquids have different specific gravities, this value is used to ensure that the delivery is in fact propane liquid. The specific gravity of propane liquid is also used to determine the amount of propane liquid being delivered.

The specific gravity value of propane liquid is also used during filling operations. In this case, the specific gravity is used to determine the proper filling limit for the container, ensuring that the container is properly filled.

### PHYSICAL PROPERTIES OF PROPANE, BUTANE, AND METHANE

<table>
<thead>
<tr>
<th></th>
<th>Propane</th>
<th>Butane</th>
<th>Natural Gas (Methane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Formula</td>
<td>C₃H₈</td>
<td>C₄H₁₀</td>
<td>CH₄</td>
</tr>
<tr>
<td>Specific Gravity (Liquid)</td>
<td>.504</td>
<td>.582</td>
<td>.3</td>
</tr>
<tr>
<td>Vapor Density</td>
<td>1.50</td>
<td>2.01</td>
<td>.60</td>
</tr>
<tr>
<td>Weight Per Gallon</td>
<td>4.20 lbs.</td>
<td>4.86 lbs.</td>
<td>3.55 lbs.</td>
</tr>
<tr>
<td>Boiling Point (Atmospheric)</td>
<td>-44° F</td>
<td>31° F</td>
<td>-260° F</td>
</tr>
<tr>
<td>Ignition Temperature</td>
<td>920° F</td>
<td>900 – 1000° F</td>
<td>1,150° F</td>
</tr>
<tr>
<td>Maximum Flame Temperature</td>
<td>3,595° F</td>
<td>3,615° F</td>
<td>3,400° F</td>
</tr>
<tr>
<td>Upper Flammable Limit</td>
<td>9.60%</td>
<td>8.60%</td>
<td>14%</td>
</tr>
<tr>
<td>Lower Flammable Limit</td>
<td>2.15%</td>
<td>1.55%</td>
<td>4%</td>
</tr>
<tr>
<td>Ideal Combustion Ratio (Air to Gas)</td>
<td>24 to 1</td>
<td>31 to 1</td>
<td>10 to 1</td>
</tr>
<tr>
<td>Heat Value Per Cu. Ft. (Vapor)</td>
<td>2,488 BTU</td>
<td>3,280 BTU</td>
<td>1,000 BTU</td>
</tr>
<tr>
<td>Heat Value Per Pound (Liquid)</td>
<td>21,548 BTU</td>
<td>21,221 BTU</td>
<td>___</td>
</tr>
<tr>
<td>Heat Value Per Gallon (Liquid)</td>
<td>91,502 BTU</td>
<td>102,032 BTU</td>
<td>___</td>
</tr>
<tr>
<td>Cubic Feet Vapor Per Gallon</td>
<td>36.38 Cu. Ft.</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Cubic Feet Vapor Per Pound</td>
<td>8.66 Cu. Ft.</td>
<td>___</td>
<td>___</td>
</tr>
<tr>
<td>Latent Heat of Vaporization at Boiling Point Per Pound</td>
<td>184 BTU</td>
<td>153.59 BTU</td>
<td>219.22 BTU</td>
</tr>
<tr>
<td>Latent Heat of Vaporization at Boiling Point Per Gallon</td>
<td>773 BTU</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>

**TABLE 2-1**
VAPOUR DENSITY

Vapour density is the comparison of the weight of a given volume of a gas at a certain temperature with the same volume of air at the same temperature. Propane vapor has a vapour density of 1.52 at 60°F (15.6°C).

The important point to remember is that propane vapor is about 1.5 times heavier than air (air = 1.00). If a leak develops in a gas line or container, propane readily dissipates. However, under the right conditions, propane gas may settle in low unventilated areas and can become concentrated if there is little or no air movement. This is critical information when trying to find the source of a leak, or working in an area where a leak has occurred. See Table 2-1 for a comparison of the physical properties between propane, butane and methane.

ODORIZATION OF PROPANE

Propane is both odorless and colorless in its natural state. In order to facilitate the detection of propane leaks, a commercial odorant is added. Effective odorization serves two primary purposes, including:

- Permits the detection of leaks before gas concentrations reach a hazardous level, and
- Reduces gas losses through early detection and repair of leaks.

NFPA 58 states that all LP-gases must be odorized prior to delivery to the bulk plant by the addition of a warning agent that can be detected by a distinct odor down to a concentration in air of not over 20% of the lower flammable limit (LFL).

Minimum safety standards have been set by the Department of Transportation (CFR 49 192.625), which states that a combustible gas in a distribution line must contain a natural odorant or be odorized so that at a concentration in air of 20% of the lower flammable limit (LFL) the gas is readily detectable by a person with a normal sense of smell.

Unodorized LP-Gas may be encountered in some response scenarios. For example, unodorized propane is often used in petrochemicals and as a propellant gas for aerosol cylinders. When transported in bulk containers such as rail cars and cargo tank trucks, both the container and shipping papers must specifically state that the LP-gas is not odorized.

Although other odorants may be used, the most commonly used is ethyl mercaptan that is added at the rate of approximately one pound per 10,000 gallons of propane. The odor threshold of the mercaptans is in the range of one part per billion (ppb).

Desirable characteristics for a gas odorant vary considerably, depending upon the gas processor’s objectives and needs and geographic locations. Some of these characteristics include:

- **Odor**—The odor should be unpleasant and distinctive. It should be readily identifiable as gas and dissimilar to other household odors or to odors prevailing in the area. It should not fatigue the olfactory senses unduly.
- **Volutility**—Odorant should not condense out of the gas at pressures, temperatures, and odorizing rates employed.
- **Inertness**—Odorant should be inert enough not to polymerize, decompose, or react with other constituents of the gas or with materials in the distribution system or appliances.
Absorption by Soil—Gas passing through the soil should retain sufficient odor to remain detectable.

Corrosion—Odorant should be non-corrosive under any conditions encountered in transmission, distribution, and utilization. This calls for both a lower sulfur content and a low reactive type of sulfur bonding in the molecule.

Combustion Products—Odorant should burn completely in the gas flame to form products which are not corrosive, irritating, or toxic.

EFFECTS OF PRESSURE AND TEMPERATURE ON PROpane

Propane behaves in different ways when it is stored in containers under varying conditions. There are three relationships concerning this behavior which must be understood: (1) the effect of heat on liquids; (2) liquids and their boiling points; and (3) storing liquids above their normal boiling points in a closed container. Before beginning the discussion about the effects of pressure and temperature on propane, the effects of pressure and temperature on liquids in general will be discussed.

THE EFFECT OF HEAT ON LIQUIDS

Water is the best example to use to explain the effect of heat on liquids. Figure 2-1A shows one pound of water in a metal container on top of a gas burner. The burner is off and the water is at 60°F (15.6°C). As long as additional heat is not transferred to the water, the temperature will remain at 60°F (15.6°C). As long as additional heat is not transferred to the water, the temperature will remain at 60°F (15.6°C). Figure 2-1B shows the same water after it has been heated for a period of time. In this case, energy (in the form of heat) has been added to the water. Notice three things about this example.

- The water has expanded. Whether the liquid is water or propane, heat added to a liquid will always cause it to expand. This results in an increase in the volume of the liquid.

![Figure 2-1A & B Effects of heat on water.](image)
• The temperature of the liquid has increased. In this example, the temperature has increased to 160°F (71°C) (an increase of 100°F (37.8°C). As long as the liquid is at a temperature below its boiling point,

• The heat energy required to increase the temperature of the water can easily be calculated. A common value used to measure heat is the British Thermal Unit (referred to as the BTU).

A BTU is the amount of heat needed to raise the temperature of one pound of water 1°F (17.22°C). In Figure 2-1B the temperature of 1 pound of water increased 100°F (37.8°C). As a result, 100 BTU’s (100 X 1) were added directly to the water.

As long as the liquid is below its boiling point, the heat added can easily be calculated by knowing the liquid weight and any change in temperature. Once the normal boiling point is reached, it is not as easy to calculate the heat added to the liquid.

LIQUIDS AND BOILING POINTS

The boiling point of a liquid is the temperature at which a liquid will change to a vapor under normal atmospheric conditions (i.e., in an open container at sea level). For example, the normal boiling point of water is 212°F (100°C). Once a liquid reaches its normal atmospheric boiling point, the relationship between heat and liquid temperature will change, as illustrated in Figure 2-2.

Figure 2-2 shows a pound of water after it has been heated to 212°F (100°C) and the water has started to boil. Notice two things about this example:

• Once the water has started to boil, the temperature of the water will remain constant at 212°F (100°C). Even if the heat added to the water is doubled, the temperature will remain constant. Increasing the heat will cause the water to boil faster, but it will not increase the temperature of the water. Any additional heat added to the boiling water is used to change the liquid into vapor (steam). Since there is no visible change in temperature, this added heat is called latent (hidden) heat of vaporization.

• The amount of heat needed to cause a liquid to boil off and become vapor is greater than the amount needed to raise the temperature of the liquid from 60°F (15.6°C) to 212°F (100°C). If, for any reason, additional heat is no longer available (i.e., burner turned down), the water will stop boiling and the temperature will drop below 212°F (100°C).

STORING LIQUIDS ABOVE THEIR NORMAL BOILING POINTS

The examples used so far have shown the effects of adding heat to a liquid that is in an open container. As long as the container is open to the surrounding atmos-
Effects of Pressure and Temperature on Propane

The relationships between heat, temperature, and boiling points for the liquid will not be changed. However, if the liquid is placed in a closed container, these relationships will change, as illustrated in Figure 2-3.

**STORING LIQUIDS IN A CLOSED CONTAINER**

The illustration in Figure 2-3 again shows a pound of water being heated by a burner. This container has been closed with a pressure cooker lid. The important fact in this example is that although the water temperature is 250°F (121°C), the water is not boiling. This change in behavior is caused by the effects of pressure on the boiling point of the water.

In this case, water has been heated past its normal boiling point. Until the water reached 212°F (100°C), the water behaved just as it did when it was heated in an open container (increase in temperature, liquid expansion, etc.). When the water reached 212°F (100°C), the liquid began to boil off into steam. Since the container is closed, the space above the liquid is pressurizing. Once the container is pressurized to the proper point, the boiling action will stop. The increased steam pressure prevents any additional water from changing into steam. At this point the liquid and steam vapor are in balance.

The important point to remember about this example is that an increase in the temperature of the liquid will cause the liquid to boil off. If additional heat is added, the water will immediately begin to boil and increase the pressure in the container. This boiling will continue until the liquid and steam vapor are again in balance.

Also, if a relief valve in the pressure cooker opens and discharges steam, the liquid will immediately boil off trying to re-establish the balance between the liquid and steam vapor. When the relief valve closes, the pressure will again increase. As soon as the vapor pressure at the surface of the liquid and the pressure in the vapor space of the container are equal, the water will again stop boiling.

**STORING PROPANE IN A CLOSED CONTAINER**

Propane is affected by heat and pressure in much the same way as water. As long as propane is kept at a temperature below its normal boiling point, it will remain a liquid and can be stored in open containers.

The problem with storing propane in an open container is that it has a boiling point of -44°F (-42°C), well below the boiling point of water and normal ambient temperature. At temperatures above its boiling point, propane will usually boil off into vapor, as illustrated in Figure 2-4. However, it should be noted that propane can also pool as a liquid when released at very low ambient temperatures. In order to store propane as a liquid above its normal boiling point, it must be stored and transported in pressure-tight containers called cylinders or tanks.
When placed in a pressure-tight container, propane can be stored as a liquid under pressure. Figure 2-5, for example, shows propane liquid in a small cylinder at a temperature of 70°F (21°C). That temperature is 114°F (45.6°C) above its normal boiling point. In this case, as soon as the propane liquid was pumped into the cylinder, it began to boil off and pressurize the vapor space of the cylinder. Once the pressure reached 109 psig, the pressure, liquid temperature, and heat were in balance and the boiling stopped. Like water, as long as the temperature and pressure remain constant, the propane liquid will not boil.

However, if the burner shown in the illustration is ignited, the demand for gas will immediately cause a slight drop in pressure, as illustrated in Figure 2-6.

This drop in pressure causes the propane to boil off. If the demand is greater than the boiling rate of propane, the propane will continue to boil off, thereby supplying fuel to the burner. As soon as the boiling rate exceeds the demand (i.e. burner off), the cylinder will re-pressurize with vapor and the boiling will stop. Table 2-2 shows the vapor pressures of various LP-gases at specific temperatures.

To summarize, there are four important characteristics that need to be known and understood about propane gas when it is stored in a closed container:

1. **Heat added to propane in a tank or cylinder is transferred directly from the air surrounding the container.** Hot days, cool nights, rain, and snow are a few of the many factors that affect the temperature of the liquid. These changes in liquid temperature also cause changes in vapor pressure. As a result, it is common to see the vapor pressure in a tank or cylinder change as much as 50 psig in the course of a day, without an appliance being used.

2. **Propane, like water, will expand when heat is added to it.** The major difference is that propane will expand considerably more than water over the same change in temperature. Propane liquid will increase in volume nearly 17 times...
greater than water over the same temperature increase. As a result, tanks and cylinders should not be completely filled with propane liquid. Usually tanks and cylinders are filled to about 80% of their capacity. This leaves enough space above the liquid to allow the propane to expand freely due to changes in the ambient temperature.

3. Due to changes in liquid volume, and the high storage pressures, every propane container is equipped with at least one pressure relief valve. If the pressure inside the container becomes too high, the pressure relief valve will discharge some vapor, reducing the internal pressure to a safe level. This ensures that the vapor pressure never reaches the design pressure of the container. However, it is very important to note that if a container is turned on its side and is discharging liquid from the pressure relief valve, no significant internal pressure drop will occur inside the container.

4. Remember, liquid leaks are generally more dangerous than gas leaks. A small volume of liquid propane can boil off into a large volume of propane vapor. One cubic foot of propane liquid, for example, will boil off into approximately 270 cubic feet of vapor. As a result, a liquid leak in any propane container, large or small, can easily lead to a flammable mixture of propane and air that may impact a large area under the right conditions.

### VAPOR PRESSURES OF LP-GASES

<table>
<thead>
<tr>
<th>Temperature (F)</th>
<th>Propane</th>
<th>Commercial Propane Max.</th>
<th>Butane</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40</td>
<td>4</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>-30</td>
<td>8</td>
<td></td>
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<tr>
<td>130</td>
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<td>69</td>
</tr>
</tbody>
</table>

**TABLE 2-2**
CHEMICAL PROPERTIES AND COMBUSTION CHARACTERISTICS

Chemical properties are the intrinsic characteristics or properties of a substance described by its tendency to undergo chemical change. They typically provide responders with an understanding of how a material may harm. Examples include flammable or explosive range and ignition temperature.

Combustion is a chemical reaction. It is a method of changing a fuel source into a useful form of energy (e.g., heat). The three basic ingredients needed to start and sustain combustion are fuel, oxygen, and an ignition source, as illustrated in Figure 2-7. All three items must be present in the proper proportions for combustion to occur.

The combustible materials in propane are carbon and hydrogen, or hydrocarbons. The oxygen needed to burn propane vapor is obtained from the air. Air is made up of 20% oxygen, 79% nitrogen, and about 1% of other miscellaneous gases. The ignition source must provide enough heat to the mixture of fuel and oxygen to raise the temperature of the propane to its ignition temperature, which is between 920°F (493°C) and 1,120°F (604°C).

FLAMMABLE LIMITS

Even with an abundant supply of both air and propane, combustion cannot occur unless they are mixed together in the proper proportions. The most common way of expressing the proper mixtures needed for combustion is in terms of flammability limits (also known as explosive limits).

NOTE: The terms flammable limits and explosive limits are often used interchangeably. Within the propane industry, the term flammable limits is used most often in technical literature. Within emergency services, the term explosive range is most common. Both terms have the same meaning.

A flammable limit is simply the percentage of gas needed in a gas/air mixture to support combustion. Normally, this value is given in both upper and lower limits of flammability. The upper limit is the percentage of gas in the richest (most gas) mixture that will support combustion. The lower limit is the percentage of gas in the leanest (least gas) mixture that will support combustion. The lower flammable limit (LFL) for commercial propane is 2.15%, while the upper flammable limit (UFL) is 9.60%. Refer to Table 2-1 for limits of flammability of propane, and its comparison with butane and natural gas.
COMBUSTION RATIO

Although propane vapor will burn in any mixture within its flammability limits, combustion may not produce a “clean burn.” Insufficient heat, unburned gas, and harmful combustion by-products (i.e., carbon monoxide) are only a few of the problems that can develop from incomplete combustion. As a result, most gas appliance burners are designed and adjusted to burn a gas air mixture that is as close to ideal as possible by designing the appliances to use a very efficient gas/air ratio. This mixture is commonly referred to as the ideal combustion ratio. The ideal combustion ratio for propane is 24 parts of air (96%) to 1 part of propane (4%).

There is a very narrow range of gas/air mixtures that will support combustion. Even within this range there is only one mixture that will give efficient combustion. Although this “ideal” combustion ratio may only be possible under “ideal” conditions, gas appliances should be inspected or adjusted periodically to be sure that the appliances are as safe and efficient as possible.

IGNITION TEMPERATURE

Even with an ideal propane and air mixture, there must still be an ignition source present for combustion to occur. Ignition sources are usually expressed as the minimum temperature needed for a mixture of propane and air to ignite. The ignition temperature of propane is approximately 920°F (493°C). While it should be noted that temperature may seem very high, the flame of a match can develop temperatures up to about 3,000°F (1,649°C).

A common ignition source for propane is another flame, such as the flame of a pilot burner, match, or cigarette lighter. Other sources of ignition that can develop enough heat to ignite a combustible mixture of air and propane include sparks from electric motors and switches, lit cigarettes, highway flares, a motor vehicle’s catalytic converter, or a static discharge.

HEAT VALUE

The purpose of burning propane as efficiently as possible is to develop as much heat as possible per cubic foot of propane. The heat produced by burning propane is expressed in BTU’s per cubic foot of gas or in BTU’s per gallon. According to NFPA 58, Table B-1.2.1, the heating value for propane (vapor) is 2,488 BTU/ft³.

The heat value of propane is used in engineering many propane operations, including sizing distribution lines, sizing appliance orifices, and converting appliances from natural gas to propane or butane. When the rating of an appliance is known, the heat value is also useful in determining the correct size of a tank or cylinder, size and type of distribution system, and the frequency of filling the container.

PRODUCTS OF COMPLETE COMBUSTION

When propane and air are burned in the correct ratio, (1 ft³ of propane to 24 ft³ of air) complete combustion takes place. Since propane is a mixture of hydrogen and carbon, certain by-products are generated when burned in the presence of oxygen. These products of combustion are water vapor and carbon dioxide. The carbon dioxide and water vapor formed in burning, plus the nitrogen in the reactants which enter with the combustion air, together are called combustion products. These products are also commonly known as flue gases.
PRODUCTS OF INCOMPLETE COMBUSTION

When combustion is incomplete harmful products can be generated. To obtain complete combustion, enough air must be supplied to the combustion process. If not enough air is supplied, other products will be generated, including carbon monoxide, excessive water vapor, aldehydes, and soot.

CARBON MONOXIDE (CO)

Because carbon monoxide (CO) gas is odorless, colorless, and tasteless, it cannot be detected by the body. Carbon monoxide can only enter the body through the respiratory system. Inhaled carbon monoxide is absorbed into the blood and then combines with the hemoglobin of the blood to exclude the oxygen. Symptoms of exposure include headache, nausea, chronic fatigue, confusion, and dizziness. The harmful effects of CO exposure depend on the concentration of the gas in the air, exposure time, and factors such as age, health, size, and sex.

According to the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) (Ventilation Standard 62-89), a concentration of no more than 9 parts per million (ppm) of CO is permissible in residential living spaces. In addition the Occupational Safety and Health Administration (OSHA) has established an 8-hour time-weighted threshold limit value (TLV/TWA) at 35 ppm. See Table 2-3 for additional information.

Emergency responders and propane marketers who respond to carbon monoxide incidents must be properly trained in the hazards of CO and have the proper protective clothing, equipment, and detection and monitoring instruments. A written Standard Operating Procedure for handling carbon monoxide emergencies is recommended.

SULFURIC ACID

Water vapor is also produced as a normal by-product of combustion. If sulfur impurities exist in the propane, sulfur deposits may also be produced. As a result, the condensed water will combine with the sulfur deposits to form sulfuric acid, which may be harmful to appliances and piping.

ALDEHYDES

Another class of compounds, known as aldehydes, may also be formed in incomplete combustion. While carbon monoxide is odorless, aldehydes have a sharp, penetrating odor. They are readily detected by smell even at very low concentrations. The odor of aldehydes differs from odorants added to propane, and the two should not be confused. The absence of aldehydes does not assure that carbon monoxide is not present in flue products. However, if the odor of aldehydes is present, then carbon monoxide almost always will be present. Aldehydes by themselves are also toxic.

SUMMARY

Propane and butane are the two major LP-gases extracted and used in the gases industry. About 70% of propane is processed from natural gas. LP-gases are processed from crude oil by heating the crude oil until it begins to boil. Because propane is odorless and colorless in its natural state, a commercial odorant is added
so it may be detected if it leaks from its container. The most commonly used odor-ant is ethyl mercaptan.

LP-gases belong to a family of chemical compounds known as alkane hydrocarbons. This means they are made up of hydrogen and carbon atoms only. Under normal ambient temperatures liquid propane (C\textsubscript{3}H\textsubscript{8}) will expand rapidly into gas. One cubic foot of liquid propane will boil-off and produce 270 cubic feet of propane vapor. When mixed with the proper amount of air, LP-gases can burn.

Propane vapor has a vapor density of 1.52 at 60°F (15.6°F). The important point to remember is that propane vapor is about 1.5 times heavier than air (air = 1.00). If a leak develops in a gas line or container propane readily dissipates.

Even with an abundant supply of both air and propane, combustion cannot occur unless they are mixed together in the proper proportions. The most common way of expressing the proper mixtures needed for combustion is in terms of flammability.

### Concentration Levels and Physiological Effects of Carbon Monoxide

<table>
<thead>
<tr>
<th>Concentrations of CO in Air</th>
<th>Physiological Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 ppm (0.009%)</td>
<td>The maximum allowable concentration for short-term exposure in a living area according to ASHRAE. No effects detected.</td>
</tr>
<tr>
<td>35 ppm (0.0035%)</td>
<td>The maximum allowable concentration for continuous exposure in any 8-hour period, according to federal law.</td>
</tr>
<tr>
<td>200 ppm (0.02%)</td>
<td>Slight headache, tiredness, dizziness, nausea after 2–3 hours.</td>
</tr>
<tr>
<td>400 ppm (0.04%)</td>
<td>Frontal headaches within 1–2 hours, life-threatening after 3 hours, also maximum parts per million in flue gas according to EPA and AGA.</td>
</tr>
<tr>
<td>800 ppm (0.08%)</td>
<td>Dizziness, nausea, and convulsions within 45 minutes. Unconsciousness within 2 hours. Death within 2–3 hours.</td>
</tr>
<tr>
<td>1,600 ppm (0.16%)</td>
<td>Headache, dizziness, and nausea within 20 minutes. Death within 1 hour.</td>
</tr>
<tr>
<td>3,200 ppm (0.32%)</td>
<td>Headache, dizziness, and nausea within 5–10 minutes. Death within 30 minutes.</td>
</tr>
<tr>
<td>6,400 ppm (0.64%)</td>
<td>Headache, dizziness, and nausea within 1–2 minutes. Death within 10–15 minutes.</td>
</tr>
<tr>
<td>12,800 ppm (1.28%)</td>
<td>Death within 1–3 minutes.</td>
</tr>
</tbody>
</table>

10,000 ppm (parts per million) = 1% by volume

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**TABLE 2-3**
limits. The flammability limits for propane are 2.15% for the lower limit (LFL) and 9.60 for the upper limit (UFL). The ignition temperature of propane is between 920°F (493°C) and 1,120°F (604°C).

When combustion is incomplete, harmful products can be generated. The most hazardous of these by-products is carbon monoxide. Carbon monoxide gas is odorless, colorless, and tasteless. When inhaled, carbon monoxide is absorbed into the blood and combines with the hemoglobin of the blood to exclude the oxygen. Symptoms of exposure include headache, nausea, chronic fatigue, confusion, and dizziness. Prolonged exposure can result in death.