

Off-Road Applications of Propane Engine Fuel



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Warning



Always consult recognized standards (NFPA 58 or equivalent) and Original Equipment Manufacturer (OEM) installation publications when working with propane engine-fuel systems. Pressure in fuel tanks and other propane system components may exceed 300 psig. Necessary safety precautions must be applied when installing, disconnecting or otherwise handling propane system components. Failure to apply adequate safety practices or failure to heed warnings while performing installation or repair procedures may result in serious personal injury or death to yourself or others.

Scope of This Course

This course surveys the main off-road applications of propane engine fuel.

Because the applications covered in the survey address different audiences, different approaches are taken to each chapter. For example, forklift distributors and operators are well served by the major OEMs, who provide quality training on recent models for distributors' service and maintenance staff. Accordingly, and because forklifts typically have long service lives, the forklift chapter of this manual focuses on older equipment most often serviced by forklift operators and independent repair facilities. Conversely, propane-powered mowers and lawn equipment represent a new and rapidly expanding market with a diverse, decentralized sales, service and user network. This network includes many technicians who have little or no experience with propane engine fuel or propane fuel systems. These users are best served by the introductory chapter on the history and properties of propane engine fuel, by Chapter 3's focus on current propane-fueled commercial mowers, and by the discussion in Chapter 7 of basic troubleshooting procedures applicable to a wide variety of small-engine applications.

Key customers for these applications are as follows:

- **Generators and CHP systems:** Generator service companies that install and maintain the units, and, to a lesser extent, propane service companies that install the propane systems.
- **Lawn equipment:** Turf products dealers and service shops; propane marketers who supply fuel for propane turf equipment.
- **Irrigation equipment:** Irrigation equipment dealers who install and maintain the equipment; propane marketers in agricultural areas who supply fuel.
- **Forklifts:** Independent forklift service companies who work on model year 2007 and earlier forklifts that lack electronic controls; propane marketers who supply fuel and field fuel-quality complaints.
- **Microturbines:** Generator service companies that maintain the equipment.

The survey is intended to describe the basic technologies used in these applications and identify the applicable codes, standards and safety practices for readers to use as appropriate. At the time of this publication in the United States, the nationally recognized standards for propane-powered engines and conversions are found in National Fire Protection Association manuals 58, *Liquefied Petroleum Gas Code* (NFPA 58) and 505, *Fire Safety Standard for Powered Industrial Trucks* (NFPA 505). Some states have adopted additional or different code requirements.¹ Users should check with the authority having jurisdiction in their areas to determine which requirements apply.

In every aspect of a propane equipment installation, where explicit equipment manufacturers' installation instructions exist, those instructions must be followed.

¹ For example, California has its own standard, Title 13, which regulates the safe installation of LP-gas fuel systems.

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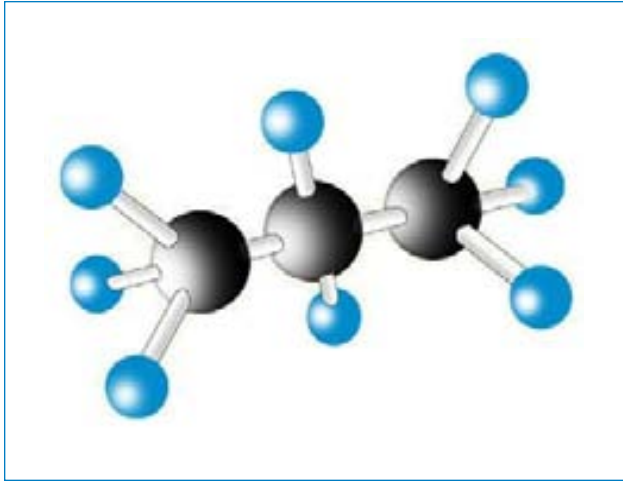
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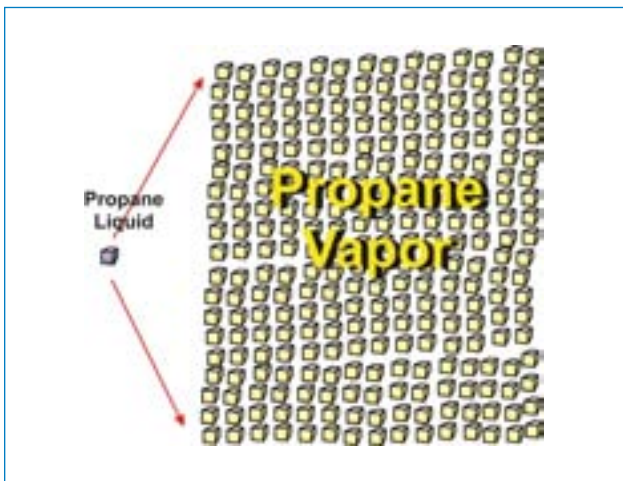
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Chapter One

Propane Fuel



CHAPTER 1: PROPANE FUEL

1.1 History of LP-Gas as an Engine Fuel

The use of LP-gas (liquefied petroleum gas) as an engine fuel is almost as old as the automobile itself. In the early 1900s, the main fuels available to power automobiles were gasoline and grain alcohol (ethanol). Gasoline rapidly became the overwhelming choice because of its price advantage and widespread availability, even though the refining practices of that time made it a highly volatile fuel that evaporated quickly.

Dr. Walter Snelling of the U. S. Bureau of Mines discovered a method of removing the lighter hydrocarbons from gasoline. He later identified these compounds as butane and propane, the primary constituents of LP-gas. The result improved motor gasoline and created a new LP-gas industry.

Dr. Snelling and his colleagues also devised methods for liquefying LP-gas. A practical means of separating butane and propane from crude oil and natural gas was developed, and the first automobiles powered by LP-gas appeared in the early 1900s.

1.2 Changes in the Fuel Blend

Until World War II, LP-gas engine fuel was mainly butane. The discovery of new uses for butane in gasoline blending and the petrochemical industry, however, shifted most of the available butane away from the engine fuel market. Propane became the primary component of LP-gas engine fuel.

In 1963 the Gas Processors Association (GPA) adopted specification HD-5 for propane engine fuel. The purpose was to provide a uniform quality propane, so engines could be designed and tuned to deliver the best performance and fuel economy. The specification is in GPA Standard 2140-97, *Liquefied Petroleum Gas Specifications and Test Methods*. It is incorporated as “special duty propane” in ASTM D-1835, *Standard Specification for Liquefied Petroleum (LP) Gases*.

The letters HD in HD-5 stand for “Heavy Duty,” and the number 5 represents the maximum percentage of propylene allowed in the fuel blend. HD-5 must be at least 90 percent propane and may contain up to 2.5 percent butane and heavier hydrocarbons by liquid volume. HD-5 must be essentially free from oily residues and other contaminants such as sulfur. A maximum vapor pressure of 208 psig at 100°F (Reid method) effectively limits ethane content.

HD-10 is the unofficial term for LPG with up to 10 percent propylene that meets the specifications set out in the *California Code of Regulations*, Title 13, Section 2292.6.

1.3 Rapid Growth

The 1973 Arab Oil Embargo increased public interest in propane engine fuel. Suddenly gasoline was in uncertain supply and expensive, resulting in rapid growth of propane fuel-system retrofits in the late 1970s and early 1980s. By 1978 about 35,000 vehicles a year were being converted to propane in the U.S. By 1981 that number was nearly 250,000. In 1989 almost 4 million vehicles worldwide were powered by propane autogas.¹

Regulatory actions increased demand for alternative-fueled vehicles in the 1990s. Some states, such as Texas, Florida, and California, required the use of these fuels as early as 1989. With the 1990 amendments to the Clean Air Act, the United States required the use of alternative fuels in certain fleets. Although the price gap between gasoline and propane subsequently narrowed, environmental concerns and cost savings continue to motivate fleets to convert their vehicles.

1.4 Physical Characteristics and Properties

Like gasoline and diesel fuel, propane is a member of the hydrocarbon (HC) family. HC's are substances whose molecular structure is composed solely of hydrogen and carbon.

There are literally thousands of different HC's, ranging from those found in asphalts, heavy oils and waxes to gasoline, kerosene, naphtha and light gases such as methane, ethane, propane and butane. Gasoline is a mixture of 40 to 400 or more different HC's.

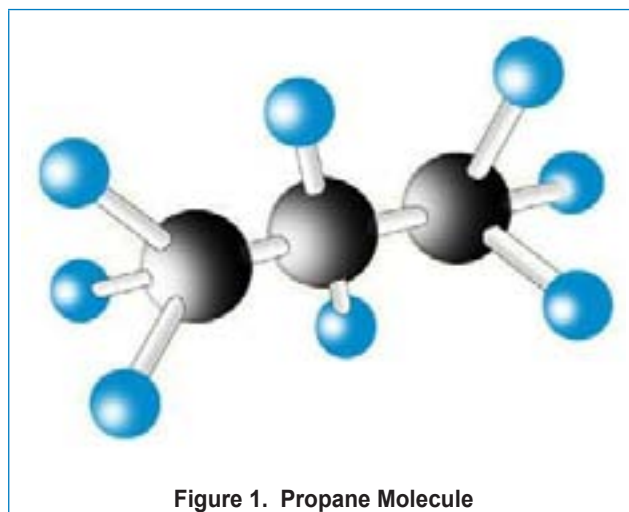


Figure 1. Propane Molecule

The number and arrangement of hydrogen and carbon atoms in a fuel's molecular structure is what gives each fuel its set of physical properties. At atmospheric pressure, propane (C_3H_8), butane (C_4H_{10}) and methane (CH_4) are gases because of their relatively low molecular weight. At atmospheric pressure, gasoline, kerosene and diesel fuel are liquids because their molecules are much larger and heavier.

1.5 Heat Content

Heating values are measured in British thermal units (Btu's). One Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. Generally speaking, the more carbon atoms in a molecule of a given fuel, the greater its heat content or energy value. Table 1 on page 13 shows how much heat is produced when a given quantity of

¹ "Propane autogas" or "autogas" is the term used internationally to refer to propane used as an engine fuel to propel on-road vehicles.

propane is burned. One gallon of propane will produce 91,502 Btu's of heat energy, compared to 124,340 Btu's for one gallon of gasoline. By weight, one pound of propane produces 21,548 Btu's, which is almost the same as gasoline.

Although propane produces almost as much heat energy as gasoline on a per-pound basis, propane weighs about two pounds less per gallon than gasoline. An engine's horsepower output depends on the quantity (mass) of fuel burned, so even though propane requires a leaner air/fuel mixture than gasoline, the net result is that it takes more propane than gasoline by volume to achieve the same power output.

Gasoline engines converted to propane will generally consume 15-25 percent more fuel, in terms of miles per gallon.

1.6 Odorant

Propane is odorless by nature, like butane or methane. An odorant, usually ethyl mercaptan, is added to give propane its distinctive, pungent smell. The odorant acts as a warning agent so that leaks can be detected quickly. It is not harmful to breathe, nor does it affect the composition of the fuel in any way except to make its vapors noticeable. Once the fuel is burned, the odor disappears.

NFPA 58 states that odorization at the rate of one pound of ethyl mercaptan per 10,000 gallons of propane has been recognized as an effective odorant. This rate allows the average person to detect a combustible mixture of air and fuel at a level of not more than 1/5 the lower flammability limit (2.1 percent fuel to air).²

1.7 Specific Gravity

Propane liquid is lighter than water, and propane vapor is heavier than air. These physical characteristics are expressed as specific gravities.

The specific gravity of a liquid is defined as the weight of a given volume of the liquid compared to the weight of the same volume of water, measured at the same temperature and pressure.

The specific gravity of water is defined as 1.0. A liquid that is twice as heavy as water has a specific gravity of 2.0, and a liquid that is half as heavy as water has a specific gravity of 0.5. The specific gravity of propane liquid is 0.504, which means propane liquid weighs about half as much as water (Figure 2).

Similarly, the specific gravity of a gas (vapor) is defined as the weight of a given volume of the vapor compared to the weight of the same volume of air, measured at the same temperature and pressure.

² NFPA 58, 2008 and 2011 eds., §4.2.1

The specific gravity of air is defined as 1.0. A vapor that is twice as heavy as air has a specific gravity of 2.0, and a vapor that is half as heavy as air has a specific gravity of 0.5 (Figure 3).

The specific gravity of propane vapor is 1.50, which means propane vapor weighs half again as much as air.

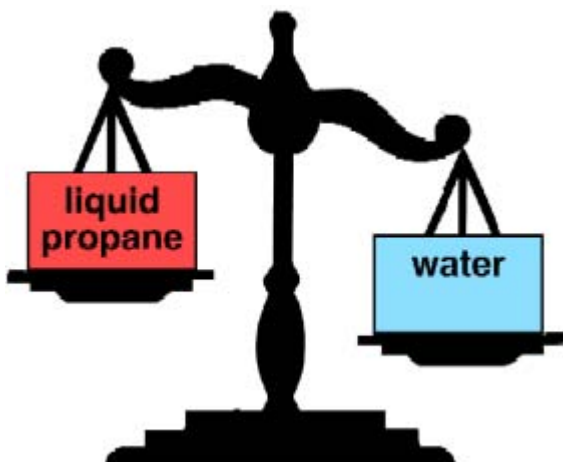


Figure 2. Propane liquid is lighter than water.

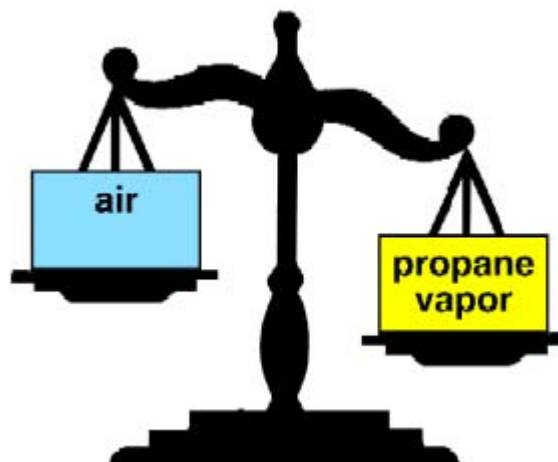


Figure 3. Propane vapor is heavier than air.

The specific gravity of propane vapor is an important physical property. Propane vapor is heavier than air. Therefore, it tends to initially accumulate at the lower level of spaces when it is released into a still environment. Sources of ignition, such as open flames, must be controlled in accordance with NFPA 58 wherever propane-fueled vehicles are parked or serviced indoors.

Repairs must be made either outdoors or in a well-ventilated area at least 25 feet away from any sources of ignition, such as smoking materials, open flames, electrical tools and lights, and at least 35 feet away from any metal grinding or oxy-welding operation. Fueling and venting operations must be performed only outdoors, and unauthorized personnel should be kept away from the repair area.

1.8 Boiling Point, Temperature and Pressure

Another important physical property of propane is its low boiling point. At standard atmospheric pressure (sea level), pure propane liquid boils (vaporizes) at any temperature warmer than -44°F . Below -44°F , propane will remain liquid at standard atmospheric pressure.

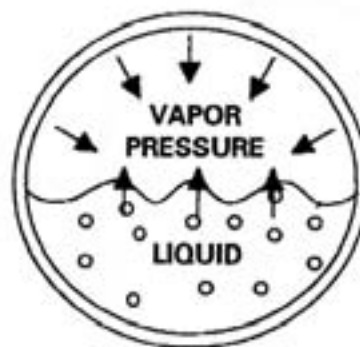


Figure 4. Propane liquid and vapor exist together in equilibrium inside a closed container.

At temperatures above -44°F , propane will exist as a vapor unless it is kept under pressure, as in a container. Propane stored in a container exists as both a vapor and a liquid.

The amount of pressure required to keep propane a liquid increases with temperature. At -20°F , for example, very little pressure (only 10.7 psi) is required, because -20°F is fairly close to propane's natural boiling point of -44°F . At 100°F , however, 205 psi of pressure is required to keep propane a liquid, because the fuel is far above its boiling point. Figure 8 shows the vapor pressure of propane at different temperatures.

If propane vapor or liquid is released from a container, the pressure in the container is reduced temporarily, causing the liquid propane to boil and generate vapor to fill the space above the liquid. Vaporization continues until a state of equilibrium is reached.

When liquid is added to the container, the rising liquid compresses the gas in the vapor space, increasing the pressure inside the container. The propane vapor then starts condensing to liquid in order to restore equilibrium at that temperature. Propane inside a sealed tank will remain a liquid as long as the pressure is maintained.

Lowering the temperature lowers the vapor pressure inside a closed fuel tank, just as increasing the temperature raises the pressure. For this reason, hot days, cool nights, direct sunlight, rain and snow all affect the vapor pressure of the fuel inside a tank. It is not unusual to see tank pressures change as much as 50 psi in the course of a day.

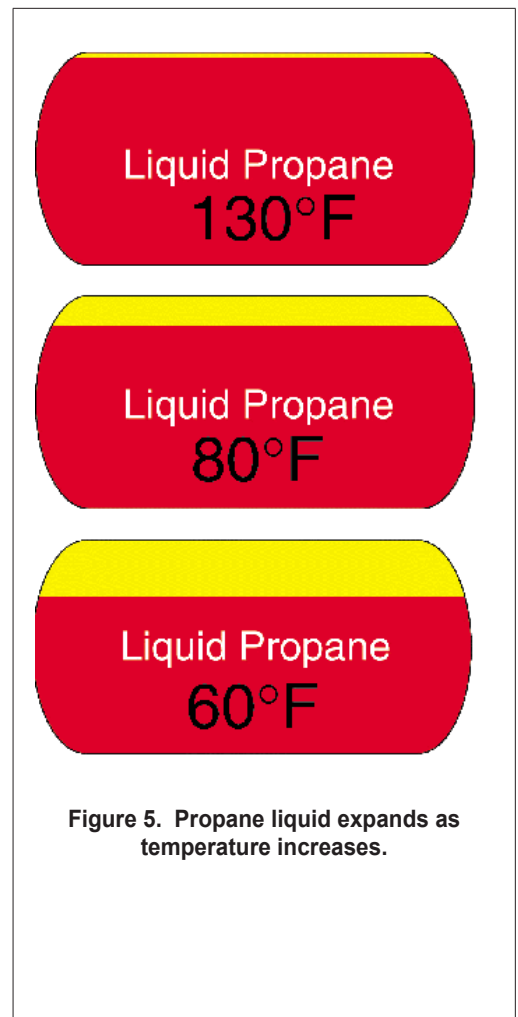
1.9 Expansion Ratio

The reason why propane is stored as a liquid under pressure is to save space. Liquid is denser than vapor, so much more fuel can be stored in a tank if the propane is in liquid form.

Like other liquids, propane expands when heated. But not all liquids expand at the same rate. Propane expands about 1 percent for each 6°F increase in its temperature.

To allow for expansion, propane fuel tanks are never completely filled with liquid. They are filled to approximately 80 percent of capacity to allow room for thermal expansion. Fuel tanks are also equipped with pressure-relief valves that vent propane vapor if the internal tank pressure exceeds the preset rating of the valve. The valve closes automatically when internal pressure is reduced below this start-to-discharge pressure.

If propane liquid is released into the air, it quickly vaporizes and expands to 270 times its original volume. Therefore, a



liquid propane leak can be more hazardous than a vapor leak due to the expanding vapor cloud.

Also, when liquid propane is released into the atmosphere, its rapid vaporization pulls heat from the surrounding air, causing a refrigerating effect that makes everything it touches extremely cold. If propane liquid contacts skin or other tissues, it can cause third-degree freeze burns.

1.10 Flammability Limits

A flammability limit is the lowest or highest percentage of fuel needed in an air/fuel mixture to support combustion. Combustion occurs when an air/fuel mixture that is within the flammability limits is ignited, e.g., by heat from a spark or compression.

Flammable air/fuel mixtures fall between the upper and lower flammability limits. The upper flammability limit is the greatest concentration of fuel—the richest air/fuel mixture—that will support combustion. Air/fuel mixtures above the upper limit will not burn because there is too much fuel and not enough air.

The lower flammability limit is the minimum concentration of fuel—the leanest air/fuel mixture—that will support combustion. Air/fuel mixtures below the lower limit will not burn because there is too much air and not enough fuel. See Table 1 for the flammability limits of propane.

1.11 Combustion Air/Fuel Ratio

Although propane vapor will burn in any mixture within its limits of flammability, combustion is most efficient and complete when there is just the right amount of fuel for the available oxygen in the air. The ideal combustion ratio for propane, also referred to as the stoichiometric³ air/fuel ratio, is 15.5:1 by weight, that is, 15.5 pounds of air for every pound of propane vapor. The ratio is 24:1 by volume, that is, 24 parts of air (96 percent) to every one part of propane vapor (4 percent). See Table 1.

An air/fuel mixture that is richer than the ideal ratio lacks enough oxygen to burn the fuel completely. The resulting partial combustion forms carbon monoxide (CO) and adds unburned HC's to the exhaust emissions. Fuel economy suffers, because excess fuel is being used. Richer mixtures tend to produce more power up to a certain point, but the trade-off is reduced performance and economy, increased exhaust emissions and higher exhaust temperatures.

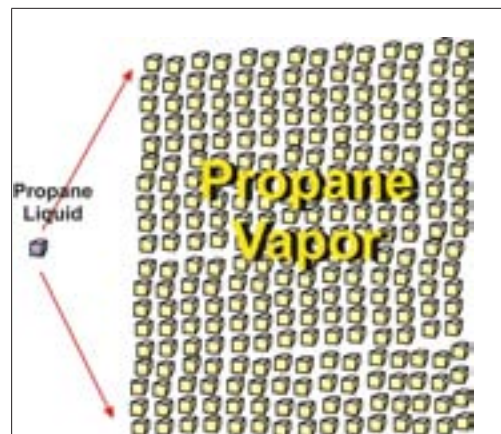


Figure 6. Propane liquid expands to 270 times its original volume when it vaporizes.

³ The term “stoichiometry” is used to describe complete combustion. SAE standard J1829 defines “stoichiometric air-fuel ratio” as “the mass of air required to burn a unit mass of fuel with no excess of oxygen or fuel left over.” See http://standards.sae.org/j1829_200210.

If an air/fuel mixture is too lean, a condition known as lean misfire can occur inside the engine. Although the mixture may be above the lower flammability limit, it may be too lean for the spark to ignite. This allows unburned fuel vapors to pass through into the exhaust, increasing HC emissions. Performance is reduced because of the misfire, and economy suffers because of the wasted fuel.

1.12 Octane Ratings

Octane ratings measure a fuel's resistance to detonation. Propane's pump octane rating (100-105) is higher than that of any premium gasoline.

Detonation occurs when the pressures inside the combustion chamber become too great for the fuel to burn evenly. Instead of a smoothly expanding flame front inside the cylinder, multiple flame fronts are formed and collide with one another, producing a sharp pinging or spark knock that signals detonation. Vibration created by these colliding flame fronts can quickly damage an engine.

A fuel's resistance to detonation may be expressed in three different ways: research octane, motor octane, and pump octane. Research octane rating is determined in a laboratory by comparing the fuel's detonation resistance to that of two known test fuels: iso-octane (100 octane, the highest grade) and normal heptane (0 octane, the lowest grade). The fuel being tested is assigned a value relative to the ratio of a mixture of iso-octane to heptane that results in the equivalent knock resistance. The research method yields the highest octane rating of the three methods.

Motor octane ratings more accurately describe a fuel's resistance to detonation in actual service. In the motor octane test, the test fuel is evaluated in an engine that simulates actual driving conditions, resulting in lower octane numbers.

Pump octane is the rating posted on a fuel dispenser. It is calculated as $R + M / 2 = P$, or the sum of research octane and motor octane divided by 2 equals pump octane. The pump octane method yields average results of:

- Regular unleaded gasoline = 87 octane
- Mid-grade unleaded gasoline = 89 octane
- Premium unleaded gasoline = 91-93 octane
- Propane (HD-5 / HD-10) = 100-105 octane (rating varies with the percentage of propane and other LP-gases)

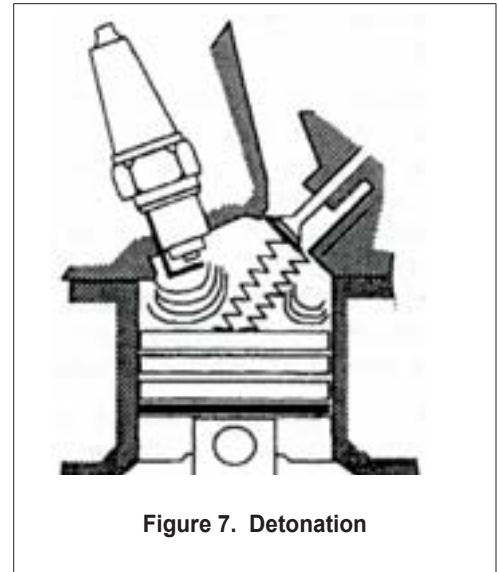


Figure 7. Detonation

1.13 Combustion Characteristics

Propane is a vapor at standard temperature (60°F) and standard atmospheric pressure (one atmosphere or 14.7 psi absolute). Gasoline and diesel fuel are liquids under these conditions. They must be vaporized to burn well.

In a gasoline fuel system, a carburetor or fuel injector creates a fine mist of liquid fuel. To vaporize completely, the fuel must pick up additional heat as it passes through the intake manifold and enters the combustion chamber. Compressing the fuel helps the droplets of gasoline mix and vaporize. If gasoline is not completely vaporized, inefficient combustion causes higher exhaust emissions and reduces fuel economy and performance. Therefore, gasoline engines require a variety of strategies to aid cold-starting.

With diesel engines, the situation is somewhat different. Diesel fuel is mixed with air by injecting it directly into the combustion chamber or pre-chamber as a highly pressurized mist. The fuel is not injected until the air inside the combustion chamber has been compressed and is extremely hot (around 1,000°F). Injection occurs a few degrees before the piston reaches top dead center on the compression stroke. The diesel fuel ignites the instant it hits the hot air. But because there is little time for the air and fuel to mix, diesel combustion is incomplete. As a result, diesels sometimes emit a lot of soot and other pollutants in their exhaust.

For cold starting, a diesel engine must be cranked fast enough to heat the air inside the cylinders to the point where it will ignite the fuel. A glow plug system is required on many engines to provide the initial starting heat. Lighter grade diesel fuel must also be used during cold weather to prevent waxing and clogging of fuel lines and injectors.

Propane has excellent cold-start properties, because it enters the engine as a vapor at temperatures as cold as -40°F. This eliminates the need for cold-starting aids and allows the fuel to mix readily with air for efficient and clean combustion.

1.14 Emissions

All internal combustion engines produce emissions, but some fuels produce less than others. The main regulated compounds in engine exhaust are hydrocarbons (HC's), carbon monoxide (CO), and various oxides of nitrogen (NOx). Some jurisdictions also regulate emissions of carbon dioxide (CO₂).

In addition to catalytic converters that treat exhaust, late-model passenger cars and most light- and medium-duty trucks have charcoal canisters that trap evaporative emissions from the gasoline fuel tank. These vapors are drawn into the engine and burned when the engine is started. Although the canisters absorb much of the fuel vapor, a saturated canister can still release raw HC's into the atmosphere. Studies indicate that HC's may account for as much as 20 percent of total emissions from a vehicle.

Propane fuel systems are sealed to maintain pressure and are therefore less likely to produce evaporative emissions. Even well-tuned propane-powered engines still produce some emissions, and electronic engine controls and exhaust catalysts are required to minimize engine emissions.

1.15 Engine Performance

Many engines perform better on propane than on gasoline. One reason is that propane mixes more readily with air. Propane's higher octane rating also allows the engine to use a more aggressive ignition timing curve at lower rpm and still resist detonation. On engines where timing is controlled by an on-board computer, some propane fuel systems use a modified OEM computer that has been reprogrammed with a new fuel and ignition timing map.

Another factor that contributes to increased performance is a denser air/fuel mixture entering the cylinders. Since propane is already vaporized when it enters the intake manifold, heating is not necessary or desirable. Lower intake temperatures promote a denser mixture for more power.

1.16 Engine Maintenance and Life

Clean combustion extends spark plug life, decreases valve train wear, and reduces wear on internal engine components, thus extending engine life and reducing maintenance costs.

When sludge and acid build up as a result of combustion blow-by, especially during engine warm-up, additives in the engine oil are rapidly used up. Bearings, rings, valve guides, cam lobes, and other friction surfaces wear more rapidly as the lubricant breaks down. Propane virtually eliminates the buildup of carbon, varnish and sludge inside the engine. Fewer contaminants in the crankcase means that oil change intervals may be safely extended.

Specially formulated oils are available with additive packages designed for propane-powered engines. Additives that are used in regular motor oils to disperse acids and varnish are not necessary in a propane-powered engine; in fact, they can form harmful deposits on the valves. Propane engine oils also contain additives that prevent the oil viscosity from changing or thickening when change intervals are extended.

Oils designed for propane service are not recommended for bifuel applications.

1.17 Propane Fuel Containers and Fuel Lines

Propane containers are designed and built to American Society of Mechanical Engineers (ASME) and U. S. Department of Transportation (DOT) standards for pressure vessels. ASME tanks and DOT cylinders are significantly stronger and more resistant to damage or punctures than conventional gasoline fuel tanks.

Most propane fuel containers used with mobile industrial equipment (e.g., forklifts, tugs, and mowers) use DOT cylinders, since they can be removed and quickly exchanged for full cylinders. These containers rarely exceed 33 pounds of propane each and may combine two containers on

one unit. A DOT cylinder has a minimum of a 240 psig working pressure with a 375 psig pressure relief valve.

Most propane fuel containers used for stationary equipment (e.g., irrigation engines, generators, CHP) are ASME containers and are not transported when fuel is present. These containers may range from 5 gallons to up to 1,000 gallons water capacity or larger, depending on the application. The tanks have either a 250 psig working pressure or a 312 psig working pressure, depending on the date of manufacture and the type of service. Tanks used for mobile applications (permanently mounted on mobile equipment manufactured after April 1, 2001) are rated for 312 psig, with a 312-psig pressure relief valve. Tanks used for stationary applications, which are installed on a permanent base and do not move, are rated for 250 psig with a 250-psig pressure relief valve.

Propane containers store propane under pressures similar to those in conventional automotive air-conditioning systems, truck air-brake systems or large truck tires. The containers are rated for more than 3½ times their maximum working pressure (960 psig burst pressure, or more).

Propane moves from the container to the engine through fuel lines that are rated for more than five times their maximum anticipated working pressure (350 psig working pressure, 1,750 psig burst pressure, or more).

1.18 Vapor Pressure

The vapor pressure of propane in a container varies with temperature, as shown in Figure 8. This relationship is propane's vapor pressure index (VPI).

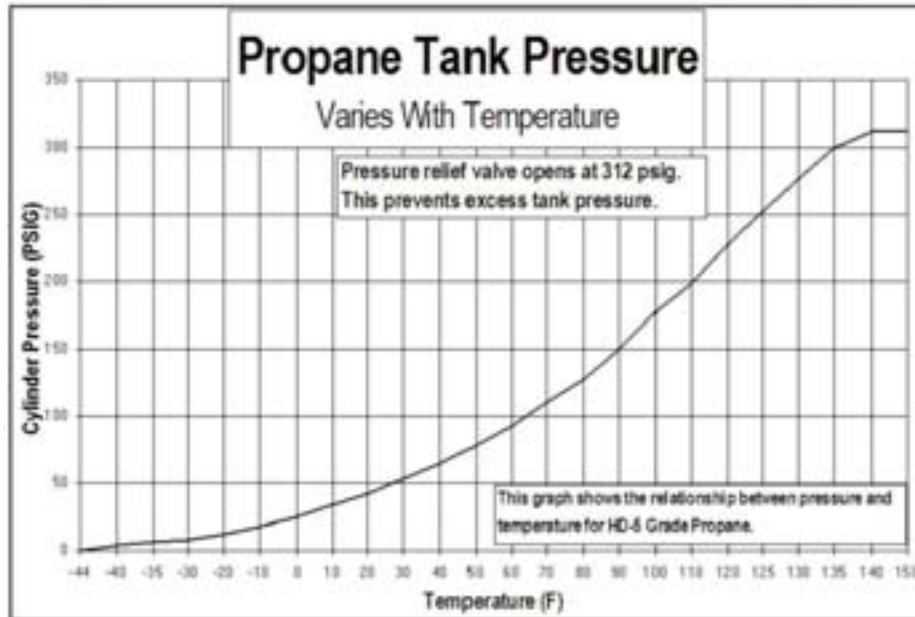


Figure 8. Vapor pressure of HD-5 propane

Pressure and temperature may be plotted on the chart above by measuring the pressure at the outlet of a propane container and the ambient temperature.

Assuming the ambient temperature is 70°F, place the point directly above the 70° mark at the curved line. At this reference point, draw a line directly to the left. We see a pressure of approximately 109-120 psig. This is the vapor pressure inside the tank. The pressure may vary depending on the fuel mixture, but typically less than 10 percent. If the variance is greater than 20 percent, the tank contents might be tested to identify which fuel is present in the greatest concentration.

Any point above and to the left of the curved line indicates propane in liquid form. Any point below and to the right of the curved line indicates propane in vapor form. The curved line indicates saturation or equilibrium. At any point along this line, if pressure is added or the temperature is reduced, propane vapor condenses to liquid. Similarly, if the pressure is reduced or the temperature is increased, propane liquid boils and becomes vapor.

The curved line describes the pressure needed to keep propane in liquid form. This is the pressure available to provide the necessary force to feed propane to the engine.

Table 1. Physical Properties of Propane

Chemical Formula	C_3H_8
Vapor Pressure at:	(in psig)
-44°F	0
-20°F	10.7
70°F	127
100°F	196
105°F	210
130°F	287
Specific gravity of liquid at 60°F	0.504
Initial boiling point at 14.7 psig in °F	-44°F
Weight per liquid gallon at 60°F	4.20 lbs
Specific heat of liquid (BTU/lb at 60°F)	0.63
Cu. ft. of vapor per liquid gallon at 60°F	36.38
Cu. ft. of vapor per pound at 60°F	8.66
Specific gravity of vapor (air = 1) at 60°F	1.5
Ignition temperature in air	920-1120°F
Maximum flame temperature in air	3,595°F
Limits of flammability in air, in % of gas to air	2.1% to 9.6% (lean and rich limits)
Ideal air-to-fuel ratio by volume	24:1
Ideal air-to-fuel ratio by weight	15.5:1
Latent heat of vaporization at boiling point	
BTU per pound	184
BTU per gallon	773
Total heating value after vaporization	
BTU per cubic foot	2,488
BTU per pound	21,548
BTU per gallon	91,502
Octane ratings	
Research	110
Motor	95
Pump	103

Review of Chapter 1

Directions: Select from the list below the response that most correctly completes each of the following statements. Write the letter of your choice in the space provided. Answers may be used more than once.

- | | |
|----------------|--------------|
| A. -44 | J. 10 |
| B. heavier | K. frostbite |
| C. colorless | L. 0.504 |
| D. 1 | M. 1.50 |
| E. 1 1/2% | N. lighter |
| F. 24 | O. 270 |
| G. 15.5 | P. 1/2 |
| H. natural gas | Q. 6 |
| I. NFPA 58 | R. 1.5 |

- ___ 1. Propane vapor is _____ than air.
- ___ 2. Propane liquid weighs _____ as much as water.
- ___ 3. Propane expands in volume _____ times when it boils and changes from liquid to vapor.
- ___ 4. The specific gravity of propane vapor is _____.
- ___ 5. The stoichiometry ratio for propane by weight is _____:1.
- ___ 6. Propane is produced by the processing of crude oil and/or _____.
- ___ 7. Propane liquid is _____ than water.
- ___ 8. The boiling point of propane liquid at normal atmospheric pressure is _____ degrees F.
- ___ 9. The ideal air-to-fuel ratio of propane by volume is _____:1.
- ___ 10. The specific gravity of propane liquid is _____.
- ___ 11. Liquid propane can cause _____ when it comes in contact with body tissue.
- ___ 12. Propane liquid expands approximately _____₁₂ percent for every _____₁₃ degrees F increase in temperature.
- ___ 13.

Answers: 1-B, 2-P, 3-O, 4-M, 5-G, 6-H, 7-N, 8-A, 9-F, 10-L, 11-K, 12-D, 13-Q



Chapter Two

Generators and CHP Systems

CHAPTER 2: GENERATORS AND CHP SYSTEMS

This chapter covers propane-fueled generators and combined heat and power (CHP) units. It describes how the units are rated, explains different cooling-system and control strategies, and identifies the basic operating principles of key fuel-system components.

2.1 Generators and CHP Systems

A generator provides power for continuous use or for standby or emergency use. When waste heat is recovered from the engine's cooling system or exhaust and used to heat water or provide comfort heating, the package is called a combined heat and power or CHP system. CHP packages for residential use may be called micro-CHP systems.

2.1.1 Markets

The two basic generator target markets are residential and commercial. Either application may incorporate a backup generator for emergency use during a power outage. The commercial consumer may use a backup generator rated at 75kW and above, while the residential consumer may rarely use a backup generator larger than 25kW, although residential backup generators are available up to 45 kW. Generators used as the sole source of power are called "prime power." These generators operate under varying load conditions, depending on the installation.

Propane generator manufacturers

- Briggs and Stratton
- Cummins-Onan
- Generac
- Honda
- Kawasaki
- Kohler

Propane CHP system manufacturers¹

- Honda
- Marathon
- Yanmar

¹ www.epa.gov/chp/partnership/partners.html



Figure 9. Marathon Ecopower residential CHP unit with a water buffer tank



Figure 10. Honda Freewatt residential CHP unit with a water-to-air heat exchanger and auxiliary high-efficiency furnace

2.1.2 Operating power ratings

Even though most engines are capable of operating at horsepower levels far in excess of that indicated by their rating, the reader should realize that these ratings are taken at either 1,800 or 3,600 rpm, the speed at which a generator (not the engine) operates most efficiently. This rpm is needed to output 120 or 240 volts AC at 60 cycles per second (60 Hz), where the engine operates in multiples of 60 rpm.

Most engines produce peak power between 2,800 and 4,500 rpm. Therefore, an engine operating at the 1,800 rpm required by the generator may be operating at less than peak power. Such an engine will not experience abnormal wear, even though it may be operating at peak power load at that rpm.

An engine operating in prime power may operate at lower power levels than an engine operating in standby or emergency mode. Smaller air-cooled engines may operate at 3,600 rpm to provide the necessary power levels. Modern electronic load-leveling rectifiers on generators can provide the necessary 60 Hz output regardless of engine rpm, allowing engines to operate closer to their peak efficient power/economical level.

Generators and CHP units operate at a steady engine rpm and load. Ideally, the engine will be rated for continuous operation at that load range. Two important factors to consider when comparing generator packages are rated kW and starting kW. Rated kW means the kilowatts provided at the rated load. Starting kW shows what the unit may experience during appliance startup. For example, an air conditioning system may require 10kW while in operational mode, but when the air conditioning compressor cycles on, the generator may experience a momentary 30 percent load increase. Once the compressor starts and the starting load stabilizes, the electrical load drops back to its normal level.

Generators operating in CHP mode recover engine exhaust and cooling system heat for consumer use. The waste heat may be used for water heating, space heating, or to drive a heat pump for air conditioning. A means to store the heat must be provided. Usually this storage is in the form of an insulated water storage tank, resembling a large conventional water heater. In other cases, the heat may be transferred directly to a conventional water heater storage tank or buffer.

2.1.3 Horsepower-kilowatt conversion

1 hp = 0.75 kW

1 kW = 1.34 hp

To convert kilowatt ratings to horsepower, multiply the kW rating of an engine by 1.3. To convert horsepower ratings to kW, multiply the horsepower rating by 0.75.

2.1.4 Generator de-rating

Most generator manufacturers rate their generator packages at sea level and 60°F. Many generator manufacturers also indicate that their units will perform at rated power levels up to about 3,000 feet above sea level, at ambient temperatures up to 104°F. Above 3,000 feet, engines lose approximately 3 to 4 percent power per 1,000 feet, and 1 to 2.5 percent power per each 10°F increase above 104°F.

2.2 Engine Types, Sizes and Manufacturers

2.2.1 Liquid-cooled engines

Up to 20kW, generator manufacturers typically use an air-cooled engine up to about 950 to 1,000 cc (one liter) displacement. Generators bigger than 20kW typically use liquid-cooled engines. Heavy-duty engines traditionally use liquid cooling for enhanced durability.

In the U.S., the most frequently used spark-ignited industrial engines are the General Motors (Chevrolet) 3.0L inline 4, 4.3L V-6, and 5.7L and 8.1L V-8s, and the Ford 4.9L inline 6 and 6.8L V-10. Most generator package upfitters use these engines in various configurations.

Some of these engines, or variants of these engines, have been used continuously since the 1960's. For example, the GM 350, 454, Ford 390 and 460, Chrysler 318, 361, 392 and 440 cid were popular engines that were essentially re-purposed automotive applications. These engines were often obtained from wrecked or salvaged vehicles and placed in service with a minimal amount of freshening.

Liquid-cooled engines have regular maintenance requirements based on hours of operation, or if not in prime power mode, on a seasonal schedule. Many of these engines have large capacity oil reservoirs and extra capacity oil and air filters to allow for an extended service interval.

2.2.2 Air-cooled engines

Engines operating in standby or light duty residential use may use air cooling. These engines are less expensive to build and buy and require less maintenance, often consisting of an annual oil and filter change and replacement of the spark plug and wire. Standby generators that are not routinely operated (monthly or quarterly), should have the engine oil changed annually regardless of the operating hours.

Briggs and Stratton, Honda, Kawasaki, Kohler, and Onan represent the largest portion of the air-cooled market with engine displacements ranging from 550cc to approximately 990cc.

2.3 Fuel Storage and Supply

Standby and emergency generators typically use residential-type propane fuel tanks. Most of these applications run on propane vapor served from the top of the tank; however, some applications run on propane liquid served from the bottom of the tank. No rules require vapor or liquid service. The decision on which phase to use is up to the installer or engine manufacturer.

Some standby generator providers specify vapor service. Vapor service allows an emergency or standby generator to start and reach full power immediately, without waiting for a remote vaporizer to reach operating temperature. This prevents partially vaporized fuel from entering the engine.

2.4 Fuel Consumption

20kW, 30kW, 45kW, and 75kW generator packages are commonly used in residential and commercial applications for standby or backup power.² These packages may be used as prime power for short periods, but are not rated for continuous long-term use.

Table 2. Estimated Fuel Consumption

Continuous load	20kW	30kW	45kW	75kW
Starting load	25kW	38kW	55kW	95kW
Engine	995cc air-cooled	3.0L inline 4	5.0L V8	5.7L V8 (turbo)
Operating RPM	3600	1800		
Fuel consumption at 1/2 load ³	70 cubic ft/hr 2.0 gallons/hr	90 cubic ft/hr 2.5 gallons/hr	180 cubic ft/hr 5.0 gallons/hr	320 cubic ft/hr 9.0 gallons/hr
Fuel consumption at full load ⁴	90 cubic ft/hr 2.5 gallons/hr	120 cubic ft/hr 3.5 gallons/hr	230 cubic ft/hr 6.5 gallons/hr	415 cubic ft/hr 12.0 gallons/hr

² Home-use generators under 20kW are not included in this evaluation.

³ 1 gallon of propane liquid at 60°F = 35 cubic feet of propane vapor.

⁴ Fuel consumption at half and full load is based on an average of units in the same kW range. These values should be used for comparison purposes only.

2.5 Transfer Switch

A transfer switch is used to disconnect the customer's load from the main electrical grid and then connect the standby or backup generator. If a power outage is detected, a generator may automatically start to provide power. If the generator is not disconnected from the power grid, the generator will back-feed the utility grid and may be hazardous to anyone attempting to perform repairs.

Figure 11 shows two common transfer-switch panels.



Figure 11. Automatic transfer switches

If the generator is connected to a building load and grid power is subsequently restored, the generator may be permanently destroyed by the back-feed. The back-feed may also overload the building's wiring and cause an electrical overload, resulting in a fire.



WARNING

A propane generator should be installed only by a person who is licensed to perform electrical system connections to the building and to install the necessary safety transfer switches. Some generator installations may require additional local permitting and may need to comply with local noise ordinances.

2.6 Carburetion

Air-cooled engines use carbureted fuel systems similar to those on lawn-maintenance equipment. Liquid-cooled engines use systems similar to those on forklifts or older over-the-road motor vehicles.

Figure 12 illustrates the venturi carburetion principle used by most small-engine manufacturers. In these systems, the mixer body includes a venturi—a tube whose throat narrows and then widens out again. As air moves through the narrowing throat, its velocity increases and its pressure decreases.⁴ Gas delivery ports are located at the narrow part of the tube, where the pressure drop draws propane vapor into the air stream. The amount of fuel supplied is proportional to the volume of air passing through the venturi, resulting in a balanced air-to-fuel ratio.

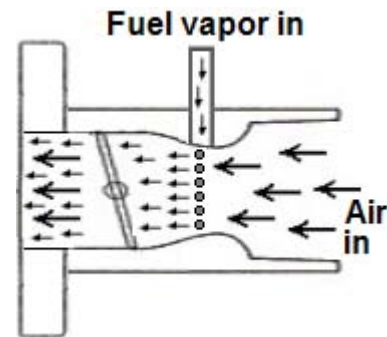


Figure 12. Venturi carburetor/mixer

A venturi mixer has no moving parts and requires no maintenance. Idle or low speed fuel-mixture adjustments are provided at the vaporizer/regulator. A “load block” (also called a max gas valve, power valve, or a load adjuster) mounted in the main vapor fuel line limits the maximum amount of fuel at full engine load.

NOTE: Generators rarely operate at idle mode. Idle fuel mixture adjustments may not be provided.

2.6.1 Air-cooled engines

Air-cooled engines may accept either liquid or vapor from the fuel tank or cylinder. If fuel is provided in vapor form, the vaporization occurs inside the fuel container and all that is required is a single pressure regulator at the engine, or two regulators, one at the container, the other at the engine. If the fuel is supplied from the tank to the engine in liquid form, vaporization must occur at the engine with an air-to-air heated vaporizer. This unit may be either a combined air-to-air vaporizer and a dual-stage pressure regulator, or two separate components.

2.6.2 Liquid-cooled engines

Liquid-cooled engines may run on either propane vapor or propane liquid. Fuel is introduced into the engine as vapor in either case.

If fuel is provided as a vapor, the vaporization occurs inside the fuel container, and all that is required is a single pressure regulator at the engine, or two regulators, one at the container, the other at the engine. If the fuel is supplied as liquid, the vaporization must occur at the engine using a vaporizer heated by engine coolant. This unit may be a combined liquid-heated vaporizer and a dual-stage pressure regulator.

4 See “Bernoulli’s Principle,” <http://goo.gl/4DZuj>

2.7 Unique Components Required for Small Engines

- Pressure regulator (may be combined with a vaporizer)
- Venturi mixer body

2.7.1 Regulators and vaporizers

2.7.1.1 High-pressure regulators used in vapor-withdrawal applications

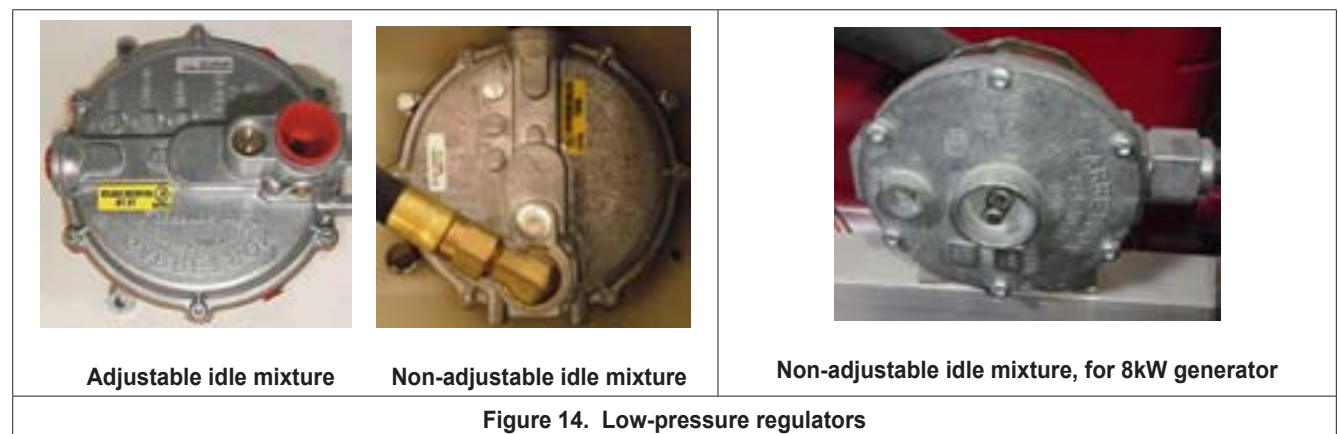
Figure 13 shows the first-stage or primary-stage pressure regulator used in vapor service. First-stage regulators are located at the fuel tank where pressure is reduced from tank pressure to approximately 10 psig.



NOTE: The secondary regulators shown below rely on a reduced inlet pressure of approximately household appliance pressure, or 10-14 inches water column (about 0.5 psi).

2.7.1.2 Low-pressure regulators used in vapor-withdrawal applications

A low-pressure regulator reduces pressure from the outlet pressure of the primary regulator to atmospheric pressure (Figure 14). This component may also be called a “zero pressure governor.” No fuel flows unless there is a vacuum draw from a venturi carburetor/mixer.



Maximum gas flow is controlled by a load block, also called a “power valve” or “max gas adjustment.”



Figure 15. Secondary regulator with max gas adjustment or load block

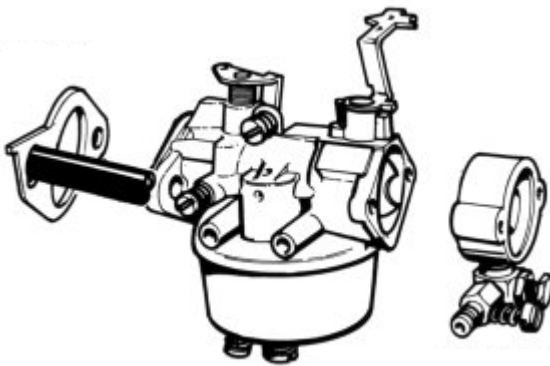


Figure 16. Original gasoline carburetor with an adapter as the venturi mixer

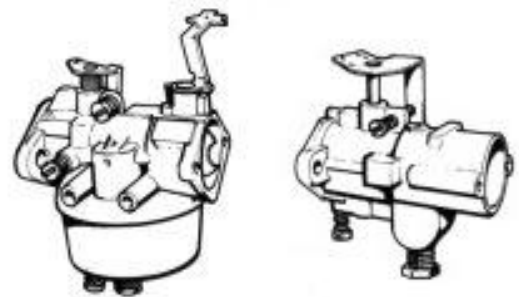


Figure 17. Gasoline carburetor replaced by a purpose-built gaseous fuel carburetor



Figure 18. Venturi mixer/air cleaner base installed above the gasoline carburetor. Either fuel may be used, but not both at the same time.

These designs are commonly used on air-cooled engines.

2.8 Large Generators

Engines approximately 10 kW and larger may use a mechanical mixer with moving internal components, frequently called an air-valve mixer. The mechanical mixer uses the air valve to generate the pressure differential (vacuum) needed to draw fuel from the regulator into the mixer assembly.

Figure 19 shows a liquid fuel system installed on a GM 5.7L engine powering a 40 kW generator. This fuel system has electronic fuel-mixture controls to comply with EPA emissions requirements.



Figure 19. Liquid fuel system with electronic controls

2.8.1 Unique components required

- Pressure regulator, usually combined with a vaporizer if the engine is liquid cooled or if the fuel is drawn from the storage tank in vapor form
- Mixer assembly

2.8.1.1 Regulators and vaporizers

Larger generator packages require larger pressure regulators and/or vaporizers.



Figure 20. First- or primary-stage pressure regulator used in vapor service

This component is located at the fuel tank where pressure is reduced from tank pressure to approximately 10 psig.



Figure 21. Second-stage pressure regulator used in vapor service.

This component is located at the engine where pressure is reduced from the first-stage or primary pressure regulator to approximately 14 inches water column.



Figure 22. Pilot pressure regulator used in vapor withdrawal systems

The pilot pressure regulator shown in Figure 22 is installed between the final pressure regulator and the mixer. This regulator is typically installed with the adjustment screw facing downwards. This regulator reduces the pressure from the outlet pressure of the second-stage regulator to -1 inch water column, i.e., no fuel flows unless there is a vacuum draw of at least 1" water column.



Figure 23. Combined liquid fuel vaporizer and two-stage pressure regulator used in liquid withdrawal systems

The pressure regulator/vaporizer combination shown in Figure 23 is located at the engine and incorporates first- and second-stage pressure regulators. No fuel flows unless there is a vacuum draw of approximately 1" water column. This device circulates engine coolant to assist in the full vaporization of the fuel.

2.8.1.2 Mixers

The mechanical mixers shown below use a simple vaporizer. All fuel mixture adjustments are performed at the mixer/carburetor.



Figure 24. Series 55 mixer

This mixer is most commonly used on liquid-cooled engines up to 3.0L, but may be used on larger displacement air-cooled engines.



Figure 25. Series 200 mixer

This mixer is most commonly used on liquid-cooled engines of 4.0L to 5.7L displacement, and may be used on larger engines if turbocharged. The Series 225 is similar.



Figure 26. Series 425 mixer

This mixer is most commonly used on liquid-cooled engines 5.7L and larger.

2.8.3 Fuel injection

Electronically managed mechanical fuel systems are approaching their technological limit. To overcome this barrier, generator manufacturers may adopt automotive fuel-injection technology, which is in widespread use worldwide.

Fuel injection provides improved cylinder-by-cylinder fuel distribution, which improves fuel economy and reduces emissions. The amount of improvement depends on the engine design and operating conditions. These improvements come at a cost, due to the addition of on-road-type components that make the systems more complex.

2.8.3.1 Fuel injection theory of operation

Propane vapor fuel injection systems use one of two basic control strategies:

- Speed Density
- MAF (Mass Air Flow)

Speed density

The speed density control strategy uses engine displacement, engine rpm, and manifold vacuum to calculate the necessary computer inputs. A decrease in engine vacuum signifies an increase in engine load and a corresponding increase in air flow and fuel demand. The original computer program will adjust for these inputs. For additional fuel control, an automotive-type oxygen sensor will be mounted in the exhaust system, and an exhaust catalyst will be installed for further emissions control.

Mass Air Flow

The MAF control strategy uses a heated wire placed in the incoming air flow. Air moving past the heated wire changes its temperature and its corresponding resistance. This change can be directly correlated to the amount (i.e., mass) of air moving through the system. Other factors, including the engine's displacement and rpm are also used, along with individual cylinder sequencing. MAF technology mimics the sequential fuel-injection systems found on late-model highway vehicles.

Fuel is delivered from containers that store fuel under pressure. Container pressure is directly related to ambient temperature (see Table 1). Pressure regulators reduce container pressure in two stages, down to the final 10 to 25 psig required by the fuel-injection system.

Fuel injectors are mounted either directly above the intake valve (sequential injection) or in a dedicated adapter near the original propane mixer-carburetor. Since fuel is metered at the injector, the vaporizer or pressure regulator is a simple device that delivers fuel at the pressure required by the system.



Figure 27. Vapor phase fuel injectors mounted on a General Motors 6.0 engine

A computer analyzes inputs from the engine sensors and calculates the proper fuel mixture based on engine load, engine and/or ambient temperatures, and engine rpm. Based on these inputs, the computer adjusts the amount of fuel the injector delivers.

Fuel may be delivered to the engine as liquid, in which case an engine-mounted vaporizer/regulator must be used. Fuel delivered as vapor is kept at a consistent pressure by a pressure regulator.

2.8.3.2 Fuel injection for small engines

Although not yet used in production by U.S. small-engine manufacturers, propane fuel injection is being researched and field-tested.⁵ Small engine fuel injection principles would be similar to the method described in section 3.4 of this manual.

2.8.3.3 Fuel injection for large engines

Fuel injection for large engines would be similar to the fuel injection systems used on over-the-road motor vehicles.

2.8.4 Unique components required

- Pressure regulator (may be combined with a vaporizer)
- Fuel injectors
- Control module and related wiring

6 At the time of this publication, no OEM-provided propane fuel-injected conversion systems were available for small engines.

2.8.5 Advantages of fuel injection

Fuel injection allows an engine to maintain its peak tune under all operating conditions, regardless of temperature or engine condition. Fuel injection also offers reduced emissions as well as better fuel economy and possible increased engine life.

2.8.6 Limitations of fuel injection

Large engines operating in generator mode run at a fixed engine rpm, but the load may vary. Since the engine does not experience the same transient rpm changes as an over-the-road vehicle, a sophisticated fuel-injection system may not deliver its full benefits of reduced emissions and improved drivability. Fuel injection adds a level of complexity that many field service personnel may find unnecessary.

2.9 Emission Controls

Off-road applications require emission certification. See Appendix D.

2.10 CHP Load

Engines operating in combined heat and power mode experience no significant load changes due to the addition of a heat exchanger. The amount of heat recovered from the engine depends on several factors:

- Ambient temperature
- Load temperature (the temperature of the building)
- Engine load in kW
- Engine efficiency
- Engine packaging
- Heat recovery mode (cooling system, cooling system + exhaust heat recovery)



Chapter Three

Mowers



CHAPTER 3: MOWERS

This chapter covers propane-fueled commercial mowers and related groundskeeping equipment. It lists current manufacturers and models and explains different control strategies. Additional information about the requirements for storing fuel cylinders is included in Appendix C.

3.1 Engine and Equipment Manufacturers

The following lawn equipment manufacturers offer propane-powered EPA- and/or CARB-certified applications in 8 to 37 bhp¹ levels.^{2,3} Emission certification requirements are outlined in Appendix D.

Manufacturer	Model or Series	Engine
Ariens-Gravely	Pro-Master 260H XDZ LPG	Generac 28 hp
Bob-Cat	Predator Pro LP	Generac 30 hp
Cub Cadet	Tank S 6031 LP	Kawasaki 852cc
	Tank S 7237 LP	Kawasaki 999cc
	Z-Force S 48 LP	Kawasaki 726cc
	Z-Force S 60 LP	Kohler 26hp V-Twin (Courage)
Dixie Chopper	3066 LP	Generac 990cc
	3074 LP	Generac 990cc
Envirogard	50-60" Mid Cut	Kawasaki 28 hp
	54-64" Front Cut	Kawasaki 31 hp
eXmark	Lazer Z X-Series	Kawasaki FX 801 V
	Lazer Z S-Series	Kawasaki FX 801 V
	Turf Tracer X-Series	Kawasaki FX 691 V
	Turf Tracer S-Series	Kawasaki FX 600 V
Ferris Industries	IS3100ZP	Briggs & Stratton 895cc
Husqvarna	PZ6029PFX	Kawasaki 29 hp
Kawasaki	(By Zipper)	Kawasaki 31 hp
Kohler	Command Pro CH 20	624cc
	Command Pro CH 25	725cc
Kubota	ZP330P	Kubota 31 hp
LEHR	Various products, including string trimmer, walk-behind and utility lawn equipment	LEAR branded engines
SCAG	Turf Tiger LP	Kohler CH370
	Turf Tiger Dual Fuel	Kubota (31 hp on gas, 28 hp on propane)

- 1 Equipment manufacturers provide engine and power ratings in different formats. Most engine manufacturers rate their engines in pound-feet of torque (lb.-ft.) instead of horsepower.
- 2 Information provided was accurate at the time of publication.
- 3 Propane Education and Research Council, <http://goo.gl/eUQRo>; Texas Propane Gas Association, <http://goo.gl/IiqXA>.

Manufacturer	Model or Series	Engine
Snapper Pro	S200xtp	Briggs and Stratton 895cc
Toro	Professional 6000	Kawasaki 852cc
Zipper	STS-28 LP	Kubota 28 hp
	VR-31-50 LP	Kawasaki 852cc
	VR 31-60 LP	Kawasaki 852cc

Engines may be rated as per SAE J1940,⁴ which is a standardized power test that will promote uniform testing and power and torque ratings of small engines.

3.1.1 Fuel storage and delivery

Fuel is stored onboard the implement in containers designed, tested, fabricated, and marked by the U. S. Department of Transportation (DOT). These containers are rated for a minimum of 240 psig and are provided with a pressure relief valve set at 375 psig. The cylinders and retaining brackets are designed to be removed quickly for refilling or exchange. Additional cylinders may be provided for a quick return to service.

Some lawn equipment products have two cylinders mounted on the implement to permit extended hours of service.



Figure 28. Universal cylinder installation

Two types of DOT cylinders are used in lawn care equipment. Some are similar to 20- or 30-pound barbecue or RV cylinders, which must be removed from the implement and filled by weight. Others resemble forklift cylinders and are called “universal” cylinders. Universal cylinders may be installed on the chassis either horizontally or vertically and may be filled on or off the implement. They may be filled by volume or by weight.

3.1.2 Vapor or liquid service?

Propane is delivered from a container either as vapor or as liquid.

⁴ The SAE standard that outlines the power testing measurements of the engines is outlined at <http://standards.sae.org/wip/j1940>.

Vapor and liquid outlets have different ACME 1-1/4" threads to connect the withdrawal hose. Outlets for withdrawing vapor have left-hand threads. Outlets for withdrawing liquid have right-hand threads. This system keeps a vapor withdrawal hose from being connected to a liquid outlet.

A container may have two outlets, as shown here. The red arrow shows the vapor outlet, and the yellow arrow shows the liquid outlet.



Figure 29. Dual fuel outlets

Vapor fuel delivery uses a specially designed container that has the fuel withdrawal tube mounted in the vapor space, i.e., the upper part of the container. These containers typically have a green stripe on the neck ring to identify them as a vapor withdrawal container. In addition, the fuel outlet is located on the opposite side from the outlet of a liquid withdrawal container.

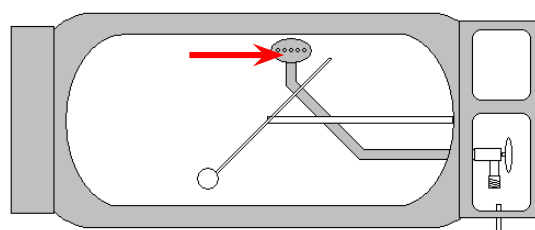


Figure 30. Vapor withdrawal tube and isolator
In vapor service, an isolating device is used to separate the fuel phases and keep liquid fuel from being fed to a vapor pressure regulator.

Liquid fuel delivery uses a conventional DOT universal forklift-style fuel container with the fuel withdrawal tube mounted in the liquid space, i.e., in the lower part of the container.



Figure 31. Liquid withdrawal tube

Where more than one cylinder is installed in a liquid-service system, NFPA 58 requires the cylinders to be isolated from one another.⁵ Isolation is accomplished by a spring-loaded check valve called a “check tee” that keeps liquid fuel from flowing between cylinders and creating an overfilled condition. Liquid-service systems also require a hydrostatic pressure relief valve, which is usually incorporated into the check tee device as shown in Figure 32.⁶

A check tee is not required in vapor-service systems.



Figure 32. “Check tee”

5 NFPA 58, 2008 ed., §11.9.1.8; NFPA 58, 2011 ed., §11.10.1.8

6 NFPA 58, 2008 ed., §11.9.2 ; NFPA 58, 2011 ed., §11.10.2

3.1.3 Vapor carburetion and vapor fuel injection systems

Propane fuel is metered to the engine by either of two methods:

- Carburetion, using a venturi to draw the correct amount of fuel based on the amount of air moving through a venturi, or
- Fuel injection, based on “speed density” calculations.

When a carburetion system is used, fuel pressure is reduced to near atmospheric pressure.

3.2 Regulator/Vaporizer

Propane’s low boiling point (-44°F) means that liquid fuel “auto-refrigerates” as its pressure is reduced, unless supplemental heat is provided. The supplemental heat may be provided by the mass of the fuel storage container (vapor supply) or by a vaporizer mounted on the implement (liquid supply). The vaporizer may be incorporated into the regulator or may be a separate component. If the engine is air-cooled, the vaporizer may use the ambient air flow created by the engine to provide supplemental heat to aid in vaporization. If the engine is liquid-cooled, the vaporizer may use engine coolant to provide the necessary heat.

During vaporization, remnants of the refining process—heavier hydrocarbon deposits resembling oils or light grease—may remain behind inside the vaporizer or regulator. These deposits should be cleaned or removed from the vaporizer or regulator as required or on the schedule recommended by the manufacturer. See Chapter 7 for additional maintenance information.



Figure 33. Air-heated vaporizer, not combined with the pressure regulator

This device is installed upstream of the vaporizer/regulator in a liquid-withdrawal fuel system. The unit absorbs heat from the surrounding air, which aids in the vaporization of the fuel.



Figure 34. Beam T-50-60 vaporizer/regulator

This component may be used as a two-stage pressure regulator, but when engine coolant or hydrostatic drive fluid is routed through the two inlets at the bottom, it becomes a vaporizer.



Figure 35. Century G-85-A air-heated vaporizer/regulator

This unit is used only with mechanical mixers in liquid-withdrawal systems. Like the unit shown in Figure 33, it absorbs heat from the surrounding air to aid in the vaporization of the fuel.



Figure 36. IMPCO Cobra combination vaporizer/regulator

This unit, similar to the IMPCO Model J series, is used with liquid-cooled engines. Engine coolant or hydrostatic drive fluid may be routed through the vaporizer to provide supplemental heat.

3.3 Carburetion (Mixer)

Figure 37 illustrates the venturi carburetion principle used by most small-engine manufacturers. In these systems, the mixer body includes a venturi—a tube whose throat narrows and then widens out again. As air moves through the narrowing throat, its velocity increases and its pressure decreases.⁷ Gas delivery ports are located at the narrow part of the tube, where the pressure drop draws propane vapor into the air stream. The amount of fuel supplied is proportional to the volume of air passing through the venturi, resulting in a balanced air-to-fuel ratio.

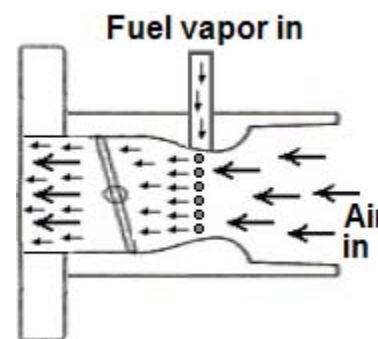


Figure 37. Venturi carburetor/mixer

A venturi mixer has no moving parts and requires no maintenance. Idle or low speed fuel mixture adjustments are provided at the vaporizer/regulator. A “load block” (also called a max gas valve, power valve, or a load adjuster) mounted in the main vapor fuel line limits the maximum amount of fuel at full engine load.



Figure 38. Dual-bore mixer for a V-twin engine



Figure 39. Single-bore mixer for a single-cylinder engine

⁷ See “Bernoulli’s Principle,” <http://goo.gl/4DZuj>



Figure 40. Mixer for Kubota 3-cylinder engine



Figure 41. Venturi mixer body installed between the air-cleaner inlet and an existing carburetor

Once the final fuel mixture is set, or if the fuel system has an emission certification, the idle speed adjustments and fuel mixture adjustments are locked or sealed to prevent tampering.

3.3.1 Advantages of venturi carburetion

A venturi mixer is relatively inexpensive to manufacture and simple to install. Since there are no moving parts in the mixer body, maintenance is practically nonexistent. The vaporizer/regulator must be cleaned periodically to remove any petroleum by-products.

3.3.2 Limitations of venturi carburetion

A venturi fuel system lacks the ability to retain long-term fuel-mixture settings. These systems are also affected by the air filter. An air filter that clogs and restricts air flow results in a richer air-fuel mixture.

3.4 Fuel Injection

Although not yet used in production by U.S. small-engine manufacturers, fuel injection is being researched and field-tested.⁸

Propane vapor fuel injection uses the “speed density” method of metering fuel. This method uses a calculation of engine displacement, engine rpm, and manifold vacuum to generate the necessary computer inputs. A decrease in engine vacuum signifies an increase in engine load and a corresponding increase in air flow and fuel demand. The original computer program will adjust for these inputs. For additional fuel control, an automotive-type oxygen sensor will be mounted in the exhaust system. Some applications may also install an exhaust catalyst.

The pressure of vapor in a container is directly related to ambient temperature (see Table 1). A pressure regulator reduces container pressure to the final pressure (10 to 25 psig) required by the fuel injection system.

⁸ At the time of this publication, no OEM or aftermarket propane fuel-injected systems were commercially available for small engines.

The fuel injectors are mounted either directly above the intake valve or in a dedicated fuel injector adapter near the carburetor. Since fuel metering is performed at the injector, the vaporizer or pressure regulator is a simple regulator that delivers fuel at the pressure required for the fuel system.

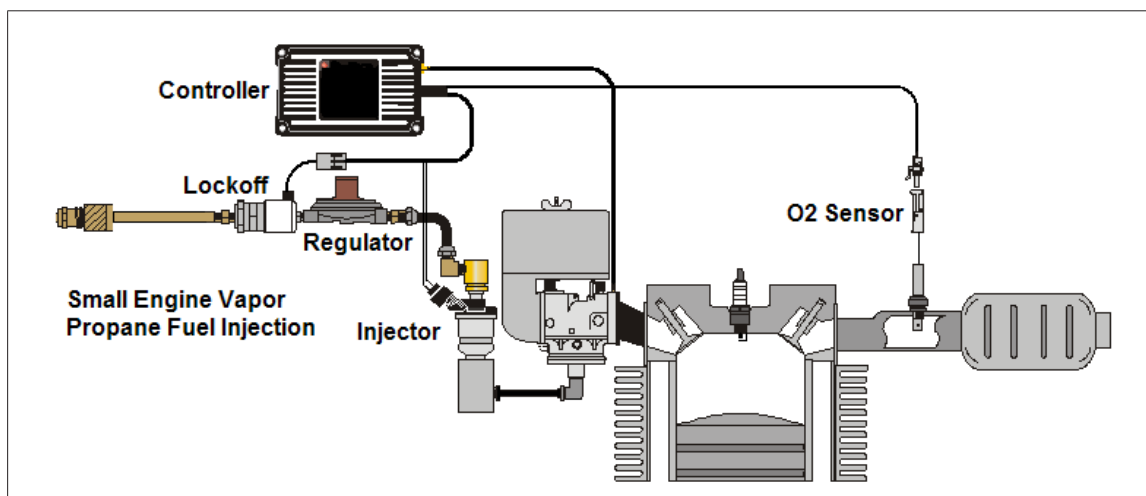


Figure 42. Small-engine fuel injection system⁹

3.4.1 Advantages of fuel injection

A main advantage of fuel injection is that it maintains an ideal air-fuel ratio, which results in better engine operation, reduced emissions, better fuel economy, easier starting and possible increased engine life, since the engine stays in its optimum tune.

3.4.2 Limitations of fuel injection

Fuel injection for small engines has not yet been used in production. Initial costs may be higher than the basic mixer-regulator design.

3.4.3 Unique components required

- Pressure regulator (may be combined with a vaporizer)
- Fuel injectors
- Control module and related wiring
- Sensors

3.5 Fuel Cylinder Storage

See Appendix C for information on storing propane fuel cylinders.

⁹ Author's rendering of a small-engine fuel injection system, assembled from a prototype system developed by DualCurve.



Chapter Four

Irrigation Engines



CHAPTER 4: IRRIGATION ENGINES

This chapter covers propane-fueled stationary irrigation engines and fuel-system technologies. Additional information on these engines is available in Propane Education and Research Council publication PRC 003900, *Maintaining and Repairing Propane Fuel Systems on Stationary Engines* (2008).

4.0 Equipment Manufacturers, Models and Specifications

Since 2008, manufacturers of all non-road stationary engines have been subject to U. S. Environmental Protection Agency (EPA) emissions standards. Aftermarket options are limited when selecting industrial or irrigation engines.

Several upfitters supply generator and irrigation engine packages. Upfitters receive base engines from Ford's and General Motors' industrial engine divisions¹ for final assembly and service optimization. Other engine suppliers may enhance or upgrade an existing engine design for propane operation.

Irrigation engine packagers or manufacturers with significant market share are:

- Buck's Engines, offering GM 3.0L - 8.0L engines
- Don Hardy Engines, offering GM 3.0L - 8.0L engines
- Industrial Irrigation, offering GM 2.4L – 8.1L engines
- PowerTech Engines, offering Ford 2.5L – 6.8L engines
- TGP-West, offering GM 8.0L and Cummins 14L engines

4.1 Emission Regulations for Stationary Industrial Engines

The same EPA exhaust and evaporative emissions standards apply to engines used for irrigation or power generation. See Appendix D.

4.1.1 Blue Sky engines

Blue Sky engines meet more stringent emission standards than the EPA's mandatory standards, usually by at least 40 percent. Meeting this voluntary standard earns manufacturers a "Blue Sky Series" designation for these engines. Manufacturers who choose to get this certification agree to keep these engines at Blue Sky levels throughout their useful life. There are Blue Sky standards for land-based non-road spark-ignition engines over 25 hp (see 40 CFR part 1048).²

¹ For additional information on GM industrial engines see <http://goo.gl/aDYBy>

² For additional information on BlueSky engines see <http://goo.gl/zKLqm> and <http://goo.gl/oHqos>

4.2 Vapor Carburetion and Vapor-Injection Fuel Systems

Most off-road power generation and irrigation engines use carburetors or mixers that are similar to those used on older on-road engines. Although widely used in current-generation automotive applications, vapor fuel injection has not yet migrated to the industrial and agricultural engine market, mainly due to the additional cost and complexity. Most engines used in industrial or agricultural modes operate at a steady rpm and load condition and are not subject to the varying speeds and loads of on-road application. A carbureted industrial engine can be tuned to operate relatively efficiently with minimal electronic fuel mixture controls.

Fuel injection allows for better control of exhaust emissions. The steady engine rpm and power load levels seen in agricultural irrigation engines minimize the prime advantage of fuel injection, which is its ability to adapt quickly to changing engine operating conditions. For this reason, fuel injection may not be as practical in these applications.

4.2.1 Fuel-system technologies

Propane may be introduced into an engine by any of three basic methods of carburetion:

- Venturi
- Mechanical air-valve
- Fixed venturi with electronic controls

The venturi method works well in engines that operate in a steady mode. This basic technology has not been used for many years, mainly due to increasing emission controls. The venturi system cannot retain tight air-fuel mixture trim for long periods, mostly due to air-filter restrictions that affect the air-fuel ratio. The venturi mixer is an upsized design, similar to mixers used in commercial mower applications.

Ensign and Marvel-Shebler carburetion systems may be seen on stationary engines dating back to the 1950s. Although functional, they cannot match the efficiency and performance of today's applications.

Mechanical air-valve systems have been used successfully since the 1950s. Most current EPA and California ARB-certified fuel systems use an air-valve mixer with electronic controls.

The installation shown in Figure 43 uses an engine-mounted vaporizer and electronic air-fuel mixture controls to comply with emissions standards.



Figure 43. Mechanical air valve

The fixed venturi with electronic controls manages the air-fuel ratio by adjusting the pressure to allow for lean-burn or rich-burn combustion.

This fuel system shown in Figure 44 requires a vapor fuel supply at approximately +10" water column.



Figure 44. Continental Controls fixed venturi with electronic controls

4.3 Fuel Storage and Supply

Propane fuel may be supplied to an irrigation engine either as vapor or as liquid.

4.3.1 Vapor withdrawal

A vapor fuel system draws propane vapor directly from the storage container, eliminating the need for a separate vaporizer mounted at the engine. A primary or first-stage regulator mounted on or near the storage tank reduces tank pressure to the pressure required by the engine fuel system manufacturer or emission certification, typically about 10 psig.



Figure 45. Vapor service tank with first-stage regulator

Fuel is then transferred from the first-stage or primary regulator to a second-stage regulator that reduces its pressure to approximately 10" water column. An electric or mechanical lockoff valve may be used to isolate the fuel supply from the engine to allow service to be performed. A final pressure-reducing valve is used to provide fuel at the carburetor/mixer inlet at -1" water column, i.e., a vacuum.³

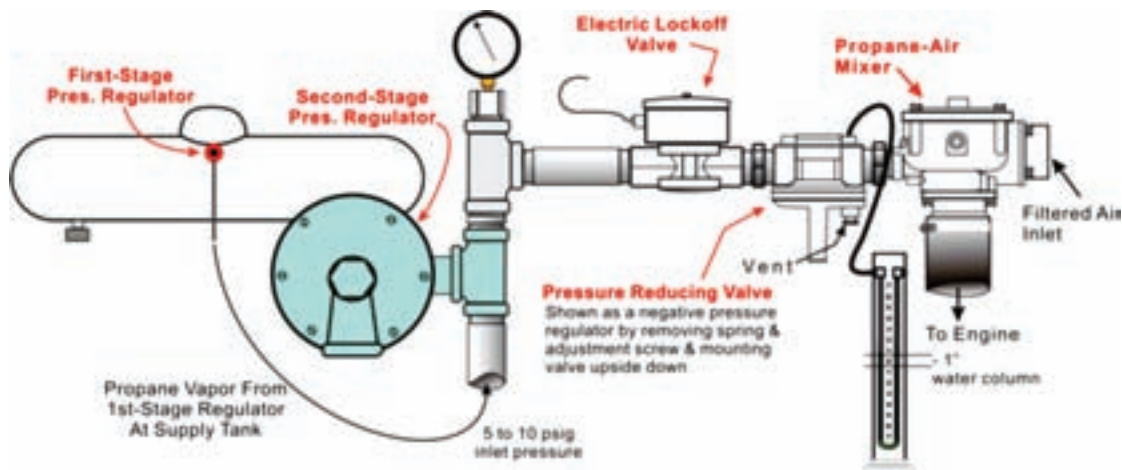


Figure 46. Vapor-supplied fuel system, with regulators

3 The term "pressure" is relative to atmospheric pressure. Any pressure above atmospheric pressure is shown as a positive pressure, either in inches of water column or pounds per square inch. Any pressure less than atmospheric pressure is shown as a vacuum or negative pressure, usually in inches of water column.

4.3.2 Liquid withdrawal

In a liquid fuel system, propane is withdrawn from the tank as a liquid and vaporized at the engine. A conventional fuel tank with a liquid withdrawal setup is used. The process is similar to systems used in earlier on-road engines and forklifts.

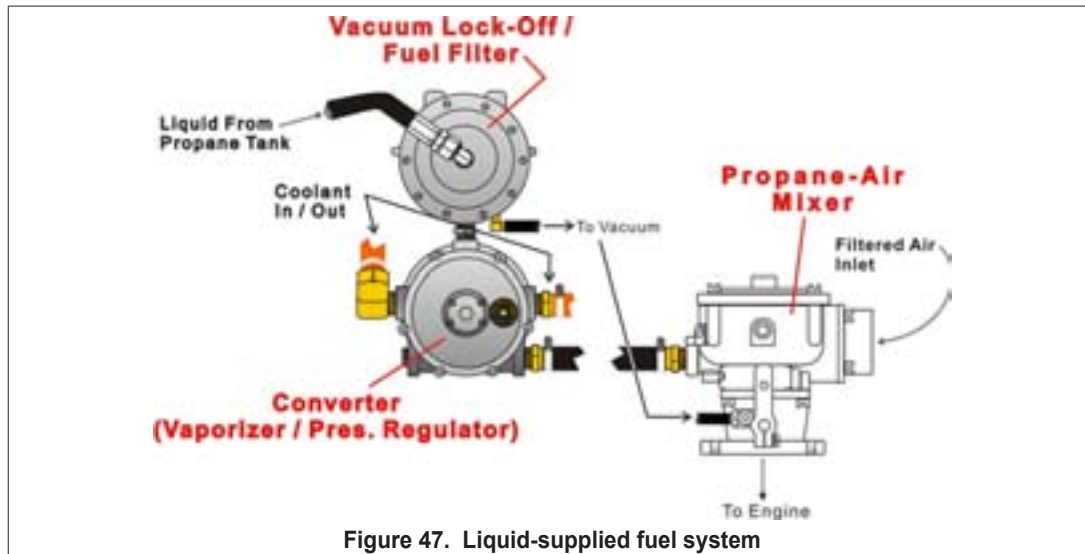


Figure 47. Liquid-supplied fuel system



Chapter Five

Forklifts



CHAPTER 5: FORKLIFTS

This chapter covers propane-fueled forklifts. It lists manufacturers and models, provides critical health and safety information related to indoor forklift operation, and describes fuel-system technologies and troubleshooting procedures commonly encountered in pre-2004 models. Additional information about storing fuel cylinders is included in Appendix C.

5.0 Forklifts

Industrial lift trucks (forklifts) may use an engine from one source and a fuel system from another. Single-point throttle-body fuel injection is common, as is multi-port fuel injection. Electrically driven mechanical mixers are in widespread use, as is a more advanced mixer design utilizing fuel-pressure control strategies.

Indoor air quality is the prime driving force for advancing the technology in forklifts today, with all manufacturers providing EPA- and California ARB-certified engine and fuel system packages.

Manufacturer	Engine type	Fuel system manufacturer
Clark	Hyundai 52-70 bhp inline 4 cyl; GM 4.3 V-6	Westport FI; E-Controls
Doosan	Hyundai G420FE, G424FE, G430FE, 46 - 66 bhp inline 4 cyl	Woodward Controls
Hyster/Yale NACCO	Mazda 2.0-2.2; GM 2.4 inline 4 cyl; GM 4.3 V-6	IMPCO
Hyundai	Hyundai 49.3, 60 bhp inline 4 cyl; GM 4.3 V-6	IMPCO
Mitsubishi-Caterpillar	Nissan K21-K25 50-63 bhp inline 4 cyl	Nikki FI
Nissan	Nissan K21-K25 50-63 bhp inline 4 cyl	Nikki FI
TCM	Nissan K21-K-25 60 bhp inline 4 cyl	Nikki FI
Toyota	Toyota 4Y-ECS 2.2 48 bhp inline 4 cyl; GM 4.3 V-6	Aisan FI; IMPCO

5.1 Carbon Monoxide

Propane has been a popular choice for forklifts that operate indoors because of its clean-burning properties. In 2004 the U.S. EPA lowered indoor emissions standards, including the standard for emissions of carbon monoxide.

Carbon monoxide is produced when any carbonaceous fuel is burned, including gasoline, diesel, or propane, and whether the fuel is burned in a campfire, furnace, kitchen stove, lawnmower, auto engine or forklift. Hydrocarbon fuels produce carbon dioxide (CO₂) and water vapor (H₂O) when burned, assuming a proper air-fuel mixture and complete combustion. Fuel mixtures that result in incomplete combustion produce carbon monoxide.

Carbon monoxide is clear, colorless, and naturally odorless. It weighs slightly less than ambient air but any air movement will tend to blend air and CO to where it is almost evenly mixed. CO cannot be detected by smell, although if the CO concentration is strong enough to cause illness, raw or unburned fuel may be present which may have an odor. Also, aldehydes may be present whenever CO is formed. Aldehydes have a noticeable odor that many people associate with chemicals or glues.

Carbon monoxide impairs the body's ability to absorb oxygen. CO binds readily to the substance (hemoglobin) in red blood cells that takes in oxygen from the air, thus reducing the oxygen-carrying capacity of the blood, leading to hypoxia. The affinity between hemoglobin and carbon monoxide is approximately 230 times stronger than the affinity between hemoglobin and oxygen, so hemoglobin binds to carbon monoxide in preference to oxygen.¹

Carbon monoxide concentrations are measured in two ways. The concentration in ambient air is shown in parts per million (ppm), while the concentration in tailpipe exhaust is measured as a percentage. An exhaust analyzer taking measurements at the tailpipe may show only 1 percent CO, which is average for a pre-2004 forklift and also the recommended CO level when setting the fuel mixture on a mechanically operated fuel system. One percent CO may also be shown as 10,000 parts per million, which is a lethal amount of CO if an individual were to inhale this concentration directly.

Tailpipe emissions should not be confused with ambient air concentrations. Engine emissions are measured directly at the engine, either through specially outfitted instruments or with a tailpipe sensor. Air-quality concentrations are measured in ambient air, away from any emissions sources that might skew the readings.

1 World Health Organization, <http://goo.gl/USSCc>

Table 3. Carbon Monoxide Levels and Health Effects

Level of Carbon Monoxide	Health Effects and Other Information <i>NOTE: Individuals may react differently to the same levels of CO, depending on their age and general health.</i>
9 ppm (0.0009%)	Maximum level of CO in a residence ²
35 ppm (0.0035%)	Headache and dizziness within six to eight hours of constant exposure
25 ppm (0.0025%)	Maximum time-weighted average exposure in an 8 hour workday ³ (ACGIH ^{**})
50 ppm (0.0050%)	Maximum permissible time-weighted average exposure in workplace ⁴
100 ppm (0.01%)	Slight headache in one to two hours
200 ppm (0.02%)	Dizzy, nausea, fatigue, headache after 2 to 3 hours of exposure.
400 ppm (0.04%)	Headache and nausea after 1 to 2 hours of exposure, life threatening in 3 hours.
800 ppm (0.08%)	Dizziness, nausea, and convulsions within 45 minutes. Insensible within two hours.
1,600 ppm (0.16%)	Headache, dizziness, and nausea within 20 minutes. Death in less than two hours.
3,200 ppm (0.32%)	Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes.
6,400 ppm (0.64%)	Headache and dizziness in one to two minutes. Death within 20 minutes.
12,800 ppm (1.28%)	Unconsciousness after 2-3 breaths. Death in less than three minutes.

5.1.1 Minimizing CO emissions

One cause of excessive CO emissions is a too-rich air-fuel mixture. In such cases, reducing the amount of fuel in the mixture should reduce CO emissions. Other causes include worn or damaged fuel-system components. In applications after 2007, further CO reductions are achieved by an exhaust catalyst and electronic engine controls.

5.2 Commonly Used Forklift Fuel-System Technologies

Forklifts may be operated on any of the following basic fuel-system technologies:

- Venturi spacer plate/adaptor placed above the gasoline carburetor;
- Venturi carburetor that replaces the gasoline carburetor;
- Mechanical carburetor/mixer;
- Electronically controlled carburetor/mixer;

2 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), <http://goo.gl/uoZVU>; EPA, <http://goo.gl/cNqak>

3 American Conference of Governmental Industrial Hygienists, <http://goo.gl/tTDJ2>

4 U.S. Occupational Safety and Health Administration, <http://goo.gl/C7euz>

- Single-point fuel injection;
- Multi-point fuel injection.

Description	Component
The venturi mixer design shown in Figure 48 is used with a complex vaporizer. It allows a forklift to operate on either gasoline or propane, but not at the same time. The mixer spacer plate is installed on top of the gasoline carburetor, under the air cleaner assembly or air inlet adapter. This design is obsolete, but may be found on older forklifts.	 Figure 48. Venturi mixer
This Aisan model shown in Figure 49 is a complete unit, with throttle shaft, used with a complex vaporizer. It provides both idle and full-throttle mixture controls.	 Figure 49. Dedicated propane carburetor

The Series 55 mixer-carburetor is one of the most common mechanical mixers used on forklifts up through about 2004. It combines idle and full-throttle mixture controls.



Figure 50. IMPCO Series 55 mixer-carburetor

The series 100 mixer was used on many 2004 and earlier forklifts and on some later applications with electronic engine controls. These mixers are available from several manufacturers and follow a common numbering convention.



Figure 51. Woodward Streamline N-CA-100 mixer

The IMPCO Spectrum fuel system uses a specially designed carburetor-mixer with an electronically controlled vaporizer/regulator. The vaporizer has the ability to change its fuel pressure from full lean to full rich.

The regulator's output pressure is controlled by the vehicle's ECM.



Figure 52. IMPCO Spectrum fuel system

These forklifts use an advanced, electrically operated mechanical fuel management system.



Figure 53. 2010 Yale forklift with a Mazda engine



Figure 54. 2009 Doosan with a Hyundai engine

The throttle-body fuel injection system shown in Figure 55 brings propane from the tank to the vaporizer, where the liquid is vaporized by adding engine heat. Fuel pressure is also reduced to the desired outlet pressure, typically about 25 psig.

Fuel is then transferred to injectors mounted on the throttle body. The injectors receive their command from a programmed ECM that controls the air-fuel ratio using inputs from engine-mounted sensors.

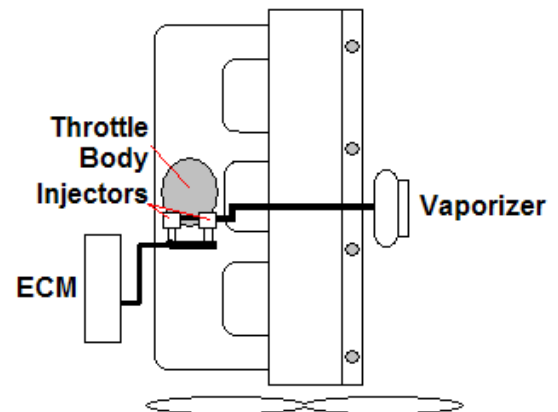


Figure 55. Throttle-body fuel injection system

The multi-point (or multi-port) fuel injection system shown in Figure 56 brings liquid from the tank to the vaporizer, where the liquid is vaporized by adding engine heat. Fuel pressure is also reduced to the desired outlet pressure, typically about 25 psig.

Fuel is then transferred to injectors mounted on the intake manifold. These injectors receive their command from a programmed ECM that controls the air-fuel ratio using inputs from engine-mounted sensors.

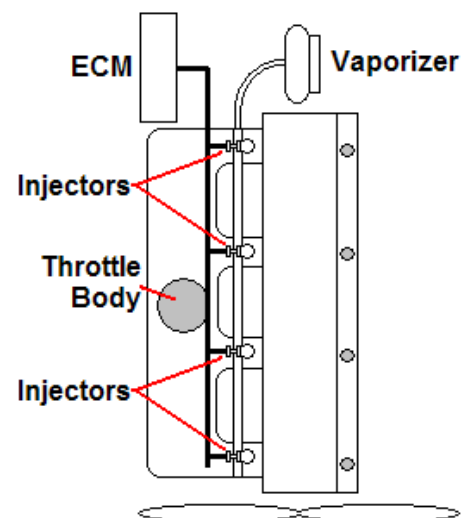


Figure 56. Multi-port fuel injection system

5.3 Troubleshooting Pre-2004 Systems

Many industrial trucks operate in dusty environments such as lumber and textile mills or granaries. Airborne particles can cause a problem with the industrial truck's air filters and vaporizer function. If not serviced regularly, these trucks' emissions (including CO emissions), fuel economy and performance will be adversely affected.

The procedures that follow focus on maintaining an industrial truck in peak operating condition. They presume that a qualified technician has determined that the truck's carbon monoxide emissions are out of spec and has eliminated any engine mechanical issues that may have contributed to excess CO emissions.

These easy diagnostic procedures apply to pre-2004 non-electronically controlled industrial trucks. Later model industrial truck fuel systems utilize electronic controls that are similar to automotive applications and are diagnosed and repaired by the manufacturers' authorized representatives. Access to the diagnostic software and communications cables by the aftermarket service industry may be restricted.

The following steps should be followed in sequence:



WARNING

Several of these diagnostic procedures require the engine to be operating. Eye protection should be worn. Keep hands and fingers away from moving components.

Step 1

WITH THE ENGINE OFF

The air-filter assembly is the first component to receive incoming ambient air. Any restriction in the air cleaner will result in an imbalance in the air-fuel ratio and a corresponding increase in emissions.

Remove the air-cleaner assembly inlet and examine the filter element or the filter trap for accumulated debris. Service or replace the air filter element as necessary.



Figure 57. Dirt in air-filter assembly

Step 2

WITH THE ENGINE RUNNING

If the engine is equipped with a vacuum filter-lockoff, pinch the hose with a pair of pliers at the point shown in Figure 58.

NOTE: *This step will not be performed on an engine with an electric fuel lockoff.*

1. If the engine rpm changes, the lockoff lip-seal is defective and requires service or replacement. Fuel is leaking around the pin and seal and being drawn into the vacuum hose. If the exhaust is being monitored, a decrease in CO emissions indicates the lip-seal leakage (Figure 59).
2. While the hose is pinched off, slip the hose off the fitting at the vacuum lockoff. The engine should quit running within 10 to 20 seconds. If it keeps running, the seat is defective or the pin is seized in the lockoff body. Service or replace as necessary.
3. If the hose cracks or is too brittle to squeeze, replace the hose and retest.



Figure 58. Hose for vacuum lockoff

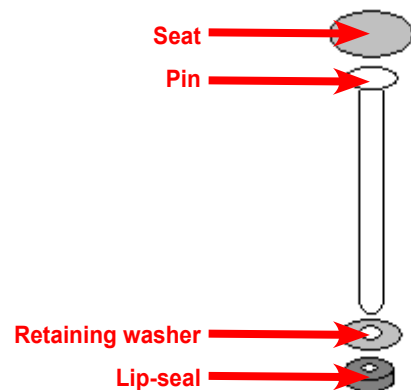


Figure 59. Pin and seat assembly

Step 3

WITH THE ENGINE RUNNING

Locate the vaporizer, typically adjacent to the vacuum lockoff (Figure 60). If the vaporizer has a “primer” button, gently depress the button (Figure 61) and apply light pressure.

NOTE: The primer button has been eliminated on later production units.

The engine rpm should change, and the engine should almost stall or quit running. When the pressure on the plunger is released, the engine should return to a smooth idle. If this occurs, the vaporizer is functioning normally and not in need of service. If depressing the plunger causes the engine rpm to smooth out or increase, the mixer air-fuel mixture is too lean and should be adjusted.



Primer Button



Figures 60 and 61. Approximate location of the vaporizer and lockoff assembly and the vaporizer.

Note that it is preferable to perform a pressure test on the unit to verify the pressures:

- Primary pressure should be +1.5 to +3.5 psig.
- Secondary pressure should read -0.5” to -1.5” H₂O (a vacuum) with the engine running, depending on which spring is installed.

Step 4

The idle fuel mixture adjusting screw is adjusted to achieve the lowest possible CO and HC readings, before an increase in O₂ is recorded.

Figure 62 shows location of the Series 55 mixer idle adjustment screw adjacent to the fuel inlet.

Desired CO emission readings at idle:
0.5 percent to 1.0 percent

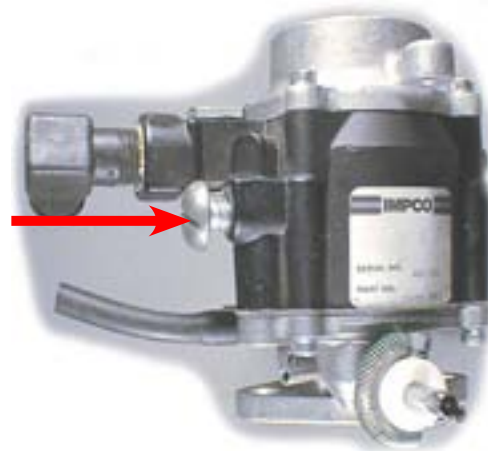


Figure 62. Idle mixture adjustment screw on Series 55 mixer

Figure 63 shows the location of the idle mixture screw adjacent to the fuel inlet, opposite from the air inlet, on the Series 100 mixer.



Figure 63. Idle mixture adjustment screw on Series 100 mixer

Figure 64 shows the location of the idle speed adjustment screw on the Aisan mixer-carburetor, as used on some Toyota forklifts. The mixture adjustment is located on the vaporizer as shown in Figure 65.

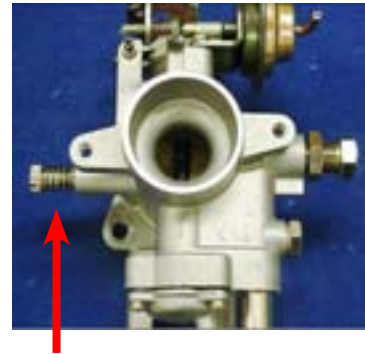


Figure 64. Idle speed adjustment screw on Aisan mixer-carburetor.

Some Aisan vaporizers also have an idle mixture adjustment screw. Early NIKKI style vaporizers are similar.

The “complex” vaporizer is only used on venturi-style mixers. A screw places spring tension on the vaporizer’s secondary diaphragm, which changes its outlet pressure. The resulting change alters the amount of fuel available at the venturi mixer.



Figure 65. Idle mixture adjustment on Aisan vaporizer

Step 5

Run the engine at maximum rpm with no load and measure the exhaust emissions. At cruise, high speed, no load, the reading should not exceed 0.20 percent. While the engine is at full rpm, pull the mast back to full mast tilt. The CO emissions should be around or below 0.30 percent.

Measure the hydrocarbon (HC) emissions while monitoring the CO emissions. If HC emissions readings start to rise while the CO readings are falling, the mixture is too lean.

Max Gas Flow Adjustment

Figure 66 shows the maximum gas flow adjustment on an IMPCO Series 55 mixer. The adjusting screw is located directly above the fuel inlet.

A 7/16" (11mm) open end wrench is required.



Figure 66. Series 55 max gas flow adjustment

Figure 67 shows the max gas flow adjustment on IMPCO Series 100-125-200-225 mixers. The adjustment is located directly under the fuel inlet.

A 7/16" (11mm) open end wrench is required



Figure 67. Series 100-125-200-225 max gas flow adjustment

Figure 68 shows the location of the max gas flow adjustment on the Aisan mixer-carburetor used on some Toyota forklifts.

Loosen the nut and turn the hex head screw in to make the mixture leaner, or turn it out to make the mixture richer.



Figure 68. Aisan max gas flow adjustment

Step 6

If the adjustments are not successful, mixer and/or vaporizer service is probably required. Remove the mixer and clean as necessary. Pay close attention to the air and gas valve assembly, especially on the Series 55 mixer. Do NOT allow spray cleaning solvent containing petroleum distillates to contact the diaphragm or any vaporizer/regulator seal or seat material.

Accumulated oils should be drained from the vaporizer during every engine oil change. Accumulated oils will dampen the movement of the diaphragm and affect the engine's operation.

Step 7

If all steps above have not reduced CO satisfactorily, the mixer/carburetor and/or vaporizer may need to be replaced. Depending on the application, it may be possible to upgrade the mixer to a different style, e.g., by replacing a Series 55 mixer with a Series 100 mixer.

5.4 Troubleshooting 2004-2007 and newer

NOTE: If the fuel system is 2004-2007 or newer, fuel mixture adjustments are not provided. All controls are managed electronically. Specialized or proprietary PC-based diagnostic software and additional communications links may be required.

5.5 Additional repair procedures

For additional troubleshooting and repair procedures, see Chapter 7.

5.6 Fuel Cylinder Storage

See Appendix C for information on storing fuel cylinders.



Chapter Six

Microturbines



CHAPTER 6: MICROTURBINES

This chapter describes the operation of a propane-fueled microturbine.¹

6.0 Microturbines

Microturbines are essentially miniature versions of the power plant used in turboprop aircraft engines. Instead of providing thrust, as in a turbojet engine, a microturbine provides rotational power that is coupled to an electric generator.

6.1 Theory of Operation

The turbine has a common shaft attached to a series of blades or fins. As air enters the front of the turbine, it is first compressed by the rotating shaft. As the air is compressed, it generates enough heat to ignite the fuel, which is injected into a combustion chamber before the final or turbine stage. The heated, combusted gases then pass through the turbine stage. The turbine is connected to the compressor stage via a common shaft that in turn pulls more air into the intake. The amount of power the turbine produces is governed by the amount of fuel injected and the amount of air entering the turbine.

Turbine engines may have more than one compressor and turbine stages. Turbojet engines have multiple stages to aid in high-altitude operation. Stationary turbines rarely have more than one or two stages.

1. Air inlet
2. Compressor stage
3. Fuel injector
4. Combustion chamber
5. Turbine
6. Outlet
7. Exhaust

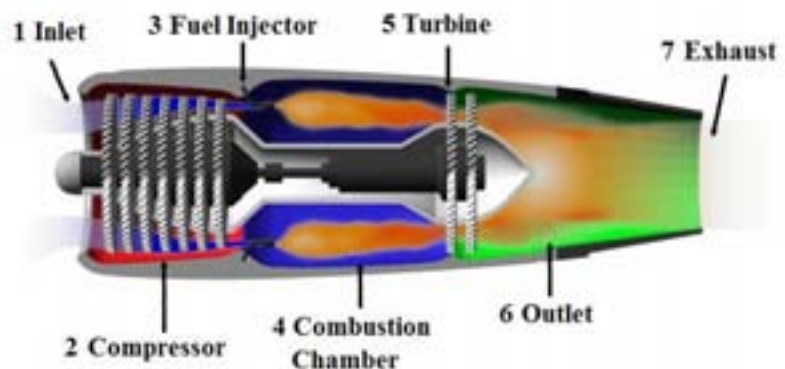


Figure 69. Turbojet engine. All turbine engines operate similarly.

¹ For more information, visit www.microturbine.com.

A propane-fueled microturbine adds a generator to the inlet for cooling and access. The microturbine also utilizes bearings that ride on air instead of traditional ball or needle bearings.

Since the microturbine does not produce thrust, all the exhaust gases are directed to a common exhaust port which can then be used for heat recovery (CHP).

The recuperator aids in this process, recovering exhaust heat and transferring it to a storage bank consisting of heated water or air.

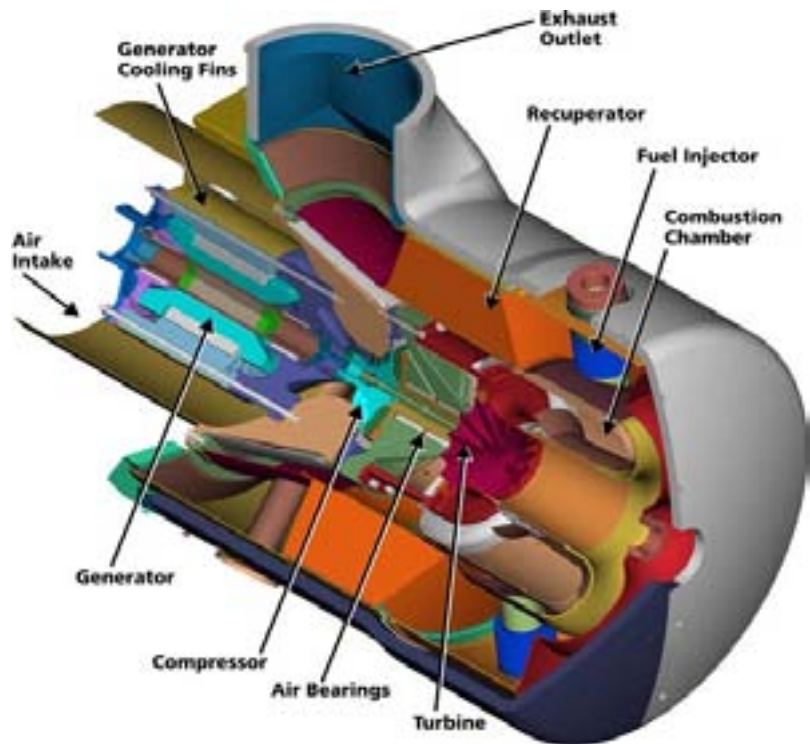


Figure 70. Capstone microturbine

Microturbines may be ganged together for additional power output.



Figure 71. Ganged microturbines



Figure 72. Ganged microturbines



Figure 73. Ganged microturbines

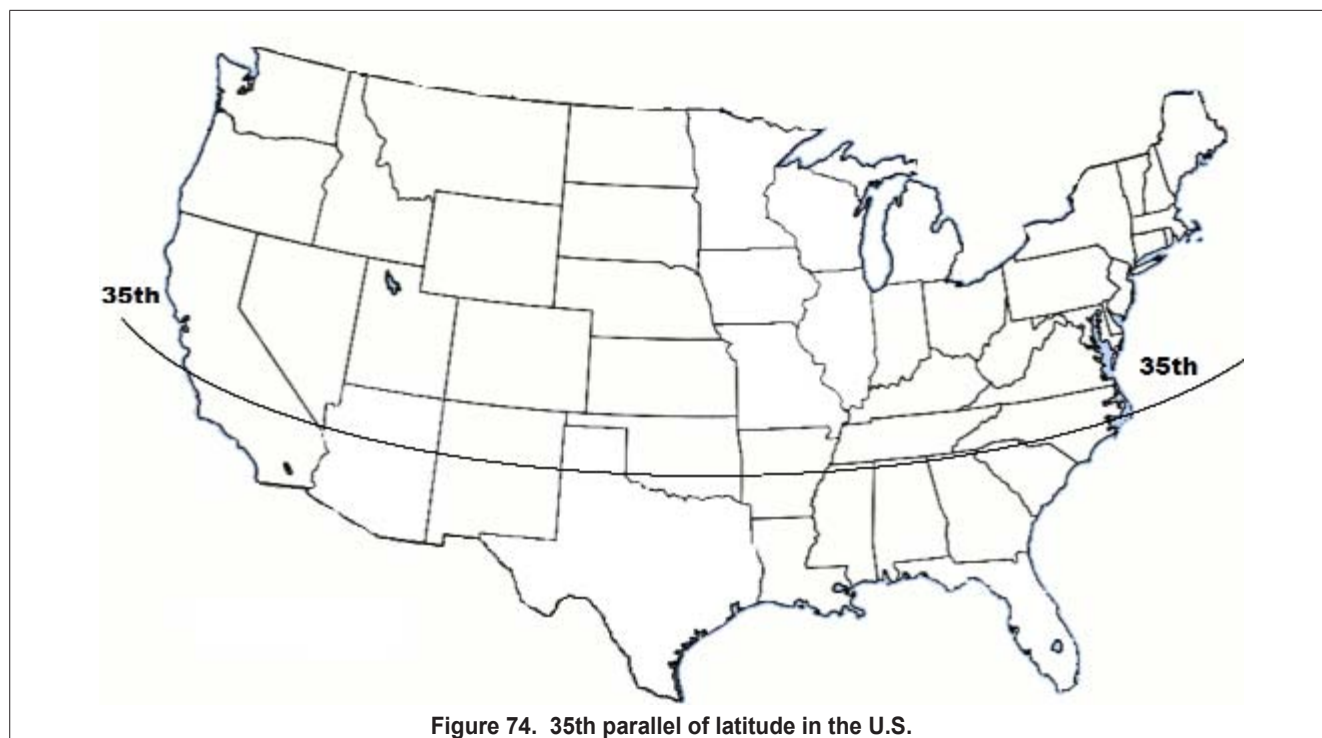
6.2 Fuel supply

Propane liquid must first be vaporized. The microturbine may only use propane vapor, at a stable propane vapor pressure of about 55 to 80 psig. The vapor is filtered and regulated to the inlet pressure specified by the manufacturer.

Vapor withdrawn directly from the top of a liquid storage tank may be below the pressure required to operate a Capstone C30 microturbine (vapor pressure at 50°F is 77 psig).² In general, areas north of the 35th parallel in the U.S. may require a pump and vaporizer. Areas south of the 35th parallel may have adequate vapor pressure directly from the tank (Figure 74).

Installations requiring supplemental vaporizing and pumping capabilities are those where:

- Minimum temperature is below 35°F,
- More than three C30's are being operated from a single 1,000 gallon tank,
- A mixture of propane and butane is being used, or
- The equipment is located at high elevations.



6.2.1 Fuel consumption estimates

A 30kW microturbine may require approximately 4.25 gallons of propane per hour (estimated at 7 kW-hr/gallon), based on 100 percent duty cycle. A 60kW microturbine may consume approximately 8-8.5 gallons of propane per hour.

A fuel-fired vaporizer capable of vaporizing 15 gal./hr may use an additional 20,000 Btu/hr (4.5 hours per liquid gallon).³ This additional consumption should be included in fuel-use calculations.

6.3 Microturbine Maintenance

Some microturbines may never require service over their useful lives. There are no mechanical ball or roller bearings that require lubrication, and no oil to change, since the microturbine is equipped with airfoil bearings that provide an almost frictionless surface. Microturbines may be equipped with an air filter to remove airborne particles that may damage the turbine's internal components. Air filters may be replaced around 8,000 hours of use, and engine service at 40,000 hours of use. Severe operating conditions may require a modified maintenance schedule.

Table 4. Engine and Fuel-Related Maintenance⁴

Item	Action	Service Interval
Air filter, microturbine engine	Clean / replace	Clean/ replace / 4,000 hours
Air assist filter, liquid fuel system	Inspect	8,000 hours or as required
Fuel filter, internal	Inspect / replace	8,000 hours or as required
Fuel filter, external	Inspect and/or replace	8,000 hours or as required
Igniter	Replace	8,000 hours
Injector assemblies	Replace	20,000 hours (natural or LP gas)

6.4 Microturbine Troubleshooting

All troubleshooting is performed by the microturbine manufacturer or the manufacturer's representative. There are no recommended field repair diagnostic or procedures that the end user may perform.

⁴ Capstone Turbine Corporation: <http://goo.gl/o4yvy>



Chapter Seven

Basic Troubleshooting



CHAPTER 7: BASIC TROUBLESHOOTING

7.0 Fuel-System Maintenance and Troubleshooting

This chapter introduces basic troubleshooting procedures common to many propane-fueled small-engine applications.

WARNING



When working on a pressurized fuel system, the technician should follow basic safety rules:

- Wear eye protection, to guard against potentially serious eye injury.
- Wear protective gloves.
- Eliminate any ignition sources within 25 feet of the service.
- Disconnect the battery or remove the ignition key (or equipment equivalent of decommissioning the starter).
- Ensure that a suitable fire extinguisher is located adjacent to the service area. A minimum 20-lb. type B:C fire extinguisher is recommended.
- Avoid using cleaning solvents that may react with the internal components of the fuel system.
- Replacement components should be available before any disassembly.

7.1 Propane Vaporizer with Air-Valve Carburetion

On engine applications more than about 35 horsepower, the air valve should be inspected according to the manufacturer's recommendations or once a year, depending on operating conditions.

CAUTION

Air-valve mixer/carburetors use a spring to maintain pressure against the air valve. If the air-valve cover is removed without holding pressure against the cover, the spring may eject. Hold the cover down as the last screws are removed. If the cover is sticking to the diaphragm and gasket, separate them carefully using a thin knife.



Figure 75. Air-valve spring

A Series 55 mixer must be removed from the engine for service and disassembled from the bottom.

A Series 55 mixer may be temporarily cleaned by removing the four screws at the top and removing the air horn inlet. Spray light lubricating solvent into the top while depressing the air valve fully downwards several times. The air valve should move easily. Repeat as necessary. If the air valve binds or does not return to the upmost position, the mixer assembly must be removed and fully disassembled for cleaning.



Figure 76. Series 55 mixer

To service the Series 60 mixer, remove the four small screws at the top cover and remove the diaphragm. Inspect the diaphragm for damage, cracks, or contamination. Clean or replace as necessary.



Figure 77. Series 60 mixer

To service the Series 100 mixer, remove the four small screws at the top cover and remove the diaphragm. Inspect the diaphragm for damage, cracks, or contamination. Clean or replace as necessary.



Figure 78. Series 60 mixer

To service the Series 125 mixer, remove the air inlet and the inlet adapter by removing the single 1/4" bolt in the center. Next, remove the four small screws at the top cover and remove the diaphragm. Inspect the diaphragm for damage, cracks, or contamination. Clean or replace as necessary.



Figure 79. Series 125 mixer

To service the Series 200 mixer, remove the five small screws at the top cover. Carefully lift the cover and remove the spring and diaphragm. Inspect the diaphragm for damage, cracks, or contamination. Clean or replace as necessary.

NOTE: The Series 200 diaphragm has a square locating tab that must be replaced in its original position.



Figure 80. Series 200 mixer

To service the Series 225 mixer, remove the air inlet and the inlet adapter by removing the single 1/4" bolt in the center. Next, remove the five small screws at the top cover and remove the diaphragm. Inspect the diaphragm for damage, cracks, or contamination. Clean or replace as necessary.

NOTE: The Series 225 mixer diaphragm has a square locating tab that must be replaced in its original position.

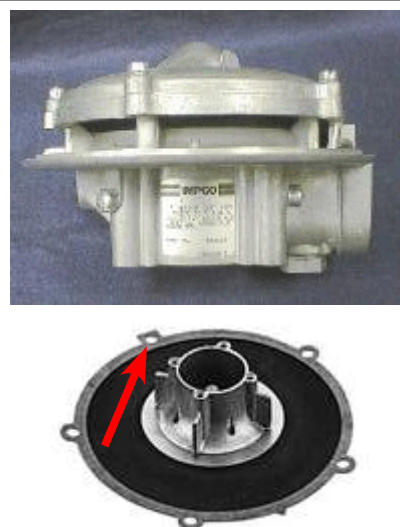


Figure 81. Series 225 mixer

The Series 425 mixer uses two diaphragms, one for the main fuel mixture, the other for the idle mixture. To service the main diaphragm, carefully remove the four small screws at the top of the mixer. Remove the spring and the air valve. Inspect the gas valve portion of the valve for scratches and wear. The valve should move smoothly in the mixer body bore. Inspect the diaphragm for damage, cracks, or contamination. Clean or replace as necessary.

NOTE: As shown in Figure 82, different gas valves are available for the air-valve assembly. The degree of taper and the machined slots allow for different air-fuel mixtures (red arrows). The replacement valve assembly should be identical to the valve that was removed from the mixer body. The part number for the gas valve is stamped into the bottom of the cone and printed on the reinforcement plate for the diaphragm.

NOTE: Different diaphragm materials are also available for the air-valves (white arrows). The standard diaphragm is black. The uprated material is yellow reinforced silicone.

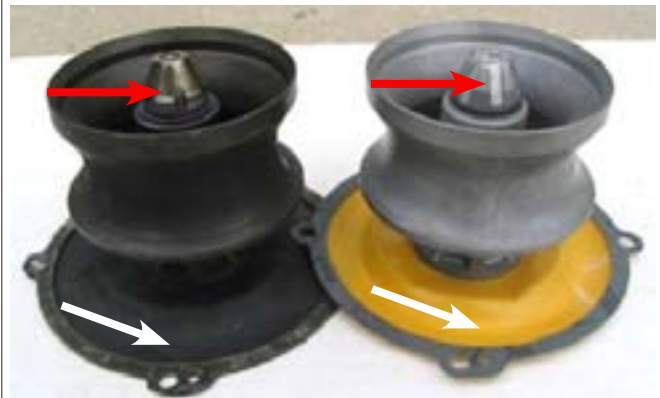


Figure 82. Series 425 mixer, showing different gas valves and diaphragm materials

Figure 83 shows the part number imprinted on the diaphragm reinforcing plate on the air valve.

NOTE: Most mechanical mixers have identification labels in this location.



Figure 83. Air valve label

To inspect the idle diaphragm as shown in Figure 84, carefully remove the four screws on the side cover. A small conical spring is located between the cover and the diaphragm. The cover can be carefully removed.

NOTE: The diaphragm and the sealing gasket are very fragile. The gasket will frequently tear during disassembly. Replacement parts should be available before disassembly.



Figure 84. Idle diaphragm and spring

7.2 Maintenance and Troubleshooting of Mowers and Lawn Equipment

The maintenance of propane-fueled mowers and similar equipment is relatively simple, typically consisting of changing the engine oil, air filter, and spark plug at regular intervals. These service intervals are usually determined by the operating conditions, but not less often than once per year. Grounds maintenance equipment operating in dusty environments may require weekly service.

Fuel-mixture adjustments should not be required if the unit has EPA or California ARB certification.

7.2.1 Draining regulator/vaporizer oils from liquid-supply fuel systems

NOTE: Regulator oils are typically not required to be drained on vapor-supplied fuel systems.

1. Close the manual service valve on the supply container.
2. Allow the engine to run until it stops due to a lack of fuel.
 - a. **NOTE:** Some fuel systems have a low pressure fuel lockout that stops the engine if a low fuel-pressure condition is observed.
 - b. There may still be fuel pressure in the system.
3. Attempt to restart the engine. If it restarts, verify that the manual valve on the supply container is fully closed.
4. Carefully follow the manufacturer's recommended procedures. Locate the regulator or vaporizer drain and open it slowly, to relieve any accumulated pressure.
5. Place a suitable container under the vaporizer to retrieve any accumulated oil.
6. Properly dispose of any drained contaminants and any cleaning materials.
7. Reinstall the drain.
8. Pressurize the fuel system and leak-check the regulator-vaporizer drain.



Figure 85. Drain plug on Aisan complex vaporizer used on Toyota engine

The drain plug is located at the lower part of the vaporizer chamber. Aisan vaporizers installed on other engines are similar.



Figure 86. Drain plug and vacuum fuel filter lockoff on a simple vaporizer

The red arrow shows the drain plug location. The lockoff is positioned directly above the vaporizer. Some lockoffs may be located next to the vaporizer.

7.3 Maintaining Vapor-Supply Fuel Systems

Mixer Assembly

The mixer may require annual internal cleaning to remove accumulated oily deposits and dirt that may have passed through or around the air filter assembly. If the manufacturer does not provide a maintenance schedule, the technician should review the general operating conditions and coordinate a specialized maintenance schedule with the operator.

Mixers fed from a vapor-supply fuel tank tend to develop fewer oily residues than those fed from a vaporizer.

Regulator

The primary and secondary regulators typically require no service except measuring and adjusting the outlet pressures. These regulators are typically not serviced; if a repair is required, the regulator is replaced. Regulators fed from a vapor-supply fuel tank tend to develop fewer oily residues than those fed from a vaporizer.

Fuel Filter

In-line cartridge filters are placed in the vapor supply line to catch any pipe scale or small particles. These filters have replaceable filter paper cartridges.



Figure 87. Cartridge filter in vapor supply line

Typically these filters are serviced or changed:

- After the run-in period of a few operating hours after the system is placed into service;
- After replacing the propane tank and/or connecting piping; or
- According to a periodic maintenance program.

Oil and Air Filters

Follow the engine manufacturer's recommended service intervals, or replace more frequently under severe service conditions. Even though the oil remains cleaner longer on engines fueled by propane, the anti-wear and anti-corrosion additives will wear out.

7.4 Maintaining Liquid-Supply Fuel Systems

Maintenance and troubleshooting of liquid-supply systems include procedures related to the propane mixer, regulator/vaporizer, filters and air valve.

Mixer Assembly	The mixer may require annual internal cleaning to remove any accumulated oily deposits and dirt that may have passed through or around the air filter assembly. Mixers fed from a liquid supply fuel tank tend to accumulate oily residues passed through the vaporizer.
Regulator / Vaporizer	The vaporizer may require annual cleaning to remove any accumulated oily compounds. Vaporizers are serviced by either field overhaul, re-kitting or replacement. Vaporizers fed from a liquid supply fuel tank tend to accumulate oily residues and may require periodic draining or cleaning.
Liquid Fuel Filter	The liquid fuel filter should be replaced annually or any time a fuel tank or fuel line is replaced.  Figure 88. Liquid fuel filter To determine when a fuel filter needs to be changed, a quick and simple test is to place your hand on the filter while the engine is running at full load. If the filter is cold, sweating, or frosting, it is partially blocked and should be replaced.

Oil and Air Filters

Follow the engine manufacturer's recommended service intervals, or service more frequently under severe operating conditions. Even though the oil remains cleaner longer in engines fueled by propane, the anti-wear and anti-corrosion additives will wear out.

7.4.1 Removing and replacing the regulator/vaporizer

1. Close the manual service valve on the supply container.
2. Allow the engine to run until it stops due to a lack of fuel.

NOTE: Some fuel systems have a low-pressure fuel lockout that stops the engine if a low fuel-pressure condition is present.



CAUTION

There may still be fuel pressure in the system.

3. Attempt to restart the engine. If it restarts, verify that the manual valve on the supply tank is fully closed. Repeat step #2.
4. Carefully disconnect any fuel hoses from the regulator or vaporizer.
5. De-pressurize the cooling system (if used) and drain the coolant to a level below the level of the vaporizer. Carefully store or dispose of the drained coolant.
6. Following the manufacturer's recommendations, remove the vaporizer.

NOTE: If the vaporizer is being replaced, proceed to step 10.

7. Place the vaporizer on a suitable working surface where it will be disassembled and cleaned.
8. Using materials approved by the fuel-system manufacturer, clean the fuel system to remove any remaining grease or oil.
9. Reassemble the regulator/vaporizer using new gaskets, seals, diaphragms, and valve seats as provided by the component manufacturer.
10. Reinstall the regulator/vaporizer and pressurize to full operating pressure. Leak-test any previously disconnected fuel line fittings and seals.
11. If removed, reconnect any liquid coolant hoses and fittings. Refill the engine with coolant.

12. Readjust any fuel pressures as necessary.
13. Start the engine and verify fuel mixtures as specified by the manufacturer.

NOTE: This step will vary by manufacturer. Some fuel mixtures adjust automatically.

7.5 Basic Troubleshooting

NOTE: These diagnostic procedures assume that the engine is electrically and mechanically sound, its ignition system is working properly, and any fail-safe controls (Murphy switches) are verified operational and rectified as needed.

7.5.1 No start

Always begin diagnostics on a no-start condition by verifying that fuel is present in the supply container.

At the tank, open the 80 percent fixed maximum liquid level gauge approximately $\frac{1}{4}$ to $\frac{1}{2}$ turn. Propane vapor should vent through the gauge orifice. The vapor may be visible as a white fog under some conditions. If no fuel vents, the tank should be filled.

Close the 80 percent valve.



Figure 89. 80 percent fixed maximum liquid level gauge

If the tank has fuel, proceed with the steps below.

1. Ensure that fuel is available to the first-stage regulator by loosening the inlet line fitting. If no fuel is present there, verify that the tank's service valve is open.
2. Verify that any fuel lockoff devices are operable.
3. Verify that any fuel filters are clean. Inspect, clean and replace as necessary.
4. If the tank's service valve is open, the valve must be closed for the next step.
5. Vapor supply: Remove the pressure test port at the primary regulator and install an appropriately rated pressure gauge (0-25 psig).
6. Liquid supply: Verify that the lockoff valve is closed, and remove the test port at the vaporizer body. Install a 0-10 psig gauge at the port.

7. Slowly open the tank's manual service valve and verify the pressure. If the manual service valve is opened quickly, the excess flow check valve may automatically close.
8. The primary vapor regulator should be at the recommended pressure, or between 5 and 15 psig.
9. The vaporizer first-stage pressure should be between 1 and 3 psig.
10. Verify that there is an unobstructed flow between the primary and secondary regulator on a vapor supply system.
11. Verify that there is an unobstructed flow between the secondary regulator or vaporizer and the mixer body. If the system has a pilot valve, ensure the valve opens on demand.
12. Verify mixer operation; disassemble if necessary to ensure component operation.

7.5.2 Low power

This step presumes the technician has:

1. Verified that there is a sufficient amount of fuel in the tank or available to the engine;
2. Eliminated excess load on the engine due to driveshaft, PTO, drive belt, or generator drag;
3. Eliminated a restricted air filter;
4. Verified all mechanical issues with the engine, including ignition, oil, coolant, or physical failures.

A pressure test at the vaporizer/regulator may pinpoint a pressure-related problem.

Low pressure

1. Extremely cold conditions, creating low vapor pressure at the container.
2. Blocked fuel filter, confirmed by a fuel filter that is cold, sweating, or frosting. The filter is partially blocked and should be replaced.

High pressure

1. Failed primary pressure regulator in a two-regulator system, overloading the secondary regulator. Replace the regulator.
2. Failed primary or first stage of a combined pressure regulator/vaporizer, overloading the secondary stage. Repair or replace the regulator/vaporizer as needed.

7.6 Fuel Injection

Maintenance and troubleshooting of fuel-injection systems include procedures related to the injectors, regulator and filters.

Electronic Monitoring	The operating conditions of the fuel system should be monitored on an annual basis, or any time an operational fault is determined.
Fuel Injectors	Relatively little long-term maintenance is required for the throttle body besides light cleaning.
Regulator	The regulator may require annual cleaning to remove any accumulated oily compounds.
Fuel Filter	The fuel filter should be replaced annually, or more frequently as recommended by the manufacturer.
Oil and Air Filters	Follow the engine manufacturer's recommended service intervals, or service more frequently under severe operating conditions. Even though the oil remains cleaner longer in propane-fueled engines, the anti-wear and anti-corrosion additives will wear out.

7.6.1 Troubleshooting of fuel-injection systems

No fuel-injection systems are commercially available for stationary or off-road engine applications. Accordingly, a standard troubleshooting or diagnostic strategy is lacking as well. When such systems become available, they will likely be manufacturer-specific but will also eventually become standardized as in SAE 1939 or SAE 1979. These standards recognize a common communication link between the engine and the electronic control module, and a standardized diagnostic process reporting procedure.

Appendices

APPENDIX A: MATERIAL SAFETY DATA SHEET

Material Safety Data Sheet

Odorized Propane

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Name: Odorized Commercial Propane

Chemical Name: Propane

Chemical Family: Hydrocarbon

Formula: C₃H₈

Synonyms: Dimethylmethane, LP-Gas, Liquefied Petroleum Gas (LPG), Propane, Propyl Hydride

Transportation Emergency No.: 800/424-9300 (CHEMTRAC)

Material Safety Data Sheet - Odorized Propane

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Product Name: Odorized Commercial Propane
 Chemical Name: Propane
 Chemical Family: Hydrocarbon
 Formula: C₃H₈
 Synonyms: Dimethylmethane, LP-Gas, Liquefied Petroleum Gas (LPG), Propane, Propyl Hydride

2. HAZARDOUS INGREDIENTS

Ingredient Name / CAS Number	Percentage	OSHA PEL
Propane / 74-98-6	87.5-100	
Ethane / 74-84-0	0-7.5	1000 ppm
Propylene / 115-07-1	0-10.0	
Butanes/Various	0-2.5	
Ethyl Mercaptan / 75-08-1	16-25 ppm	0.5 ppm

HAZARD IDENTIFICATION SYSTEM

Health Hazard 1 (Blue)
 Fire Hazard 4 (Red)
 Reactivity 0 (Yellow)

Special Hazards (White): 4 = Severe 3 = Serious 2 = Moderate 1 = Slight 0 = Minimal

2. COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENT NAME / CAS NUMBER	PERCENTAGE	OSHA PEL
Propane / 74-98-6	87.5-100	
Ethane / 74-84-0	0-7.5	1000 ppm
Propylene / 115-07-1	0-10.0	
Butanes/various	0-2.5	
Ethyl Mercaptan / 75-08-1	16-25 ppm	0.5 ppm

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW - NFPA 704 - Hazard Identification System

DANGER! Flammable liquefied gas under pressure. Keep away from heat, sparks, flame, and all other ignition sources. Vapor replaces oxygen available for breathing and may cause suffocation in confined spaces. Use only with adequate ventilation. Odor may not provide adequate warning of potentially hazardous concentrations. Vapor is heavier than air. Liquid can cause freeze burn similar to frostbite. Do not get liquid in eyes, on skin, or on clothing. Avoid breathing of vapor. Keep container valve closed when not in use.



POTENTIAL HEALTH EFFECTS INFORMATION

Routes of Exposure:

Inhalation: Asphyxiant. It should be noted that before suffocation could occur, the lower flammability limit of propane in air would be exceeded, possibly causing both an oxygen-deficient and explosive atmosphere. Exposure to concentrations >10% may cause dizziness. Exposure to atmospheres containing 8%-10% or less oxygen will bring about unconsciousness without warning, and so quickly that the individuals cannot help or protect themselves. Lack of sufficient oxygen may cause serious injury or death.

Eye Contact: Contact with liquid can cause freezing of tissue.

Skin Contact: Contact with liquid can cause frostbite.

[Skin Absorption]: None.

[Ingestion]: Liquid can cause freeze burn similar to frostbite. Ingestion not expected to occur in normal use.

Chronic Effects: None.

Medical Conditions Aggravated by Overexposure: None.

Other Effects of Overexposure: None.

Carcinogenicity: Propane is not listed by NTP, OSHA or IARC.

4. FIRST AID MEASURES

INHALATION:

Persons suffering from lack of oxygen should be removed to fresh air. If victim is not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

EYE CONTACT:

Contact with liquid can cause freezing of tissue. Gently flush eyes with lukewarm water. Obtain medical attention immediately.

SKIN CONTACT:

Contact with liquid can cause frostbite. Remove saturated clothes, shoes and jewelry. Immerse affected area in lukewarm water not exceeding 105°F. Keep immersed. Get prompt medical attention.

INGESTION: If swallowed, get immediate medical attention.

NOTES TO PHYSICIAN: None.

5. FIRE-FIGHTING MEASURES

FLASH POINT: -156°F (-104°C)

AUTOIGNITION: 842°F (432°C)

IGNITION TEMPERATURE IN AIR: 920-1120°F

FLAMMABLE LIMITS IN AIR BY VOLUME: Lower: 2.15% Upper: 9.6%

EXTINGUISHING MEDIA: Dry chemical, CO₂, water spray or fog for surrounding area. Do not extinguish fire until propane source is shut off.

SPECIAL FIRE-FIGHTING INSTRUCTIONS: Evacuate personnel from danger area. Evacuated personnel should stay upwind, and away from tank ends, and move to a distance at least 1 mile or more away from containers subject to direct flame. Immediately cool container(s) (especially upper half) with water spray from maximum distance and the sides of containers, taking care not to extinguish flames. If flames are extinguished, explosive re-ignition may occur. Stop flow of gas, if possible without risk, while continuing cooling water spray.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Propane is easily ignited. It is heavier than air; therefore, it can collect in low areas while dissipating. Vapors may be moved by wind or water spray. Vapors may move to areas where ignition sources are present and ignite, flashing back to the source. Pressure in a container can build up due to heat and container may rupture if pressure relief devices should fail to function.

HAZARDOUS COMBUSTION PRODUCTS: In typical use in properly adjusted and maintained gas appliances--None. If propane combustion is incomplete, poisonous carbon monoxide (CO) may be produced. Defective, improperly installed, adjusted, maintained, or improperly vented appliances may produce carbon monoxide or irritating aldehydes.

6. ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Evacuate the immediate area. Eliminate any possible sources of ignition and provide maximum ventilation. Shut off source of propane, if possible. If leaking from container or valve, contact your supplier and/or fire department.

7. HANDLING AND STORAGE

HANDLING PRECAUTIONS: Propane vapor is heavier than air and can collect in low areas that are without sufficient ventilation. Leak-check system with a leak detector or approved solution, never with flame. Make certain the container service valve is shut off prior to connecting or disconnecting. If container valve does not operate properly, discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into pressure relief valve or cylinder cap openings. Do not drop or abuse cylinder. Never strike an arc on a gas container or make a container part of an electrical circuit. See [Section] 16.

OTHER INFORMATION for additional precautions.

STORAGE PRECAUTIONS: Store in a safe, authorized location (outside, detached storage is preferred) with adequate ventilation. Specific requirements are listed in NFPA 58, *Liquefied Petroleum Gas Code*. Isolate from heat and ignition sources. Containers should never be allowed to reach temperature exceeding 125°F (52°C). Isolate from combustible materials. Provide separate storage locations for other compressed and flammable gases. Propane containers should be separated from oxygen cylinders, or other oxidizers, by a minimum distance of 20 feet, or by a barrier of non-combustible material at least 5 feet high, having a fire rating of at least 1 hour. Full and empty cylinders should be segregated. Store cylinders in upright position, or with pressure relief valve in

vapor space. Cylinders should be arranged so that pressure relief valves are not directed toward other cylinders. Do not drop or abuse cylinders. Keep container valve closed and plugged or capped when not in use. Install protective caps when cylinders are not connected for use. Empty containers retain some residue and should be treated as if they were full.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS

Ventilation:

Provide ventilation so propane does not reach a flammable mixture.

Ignition Source Control:

Electrical wiring in liquid transfer areas must be Class I, Group D, and explosion-proof. Other possible ignition sources should be kept away from transfer areas. NO SMOKING signs should be posted at all approaches and entries to transfer areas. Transfer and storage areas must be kept free of flammables, combustibles and vegetation.

RESPIRATORY PROTECTION (SPECIFY TYPE)

General Use: None.

Emergency Use:

If concentrations are high enough to warrant supplied-air or self-contained breathing apparatus, then the atmosphere may be flammable (See Section 5). Appropriate precautions must be taken regarding flammability.

PROTECTIVE CLOTHING:

Avoid skin contact with liquid propane because of possibility of freeze burn. Wear gloves and protective clothing which are impervious to the product for the duration of the anticipated exposure.

EYE PROTECTION:

Safety glasses are recommended when filling and handling cylinders.

OTHER PROTECTIVE EQUIPMENT:

Safety shoes are recommended when handling cylinders.

9. EXPOSURE CONTROLS/PERSONAL PROTECTION

BOILING POINT: @ 14.7 psia = -44°F

SPECIFIC GRAVITY (DENSITY) OF VAPOR (Air = 1) at 60°F: 1.50

SPECIFIC GRAVITY OF LIQUID (Water = 1) at 60°F: 0.504

VAPOR PRESSURE: @ 70°F = 127 psig @ 105°F = 210 psig

EXPANSION RATIO (from liquid to gas @ 14.7 psia): 1 to 270

SOLUBILITY IN WATER: Slight, 0.1 to 1.0%

APPEARANCE AND ODOR: A colorless and tasteless gas at normal temperature and pressure. An odorant has been added to provide a strong unpleasant odor.

ODORANT WARNING: Odorant is added to aid in the detection of leaks. One common odorant is ethyl mercaptan, CAS No. 75-08-01. Odorant has a foul smell. The ability of people to detect odors varies widely. In addition, certain chemical reactions with material in the propane system, or fugitive

propane gas from underground leaks passing through certain soils can reduce the odor level. No odorant will be 100% effective in all circumstances. If odorant appears to be weak, notify propane supplier immediately.

10. STABILITY AND REACTIVITY

STABILITY: Stable.

Conditions to avoid: Keep away from high heat, strong oxidizing agents and sources of ignition.

REACTIVITY:

Hazardous Decomposition Products: Products of combustion are fumes, smoke, carbon monoxide and aldehydes and other decomposition products. Incomplete combustion can cause carbon monoxide, a toxic gas, while burning or when used as an engine fuel.

Hazardous polymerization: Will not occur.

11. TOXICOLOGICAL INFORMATION

Propane is non-toxic and is a simple asphyxiant; however, it does have slight anesthetic properties and higher concentrations may cause dizziness.

[IRRITANCY OF MATERIAL]: None

[SENSITIZATION TO MATERIAL]: None

[REPRODUCTIVE EFFECTS]: None

[TERATOGENICITY]: None

[MUTAGENICITY]: None

[SYNERGISTIC MATERIALS]: None

12. ECOLOGICAL INFORMATION

No adverse ecological effects are expected. Propane does not contain any Class I or Class II ozone-depleting chemicals (40 CFR Part 82.) Propane is not listed as a marine pollutant by DOT (49 CFR Part 171).

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD:

Do not attempt to dispose of residual or unused product in the container. Return to supplier for safe disposal.

Residual product within process system may be burned at a controlled rate, if a suitable burning unit (flare stack) is available on site. This shall be done in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

DOT SHIPPING NAME: Liquefied Petroleum Gas

HAZARD CLASS: 2.1 (Flammable Gas)

IDENTIFICATION NUMBER: UN 1075

PRODUCT RQ: None

SHIPPING LABEL(S): Flammable gas

IMO SHIPPING NAME: Propane

PLACARD (When Required): Flammable gas

IMO IDENTIFICATION NUMBER: UN 1978

SPECIAL SHIPPING INFORMATION:

Container should be transported in a secure, upright position in a well-ventilated vehicle.

15. REGULATORY INFORMATION

The following information concerns selected regulatory requirements potentially applicable to this product. Not all such requirements are identified. Users of this product are responsible for their own regulatory compliance on a federal, state [provincial] and local level.

U.S. FEDERAL REGULATIONS:

EPA - Environmental Protection Agency

CERCLA - Comprehensive Environmental Response, Compensation and Liability Act of 1980
(40 CFR Parts 117 and 302):
Reportable Quantity (RQ): None

SARA - Superfund Amendment and Reauthorization Act

- SECTIONS 302/304: Require emergency planning on threshold planning quantities (TPQ) and release reporting on reportable quantities (RQ) of EPA extremely hazardous substances (40 CFR Part 355).

Extremely Hazardous Substances: None

Threshold Planning Quantity (TPQ): None

- SECTIONS 311/312: Require submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA-defined hazard classes (40 CFR Part 370). The hazard classes for this product are:

IMMEDIATE: Yes

PRESSURE: Yes

DELAYED: No

REACTIVITY: No

FLAMMABLE: Yes

- SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR Part 372.

Propane does not require reporting under Section 313.

40 CFR PART 68 Risk Management for Chemical Accidental Release

TSCA - Toxic Substance Control Act
Propane is not listed on the TSCA inventory.

OSHA - Occupational Safety and Health Administration
29 CFR 1910.119: Process Safety Management of Highly Hazardous Chemicals.

FDA - Food and Drug Administration

21 CFR 184.1655: Generally recognized as safe (GRAS) as a direct human food ingredient when used as a propellant, aerating agent and gas.

16. OTHER INFORMATION

SPECIAL PRECAUTIONS: Use piping and equipment adequately designed to withstand pressures to be encountered.

NFPA 58 *Liquefied Petroleum Gas Code* and OSHA 29 CFR 1910.110 require that all persons employed in handling LP-gases be trained in proper handling and operating procedures, which the employer shall document. Contact your propane supplier to arrange for the required training. Allow only trained and qualified persons to install and service propane containers and systems.

WARNING: Be aware that with odorized propane, the intensity of ethyl mercaptan stench (its Odor) may fade due to chemical oxidation (in the presence of rust, air or moisture), adsorption or absorption. Some people have nasal perception problems and may not be able to smell the ethyl mercaptan stench. Leaking propane from underground lines may lose its odor as it passes through certain soils. While ethyl mercaptan may not impart the warning of the presence of propane in every instance, it is generally effective in a majority of situations. Familiarize yourself, your employees and customers with this warning and other facts associated with the so-called odor-fade phenomenon. If you do not already know all the facts, contact your propane supplier for more information about odor, electronic gas alarms and other safety considerations associated with the handling, storage and use of propane.

Issue Date: November, 2001

ISSUE INFORMATION

This material safety data sheet and the information it contains is offered to you in good faith as accurate. Much of the information contained in this data sheet was received from outside sources. To the best of our knowledge this information is accurate, but the Propane Education and Research Council does not guarantee its accuracy or completeness. Health and safety precautions in this data sheet may not be adequate for all individuals and/or situations. It is the user's obligation to evaluate and use this product safely, comply with all applicable laws and regulations and to assume the risks involved in the use of this product.

Appendix A: Material Safety Data Sheet

NO WARRANTY OF MERCHANTABILITY, FITNESS FOR ANY PARTICULAR PURPOSES, OR ANY OTHER WARRANTY IS EXPRESSED OR IS TO BE IMPLIED REGARDING THE ACCURACY OR COMPLETENESS OF THIS INFORMATION, THE RESULTS TO BE OBTAINED FROM THE USE OF THIS INFORMATION OR THE PRODUCT, THE SAFETY OF THIS PRODUCT, OR THE HAZARDS RELATED TO ITS USE.

The purpose of this MSDS is to set forth general safety information and warnings related to the use of propane. It is not intended to be an exhaustive treatment of the subject, and should not be interpreted as precluding other authoritative information or safety procedures which would enhance safe LP-gas storage, handling or use. Issuance of this MSDS is not intended nor should it be construed as an undertaking to perform services on behalf of any party either for their protection or for the protection of third parties. The Propane Education and Research Council assumes no liability for reliance on the contents of this material safety data sheet.

APPENDIX B: GLOSSARY

Some terms and definitions used in this book reference National Fire Protection Association (NFPA) 58, *Liquefied Petroleum Gas Code*, 2008 and 2011 editions.¹ The list is not inclusive and covers only basic terms used in this manual and in the propane industry.

NOTE: Components used in some fuel systems are of European origin. The manufacturers' literature or diagnostic software may use European references.

Air-Fuel Ratio

The ratio of air to fuel in a mixture, expressed either by volume or by weight. For propane, the ideal air-fuel ratio by volume is 24:1, i.e., 24 parts air to 1 part fuel. The ideal ratio by weight is 15.5:1, i.e., 15.5 pounds of air to 1 pound of fuel.

An air-fuel ratio may be expressed as an AF number. In this system, the ideal ratio is defined as AF = 1. An AF ratio greater or less than 1 indicates a rich or lean mixture, respectively. AF 1.1 means the mixture is 10 percent richer than the ideal ratio, and AF 0.9 means the mixture is 10 percent leaner than the ideal ratio.

ALDL

Assembly Line Diagnostic Link. This connection allows access to the vehicle's electronic control module. The link is similar to the OBD (On-Board Diagnostic) connector link used on highway vehicles.

ANSI

American National Standards Institute. ANSI sets standards that are adopted by various authorities having jurisdiction. ANSI does not develop, manufacture, market components, equipment, or processes, only the standards by which they are designed. NFPA 58, §3.3.3

ASME

The American Society of Mechanical Engineers. ASME sets manufacturing standards for stationary propane tanks and propane motor-fuel tanks. The capacity of an ASME propane tank is expressed in terms of how many gallons of water the tank can hold. The propane capacity of these containers is 80 percent of the water capacity. NFPA 58, §3.3.6

ASTM

ASTM International, formerly American Society for Testing and Materials. ASTM sets manufacturing standards for physical components of propane systems such as valves and piping. Testing standards include, but are not limited to, pressure, temperature, accuracy during manufacturing, and corrosion resistance. The standard for testing propane engine fuel is ASTM 1835D.

¹ To order a copy of NFPA 58, visit <http://catalog.nfpa.org>, or call 1-800-344-3555.

Authority Having Jurisdiction

A federal, state, regional or local office or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure related to LP-gas.²

Backup

Term used to describe a generator used as a standby power source. A backup generator operates only when a loss of primary power is detected. See Prime Power; Standby.

CARB

California Air Resources Board, sometimes abbreviated ARB. The state agency that sets emissions standards for vehicles and non-road equipment bought or sold in California. Some other states adopt CARB emissions standards.

Carbon Monoxide (CO)

A colorless, odorless, highly poisonous gas produced by the incomplete combustion of hydrocarbon fuels. CO emissions are controlled by maintaining an optimum air-fuel ratio and using an exhaust catalyst. See Catalytic Converter.

Carburetor

A device that mixes air and fuel (see Mixer). The main difference between a carburetor and a mixer is that a carburetor incorporates the throttle shaft, whereas a mixer only mixes air and fuel. A mixer can be made into a carburetor by adding a throttle assembly, and a carburetor can be made into a mixer by removing the throttle assembly.

Catalytic Converter

A device (informally, “catalyst”) mounted in the exhaust system of an engine to lower tailpipe emissions. The device consists of an internal grid made of a material that when heated, removes pollutants from the exhaust by converting them into other compounds. A two-way catalyst controls carbon monoxide and hydrocarbon emissions. A three-way catalyst controls emissions of CO, hydrocarbons and oxides of nitrogen. See Carbon Monoxide; Hydrocarbon; Oxides of Nitrogen.

CFR

United States *Code of Federal Regulations*. Federal transportation regulations, including those related to the transportation of propane, are codified in Title 49 of the CFR.

CHP

Combined Heat and Power. The term describes a system or device that provides both usable heat and electricity. An example is a propane-powered, liquid-cooled generator whose engine heat is captured and used for water heating or space heating.

² NFPA 58 (2011 ed.), §§3.2.2; A.3.2.2

Closed Loop

A fuel system whose air-fuel mixture is controlled electronically. Closed-loop fuel systems incorporate an oxygen sensor in the tailpipe whose readings the engine's computer uses to trim the air-fuel mixture. See Open Loop.

Commercial Propane

LPG sold for general use, e.g., for residential heating and cooking. Commercial propane is a blend of LP gases consisting primarily of propane, with some propylene, butylenes and refinery remnants. No formal standard exists for the composition of commercial propane. The Gas Processors Association's specification for commercial propane limits sulfur content to 185 parts per million by weight.

Converter

Generic term for a device that converts propane liquid to propane vapor and incorporates a pressure regulator that reduces container pressure to the pressure required by the engine. The term is sometimes used interchangeably with vaporizer, reducer, regulator, or vaporizing regulator. See Vaporizer.

Cylinder

A portable fuel container designed, tested, marked and fabricated in accordance with standards developed by the U. S. Department of Transportation. See DOT.

DOT

The U.S. Department of Transportation. DOT is charged by Congress with setting the rules and standards for transportation safety set out in title 49 of the *Code of Federal Regulations*, including the design pressure, testing, marking and fabrication requirements for portable propane cylinders.

DOT cylinders have a minimum of 240 psig working pressure and a safety factor of four. DOT cylinders are rated by the number of pounds of propane stored in the cylinder. A typical forklift cylinder holds 33.6 pounds of propane.

DTC

Diagnostic Trouble Code. Generic term for a code sent from a vehicle's electronic control module indicating a specific malfunction in the vehicle's emissions control system. The code may be cross-referenced to help identify the fault. See ECM/PCM/ECU.

ECM/PCM/ECU

Electronic Control Module, Powertrain Control Module, and Electronic Control Unit, respectively. The terms are interchangeable and do not identify a manufacturer or brand-specific component. The ECM/PCM/ECU controls all engine functions, including emission controls and throttle position. Some aftermarket fuel systems use a supplemental or add-on module as an interceptor or translator. Dedicated liquid propane fuel injection systems typically use the original PCM, repurposed for propane.

EPA

U. S. Environmental Protection Agency. EPA oversees the testing and certification of engine-fuel systems to verify compliance with applicable emissions standards. Vehicles and equipment converted to propane must comply fully with the EPA emission regulations in force at the time of the conversion.³

Fuel Injection

Any system that injects fuel into an engine, either directly or through a port. The amount of fuel injected is calculated by a computer based on load, rpm, and size.

Gas

A substance in the gaseous (vapor) phase. In international usage, a gaseous fuel such as propane.

HD-5

A specification for propane engine fuel. “HD” means heavy duty, and “5” means no more than 5 percent propylene by volume is permitted in the fuel mixture. HD-5 propane typically conforms to ASTM 1835, which specifies a maximum of 5 percent propylene, a minimum of 90 percent propane, and the remainder trace gases. A maximum vapor pressure of 208 psig at 100°F effectively limits the amount of higher-pressure ethane in the mixture.

HD-10

Unofficial term for liquefied petroleum gas with up to 10 percent propylene that meets the specifications set out in California *Code of Regulations*, Title 13, Section 2292.6.

Heavy Ends

Semi-soluble compounds present in commercial grade and HD-5 propane. During refining it is economically impractical to remove all partially distilled oils and heavier hydrocarbons. When propane is vaporized inside a vaporizer or converter, partially vaporized heavier compounds may be left behind in the form of light oils, heavier greases or paraffins.

Hydrocarbon

Any organic compound consisting entirely of hydrogen and carbon. Propane is a hydrocarbon made up of three carbon atoms and eight hydrogen atoms (C₃H₈). Hydrocarbons in exhaust are controlled by maintaining an optimum air-fuel mixture and using an exhaust catalyst. See Catalytic Converter.

LPG

Liquefied Petroleum Gas. Any material having a vapor pressure not exceeding that allowed for commercial propane that is composed predominantly of the following hydrocarbons, either by themselves or as a mixture: propane, propylene, butane (normal or iso-butane) and butylene. NFPA 58, §3.3.34

LPI

Liquid Propane Injection. A technology in which propane liquid instead of propane vapor is injected into the intake manifold of an engine. See LPFFI.

LPFFI

Liquid Phase Propane Fuel Injection. See LPI.

Mass Air Flow (MAF)

The amount of air entering an engine, measured by weight. A MAF sensor calculates the mass of the incoming air based on variables such as inlet air temperature, air pressure, relative humidity and engine speed. The ECU uses this information to trim the engine's air-fuel ratio.

Mixer

A mechanical device that mixes air and fuel. A mixer may have moving internal components or consist of a simple venturi. See Carburetor.

MPFI

Multi-Port Fuel Injection, also called Multi Point Fuel Injection. A fuel-injection strategy incorporating an injector for each intake port. In "bank" or "batch-fire" MPFI systems, the injectors open in groups, as opposed to sequentially. See Sequential Fuel Injection.

NFPA

National Fire Protection Association. NFPA publishes codes and standards that are adopted by many U. S. jurisdictions. NFPA 58, *Liquefied Petroleum Gas Code*, includes standards on propane engine-fuel systems.

Odorant

A man-made compound added to fuel gas to aid in leak detection. The most commonly used odorant is ethyl mercaptan (ethanethiol), a sulfur-based compound that smells like rotten eggs. NFPA 58 states that odorization at the rate of 1 pound of ethyl mercaptan per 10,000 gallons of propane has been recognized as an effective odorant.

Open Loop

A fuel system whose air-fuel mixture is not controlled electronically. Also, the mode of operation of an electronically controlled engine before it switches over to closed loop. See Closed Loop.

Oxides of Nitrogen (NOx)

Compounds formed when nitrogen in the air combines with oxygen at high combustion temperatures (approximately 2,500°F) and high pressures. NOx is a regulated pollutant that forms ozone when exposed to sunlight. NOx in exhaust can be controlled by a three-way catalyst. See Catalytic Converter..

Pressure Relief Valve

A valve located in the vapor space of a fuel container that opens at a pre-set pressure, typically 312 psig. The valve controls the maximum pressure inside the container by venting fuel vapor to

the atmosphere through a duct or hose in a manner prescribed by code. The device reseats when the pressure drops below the pre-set level.

Prime Power

A generator that is the main source of electricity for a home or business and is designed to operate 100 percent of the time at various power levels. See Standby; Backup.

Propane

One of the four regulated liquefied petroleum (LP) gases. The term “propane” is often used to refer to a mixture of LP gases that is predominantly propane. See LPG.

SAE

SAE International, formerly Society of Automotive Engineers. A professional engineering organization that develops and publishes standards for the automotive and aerospace industries.

Saturation Pressure

The minimum pressure required at a given temperature to keep propane in the liquid phase. If the pressure is reduced or the temperature increases, propane will vaporize and seek to return to its saturation pressure. If the pressure is increased or the temperature decreases, propane will remain a liquid. See Vapor Pressure.

Sequential Fuel Injection (SEFI)

A fuel-injection strategy in which each cylinder receives fuel in sequence, according to the ignition firing order, or as each intake valve opens. See MPFI.

Speed Density

A calculation used to determine a fuel mixture’s air-fuel ratio based on engine rpm, engine displacement and manifold vacuum.

Standby

A generator used as a backup power source rather than as primary power. A standby generator operates only when a loss of primary power is detected. See Prime Power; Backup.

Throttle Body Injection (TBI)

A fuel injection strategy that injects fuel for all cylinders from a single location in the throttle body. TBI is more efficient than a carburetor, but less efficient than individual port fuel injection. See MPFI.

Transfer Switch

A device that disconnects a standby or backup generator from the main electrical grid when grid power is lost and the backup generator is operating. The transfer switch protects repair personnel by preventing power from the backup generator from feeding back into the grid.

Vaporizer

The most common term for the device that converts propane liquid to vapor in an engine-fuel system. See Converter.

Vaporizers may be either simple or complex.

A simple vaporizer reduces fuel pressure to the pressure required by the mixer and has no user-adjustable air-fuel mixture settings. All mixture adjustments are on the mixer body or controlled electronically.

A complex vaporizer reduces fuel pressure to the pressure required by the mixer and adjusts the idle air-fuel mixture with a spring-loaded diaphragm. Complex vaporizers are used only with venturi mixers, not with mechanical mixers or fuel injection.

Vapor Pressure

The pressure exerted by propane vapor in equilibrium with propane liquid inside a closed container. See Saturation Pressure.

Water Column (w.c.)

A means of measuring small amounts of vapor pressure or vacuum according to the amount of water that is either lifted or lowered inside a small graduated tube (manometer). Pressure is expressed in inches of water column. 10" w.c. is the pressure required to push water 10 inches up the column. -10" w.c. is the negative pressure (vacuum) required to pull water 10 inches down the column.

APPENDIX C: FUEL CYLINDER STORAGE

DOT cylinders should be secured against tampering, theft, or abuse. A cylinder storage rack or cage may provide sufficient security. The universal-type cylinders shown in Figure 90 have their pressure relief valves in the uppermost position, to keep liquid from being released if the valve relieves.

Small DOT cylinders, such as the 20-pound “bottles” used in outdoor grills, must be stored upright.

Cylinders may be exchanged at any time, but may be refilled only outdoors in a well-ventilated area at least 25 feet from any source of ignition.



Figure 90. Cylinder storage rack

If a mower or forklift is brought indoors for maintenance, the cylinder should (but is not required to) be removed and stored outdoors, unless it is needed for engine or fuel-system repairs. Cylinders may be stored indoors in limited quantities. The service valve should be closed when a cylinder is stored indoors, even if it is on the equipment.

Indoor Cylinder Storage

DOT cylinders stored indoors must comply with all applicable codes and standards. NFPA 58 considers an empty cylinder to be the same as a full cylinder when determining the amount of fuel that may be stored in a single location. The standard allows cylinders totaling no more than 300 lbs. aggregate capacity (empty or full) to be stored indoors.¹ The cylinders may not be located near exits, stairways, or in areas normally used or intended to be used for the safe egress of occupants.² Additional cylinders must be stored at least 300 feet away.

If the cylinders are stored within buildings that are frequented by the public or in residences, the aggregate amount is reduced to 200 lbs. with additional fuel no closer than 50 feet away. If the total amount exceeds 200 lbs., an approved sprinkler system must be installed that meets NFPA 13, *Standard for the Installation of Sprinkler Systems*, Ordinary Hazard Group 2.³

Outdoor Cylinder Storage

DOT cylinders stored outdoors must also comply with all applicable codes and standards.⁴ Cylinders stored outdoors awaiting use or resale or for exchange must be at least 5 feet from any doorway or opening in a building frequented by the public where there are two exits available, or at least 10 feet from any doorway or opening in a building that has only one exit. In addition, stored DOT cylinders may not be closer than 20 feet from an automotive service station dispenser.

Cylinders in a location open to the public must be protected by a lockable enclosure, as in Figure 91.⁵ The authority having jurisdiction may require additional protection.



Figure 91. Lockable storage cabinet

- 1 NFPA 58 (2011 ed.), Table 8.3.1(a)
- 2 NFPA 58 (2011 ed.), §8.2.1.3
- 3 NFPA 58 (2011 ed.), §8.3.2
- 4 NFPA 58 (2011 ed.), §8.4.1
- 5 NFPA 58 (2011 ed.), §8.4.2

APPENDIX D: EMISSIONS AND EMISSIONS STANDARDS

Emissions are produced whenever a hydrocarbon fuel is burned. Ideal combustion, where the amounts of fuel and oxygen are present in perfect proportions and are consumed completely, produces only carbon dioxide and water. Under real-world conditions combustion is never ideal. Unburned hydrocarbons, carbon monoxide, and oxides of nitrogen are also produced and emitted into the air.

Individual Emissions

NOTE: The values shown below are from a conventional exhaust gas analyzer, measured without an exhaust catalyst. A laboratory-grade exhaust or emission test will express these values in parts per million (ppm), grams per brake horsepower-hour (g/bhp-hr) or grams per kilowatt-hour (g/kW-hr). In some tests, hydrocarbon and NOx values are combined.

It is not practical to compare emissions values expressed in ppm or percentages to values expressed in g/kW-hr, because the latter are measured over time, under varying loads. Parts per million or percentages are snapshot readings, measured at the instant the reading is taken.

Table 5. Emissions Measurements From Conventional Exhaust Gas Analyzer

Emission Type	Cause	Values	Control
Hydrocarbons (HC) HCs are shown as parts per million of the sampled exhaust.	Excess fuel, too rich	Under 100 ppm	The fuel mixture should be as lean as possible without increasing O ₂ in the exhaust, which indicates a lean misfire.
Carbon monoxide (CO) CO is shown as a percentage of the sampled exhaust.	Excess fuel, too rich	Under 1%	The fuel mixture should be as lean as possible.
Oxides of nitrogen (NOx) NOx is shown as parts per million of the sampled exhaust.	Excess air, detonation, combustion too hot, elevated combustion chamber temperatures over 2,500°F.	Under 300 ppm	The fuel mixture should run at a slightly rich bias to minimize NOx production.

Emission Type	Cause	Values	Control
Oxygen (O₂) O ₂ is shown as a percentage of the sampled exhaust.	Incomplete combustion due to a lean fuel mixture.	Under 1%	The fuel mixture should not be so lean as to result in incomplete combustion, where excess oxygen is detected in the exhaust. If oxygen is present in the exhaust, not all of the fuel was properly oxidized or burned.
Carbon dioxide (CO₂) CO ₂ is shown as a percentage of the sampled exhaust.	Present during normal combustion.	Around 10-12%	Not controlled.

Figure 92 shows the relative amounts of these gases produced in exhaust at air-fuel ratios leaner than, at, and richer than the ideal ratio for propane, which is 15.5:1 by weight, i.e., 15.5 pounds of air to one pound of propane vapor. At the ideal (stoichiometric) air-fuel ratio, carbon monoxide is as low as it can be, while balancing hydrocarbons and oxygen at their lowest possible level. These three gases do not reach their low points at the same air-fuel ratio, but there is an optimum point where all three are the lowest they can be together.

This graph shows the levels of individual exhaust gases at rich, stoichiometric, and lean air-fuel ratios.

- Carbon monoxide, in red
- Hydrocarbons, in dark blue
- Oxygen, in light blue
- Carbon dioxide, in light green
- Oxides of nitrogen, in orange

The vertical red line identifies the ideal air-fuel ratio for propane, 15.5:1 by weight. Values left of the red line (lower than 15.5:1) are richer than stoichiometric, and values to the right (higher than 15.5:1) are leaner than stoichiometric.

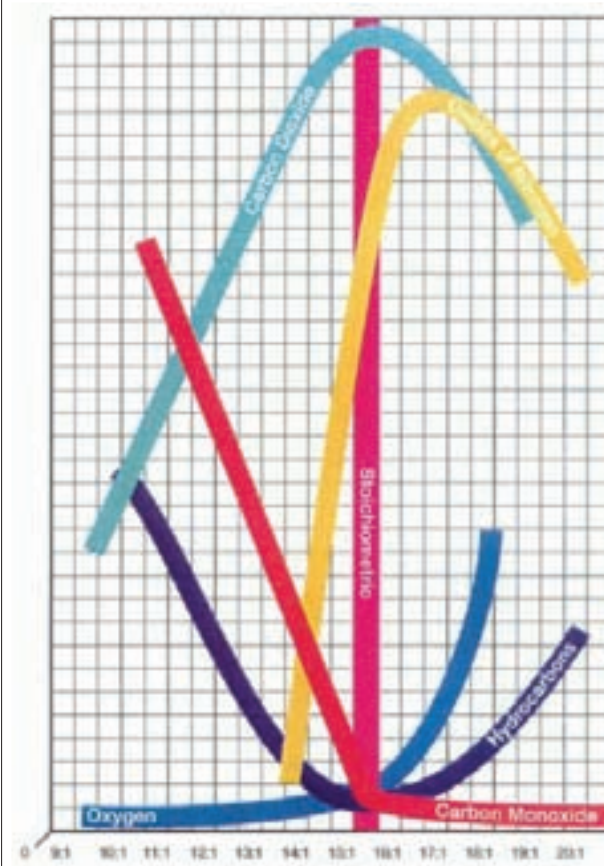


Figure 92. Exhaust gas levels

Appendix D: Emissions and Emissions Standards

As Figure 92 shows, NO_x emissions are lowest at an air-fuel ratio slightly richer than stoichiometric. Electronically controlled fuel systems can keep HC, CO, and O₂ levels low while maintaining a slightly rich bias to minimize NO_x. Fuel systems tuned by ear, or by a vacuum gauge or tachometer, cannot maintain this optimum emissions balance.



Figure 93. Exhaust catalyst and sensors

An exhaust catalyst is also required to meet strict current emission standards. The engine's air-fuel mixture must also be tightly controlled for the catalyst to operate at peak efficiency. If the mixture drifts too far lean, the catalyst will fail due to overheating (excess oxygen). If the mixture drifts too rich, the catalyst will fail due to hydrocarbon saturation, also called "loading."

Two-way and three-way catalysts each have their own requirements. Two-way catalysts control hydrocarbons and carbon monoxide emissions. Three-way catalysts also control NO_x.

Two-way catalysts keep the air-fuel mixture as close to stoichiometry as possible. Three-way catalysts have two sections, a first section that controls NO_x, and a second section that controls HCs and CO. O₂ and CO₂ are not directly controlled. The fuel mixture in an engine controlled by a three-way catalyst will drift to a slightly richer than ideal ratio, or may cycle between a lean mixture for CO and HC control and a rich mixture for NO_x control.

The catalytic converter oxidizes (burns) HC and CO emissions that pass into the exhaust system. The extreme heat (1,400°F/760°C) ignites the HCs and CO and changes them into carbon dioxide (CO₂) and water (H₂O). The catalytic materials are platinum and palladium, which treat HC and CO, and rhodium, which treats NO_x. These catalytic metals coat a ceramic honeycomb matrix in a process called a "wash."

An exhaust catalyst must be accompanied by an exhaust sensor to keep the air-fuel mixture at its ideal level. Figure 93 shows a modern 3-way catalyst equipped with two sensors, one before the catalyst and one behind. Readings are compared and used to gauge the catalyst's efficiency. The rear sensor should read a signal similar to the front sensor, but at a greatly reduced value. If the rear sensor reads the same signal as the front sensor, the catalyst has failed.

Both U.S. EPA and CARB require emissions certification for non-road engines. EPA regulations are codified in Title 40 of the *Code of Federal Regulations*, Part 1048. The general requirements for emission certification, testing, and which engines are covered or excluded are outlined on EPA's website at <http://goo.gl/ycOCD>. The standards vary by equipment type and platform and are set at different levels, called Tier 1 and Tier 2.

Small Non-Road Spark Ignited Engines (under 19 kW, 25 bhp)

Applications include:

- Engines used in household and commercial applications, including lawn and garden equipment, utility vehicles, generators, and other construction, farm, and industrial equipment.

<http://goo.gl/uYXFT>

Large Non-Road Spark Ignited Engines (over 19 kW, 25 bhp)

The regulations in part 1048 apply for all new, spark-ignition non-road engines (defined in §1048.801) with maximum engine power above 19 kW. Part 1048 applies to engines built on or after January 1, 2004.

Applications include:

- Engines used in forklifts, generators, compressors, and other industrial equipment.

<http://goo.gl/Gnq93>

Certification Requirements

Engines are submitted for testing. To obtain certification, the engine must comply with the following requirements:

- Show no degradation over the useful life of the engine (the life is determined by its size and load);
- The manufacturer may specify component overhaul during the emission certified period;
- The engine may require exhaust after-treatment in order to meet the emission standards. If so, the engine must have closed-loop fuel controls and a full diagnostic strategy.

<http://goo.gl/yDDbb>

Emissions Warranty

The manufacturer of record, i.e., the entity that holds the emissions certificate, which may or may not be the engine manufacturer, must guarantee that the engine will continue to meet the emissions standards for at least two years. The warranty for exhaust emission controls must be valid for at least 50 percent of the engine's useful life in hours of operation or three years, whichever comes first. In the case of a high-cost warranted part, the warranty must be valid for at least 70 percent of the engine's useful life in hours of operation or five years, whichever comes first.

The emissions warranty must cover any component whose failure would increase an engine's emissions of any regulated pollutant, including components listed in 40 CFR part 1068, Appendix I, and components from any other system developed to control emissions. The emission-related warranty covers all such components, whether they are manufactured by the manufacturer of record or by another company.

<http://goo.gl/qOqST>

Irrigation Engines

The requirements for emissions reductions on irrigation engines will take effect May 3, 2013.

<http://goo.gl/5XxCG>

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