

IMPCO

MATERIAL HANDLING & INDUSTRIAL ENGINE GASEOUS FUEL TRAINING MANUAL

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INTRODUCTION

IMPCO Technologies Inc. is a company dedicated to a better world through cleaner air. For over 30 years IMPCO Technologies Inc. has been a leader in the manufacture of gaseous fuel carburation equipment for internal combustion engines. Improved exhaust emissions and excellent drivability are trademarks of IMPCO carburation equipment, tested and proven reliable by thousands of satisfied customers. The future holds many challenges to the environment of our planet and IMPCO Technologies Inc. will be there in the forefront offering products and education to provide cleaner and more economical ways to get the job done.

Ian Turner
Technical Trainer
IMPCO Technologies Inc.

HOW TO USE THIS BOOK

This training manual was designed as part of a training program that includes classroom theory and hands on instruction. It is printed single sided to allow room for notes on the back of each page. Each section and sub-section is clearly labeled as to its contents for easy reference. When you need information on how a certain part works or how it should be installed just open to the contents page, select the appropriate sub-section from the column on the left. Look to the column on the right for the page number, open to that page and within a few short minutes of reading you should have the information you need. You should keep this manual close at hand so you can refer to it easily when the need arises.

SECTION 1

SAFETY INFORMATION

1.1 Shop Safety

Safety in the workplace is everyone's responsibility. Regardless of the type of work you do it is very important that you pay attention to what you are doing for your safety and the safety of those around you. The following points are things to keep in mind when working on internal combustion engines and gaseous fuel systems.

- **Before working on any fuel system study the *National Fire Protection Agency (NFPA)* standard for the fuel in use!**
- Before working on any fuel system make sure you have the **proper personal protection**.
- Before working on any vehicle make sure there are **no fuel leaks**.
- Before working on a vehicle powered by LPG make sure the fuel storage container is **not filled past the 80% liquid level**.
- Before working on any fuel system make sure there are **no sources of ignition** nearby.(sources of ignition are not only open flames but include electrical switches such as air compressor relays and other shop equipment such as bench grinders)
- Before working on any fuel system and before starting any internal combustion engine make sure that there is **adequate ventilation**.
- Before working on any fuel system (perform leak test first) **disconnect the battery**.
- Remember **LPG is heavier than air and will sink to the lowest spot possible**. Avoid areas near floor drains or lubrication pits where escaped fuel may collect.
- Remember **Natural Gas is lighter than air and will rise to the highest point possible**. Avoid areas near overhead heaters.

The National Fire Protection Agency Standards for LPG & CNG

NFPA 58
Standard
for the Storage and Handling of
Liquefied Petroleum Gases (LPG)

For easy ordering, call toll-free
1-800-344-3555
Monday – Friday 8:30 AM – 8:00 PM, ET

NFPA 52
Compressed Natural Gas (CNG)
Vehicular Fuel Systems

SECTION 2

GENERAL INFORMATION

2.1 INDUSTRY TERMINOLOGY

Air Valve Vacuum (AVV): The vacuum signal taken from below the air valve assembly and above the throttle butterfly.

ADP: Adaptive Digital Processor.

AFC: Airflow Control. A type of fuel injection system that measures the amount of air flowing past a sensor to determine engine fuel requirements.

AFE: Advanced Fuel Electronics.

Air Mass Meter: See Airflow Meter.

Air-Bleed Idle Control: Filtered air passes an adjustment screw and "bleeds" air into the incoming gas passage or air fuel mixture, for idle mixture control.

Air/Fuel Ratio: The amount of air and fuel in the air fuel mixture, which enters the engine, shown in a ratio.

Airflow Meter: Used to measure the volume of air entering the engine on many fuel injection systems.

Airflow Sensor: See Airflow Meter.

Algas Carburetion: A manufacturer of both LPG and CNG fuel systems.

Analog Voltmeter: A meter that uses a needle to point to a value on a scale of numbers usually of the low impedance type; used to measure voltage and resistance.

Aromatics: Pertaining to or containing the six-carbon ring characteristic of the benzene series. Found in many crude oils. For example, benzene and toluene.

Automotive Emissions: Harmful gaseous and particulate compounds that are emitted from a vehicle's crankcase, exhaust and fuel system. Hydrocarbons, carbon monoxide and oxides of nitrogen are considered the main emissions.

Auxiliary Air Valve: A special valve, which provides additional air into the intake manifold during cold engine starting and operation.

Backfire: Combustion of the air/fuel mixture in the intake or exhaust manifolds. A backfire can occur if the intake or exhaust valves are open when there is a mis-timed ignition spark.

Benzene: An aromatic (C₆H₆). Sometimes blended with gasoline to improve antiknock value. Benzene is toxic and suspected of causing cancer.

Bi-Fueled: A vehicle equipped to run on two fuels at the same time such as a fumigated diesel.

Blow-By: Gases formed by the combustion of fuel and air, which ordinarily should exert pressure only against the piston crown and first compression ring. When rings do not seal, these gases (blowby) escape down the side of the piston into the crankcase.

BTU: British Thermal Unit. A measurement of the amount of heat required to raise the temperature of 1lb. of water 1 degree F.

Butane: An odorless, colorless gas, C₄H₁₀ found in natural gas and petroleum. One of the five LP gases.

C3I: Computer Controlled Coil Ignition. This is General Motors' computerized ignition coil system used on many different engine applications.

CAFE: Corporate Average Fuel Economy.

CARB: California Air Resources Board.

Carbon Monoxide (CO): A chemical compound of carbon and oxygen where each carbon is bonded to only one oxygen (CO). A highly toxic gas that is both odorless and colorless. A major pollution emission from internal combustion engines, the product of incomplete combustion.

Carburetor: An apparatus for supplying an internal-combustion engine an explosive mixture of vaporized fuel and air.

Cathode Ray Tube: A vacuum tube in which cathode rays usually in the form of a slender beam are projected on a fluorescent screen and produce a luminous spot.

Cetane Index: Also Cetane Number. A measure of the ignition quality of diesel fuel. The lower the cetane index number, the higher the temperature required to ignite a diesel fuel.

CFC: Chlorofluorocarbon. Any of a group of compounds that contain carbon, chlorine, fluorine, and sometimes hydrogen and are used as refrigerants, cleaning solvents, and aerosol propellants.

CFI: Central Fuel Injection. A Ford Motor Company fuel injection system that uses an injector-mounted throttle body assembly.

Circuit: A path of conductors through which electricity flows before it returns to its source.

CIS: Continuous Injection System. A Bosch fuel injection system, which injects a steady stream of, pressurized fuel into the intake manifold. Technically a mechanical system, albeit a very elaborate one, it has a wide use throughout the industry. With the introduction of the Lambda feedback sensor in 1977 (CIS/Lambda System) and CIS-E in 1984, electronic control of the CIS was established.

Closed Loop Operation: Applies to systems utilizing an oxygen sensor. In this mode of operation, the system uses oxygen sensor information to determine air/fuel ratio. Adjustments are made accordingly and checked by comparing the new oxygen sensor to previous signals. No stored information is used.

CNG: Compressed Natural Gas.

Cold Start Injector: An auxiliary fuel injector, which injects additional fuel into the intake manifold during cold engine starting and operation.

Composite Cylinder: A CNG container fabricated of two or more materials that interact to facilitate the container design criteria.

Compressed Natural Gas (CNG): Natural gas that has been compressed to pressures up to 3600 psi. It is then stored at these pressures on a vehicle to be used as a motor fuel.

Conductor: A material, normally metallic, that permits easy passage of electricity.

Contaminants: Impurities or foreign material present in fuel.

Control Module: One of several names for a solid state microcomputer which monitors engine conditions and controls certain engine functions; i.e. air/fuel ratio, injection and ignition time, etc.

Converter: A LPG fuel system component containing varying stages of fuel pressure regulation combined with a vaporizer.

Cryogen: A refrigerant used to obtain very low temperatures.

Current: The directed flow of electrons through a conductor. Measured in amps.

D Jetronic: See MPC. "D" Jetronic is the term used by Bosch to describe a fuel injection system controlled by manifold pressure.

Dedicated Fuel System: A motor fuel system designed to operate on only one fuel type.

DEFI & DFI: A General Motors' system, similar to earlier electronic fuel injection systems but with digital microprocessors. Analog inputs from various engine sensors are converted to digital signals before processing. The system is self-monitoring and

self-diagnosing. It also has the capabilities of compensating for failed components and remembering intermittent failures.

Diaphragm: A thin, flexible membrane that separates two chambers. When the pressure in one chamber is lower than in the other chamber, the diaphragm will move toward the side with the low pressure.

Diaphragm Port: The external port located at the fuel inlet assembly and connected to the vacuum chamber above the air valve diaphragm.

Digital Volt/Ohm Meter (DVOM): A meter that uses a numerical display in place of a needle and is usually of the high impedance type.

DIS: Direct Ignition System. This is an ignition system without a distributor. Similar to the C3I system, using two coils on 4-cylinder engines and 3 coils on V6 engines.

Driveability: The ability of a vehicle to perform as the manufacturer designed it to.

Duel-Fueled: A vehicle equipped to switch from one fuel to another as desired.

DVOM: Digital volt/ohmmeter.

ECA, ECM & ECU: Electronic Control Assembly, Electronic Control Monitor, and Electronic Control Unit. Monitors engine conditions and controls certain engine functions. See Control Module.

EFI: Electronic Fuel Injection. A fuel injection system, which uses a microcomputer to determine and control the amount of fuel, required by, and injected into, a particular engine.

EGI: Electronic Gasoline Injection. This is Mazda's fuel Injection system used on Rx-7, Rx-7 Turbo, 323 and 626 models.

EGR: Exhaust gas recirculation.

Electricity: Used to run electric motors, with batteries as a storage medium. Currently available batteries do not attain high-energy density, creating range problems.

EPA: Environmental Protection Agency: A regulating agency of the Federal government which, among other duties, establishes and enforces automotive emissions standards.

Ethanol: Grain alcohol (C₂H₅OH), generally produced by fermenting starch or sugar crops. Volumetric energy content is about two-thirds that of gasoline. Octane level is 101.5, much lower vapor pressure than gasoline.

Evaporative Emissions Controls: An automotive emission control system designed to reduce hydrocarbon emissions by trapping evaporated fuel vapors from the fuel system.

Excess Flow Valve: A check valve that is caused to close by the fuel when the flow exceeds a predetermined rate.

Exhaust Gas Recirculation (EGR): An automotive emission control system designed to reduce oxides of nitrogen emissions.

FCV: Fuel Control Valve.

FFV: Flexible Fuel Vehicle.

Firing Line: The portion of an oscilloscope pattern that represents the total amount of voltage being expended through the secondary circuit.

Flex-Fuel system: A motor fuel system designed to operate on a variety of alcohol fuels and alcohol-gasoline fuel mixtures ranging from standard gasoline to straight methanol or ethanol. Primarily designed for use of alcohol/gasoline blends such as M85.

FMVSS: Federal Motor Vehicle Safety Standards.

Formaldehyde: HCHO. A toxic emission from gasoline-fueled internal combustion engine.

Fuel Distributor: Used on the Bosch CIS fuel injection system, the distributor is supplied with fuel from the fuel tank. Fuel leaves the distributor via one fuel line for each injector at a constant, predetermined pressure.

Fuel Injector: In all except CIS, CIS Lambda and CIS-E systems, a spring loaded, electromagnetic valve which delivers fuel into the intake manifold, in response to electrical from the control module. In CIS, CIS/Lambda and CIS-E systems, a spring-loaded, pressure sensitive valve, which opens at a preset value.

Fuellock: A solenoid-controlled valve located in the fuel line to stop the flow when the engine dies or the ignition switch is off. Usually controlled by a vacuum or oil pressure switch.

Fusible Plug: A device designed to vent CNG in the event that the cylinder temperature becomes excessive.

Gas Valve Screw: Provides adjustment of the gas valve position in relation to the air valve without the use of shims.

Gasohol: 10 percent ethanol, 90 percent gasoline. Often referred to as E-10.

Gasoline: A motor vehicle fuel that is a complex blend of hydrocarbons and additives. Typical octane level is 89.

GEM: Gas Engine Management. A CNG fuel system manufactured by MESA Environmental.

GFI: Gaseous Fuel Injection. A manufacturer of CNG fuel systems.

Greenhouse Effect: A scientific theory that suggests that excessive levels of carbon dioxide from the burning of fossil fuels is causing the atmosphere to trap heat and cause global warming.

HD 10: A fuel of not less than 80% liquid volume propane and not more than 10% liquid volume propylene.

HD 5: A fuel of not less than 90% liquid volume propane and not more than 5% liquid volume propylene.

HDV: Heavy Duty Vehicle.

Hg: Chemical symbol for mercury. Used in reference to vacuum (in. of Hg).

Hydrocarbon: A chemical compound made up of hydrogen and carbon (HC). A major pollution emission of the internal combustion engine. Gasoline and almost all other fuels are hydrocarbons.

Hydrogen: H₂, the lightest gas. Very low energy density even as a cryogenic liquid. Less than that of compressed natural gas. Combustion will produce no pollution except Nox. Can be used in a fuel cell, as well as in an internal combustion engine.

Hydrostatic Relief Valve: A pressure relief device installed in the liquid propane hose on a propane fuel system. Its purpose is to vent propane in the event that the line pressure is too high and the fuel cannot return to the tank.

Ideal Mixture: The air/fuel ratio at which the best compromise of engine performance to exhaust emissions is obtained. Typically 14.7:1.

Ignition Reserve: The difference between available voltage and the required voltage.

ILEV: Inherently Low Emission Vehicle.

IMPCO: Imperial Machine Products Company. IMPCO Technologies, Inc. A manufacturer of both LPG and CNG fuel systems.

Impedance: A form of opposition of AC current flow (resistance) measured in ohms.

Insulation: A nonconductive material used to cover wires in electrical circuits to prevent the leakage of electricity and to protect the wire from corrosion.

Intercept: An electrical term for a type of splice where the original circuit is interrupted and redirected through another circuit.

K Jetronic: See CIS. "K" Jetronic is the term used by Bosch to describe a fuel injection system which features continuous injection.

Knock: Sound produced when an engine's air/fuel mixture is ignited by something other than the spark plug, such as a hot spot in the combustion chamber. Can be caused by a fuel with an octane rating that is too low or maladjusted ignition timing. Also called detonation or ping.

L Jetronic: See AFC. "L" Jetronic is the term used by Bosch to describe a fuel injection system controlled by the air flowing through a sensor.

Lambda Sensor: A feedback device, usually located in the exhaust manifold, which detects the amount of oxygen present in exhaust gases in relation to the surrounding atmosphere.

LDV: Light Duty Vehicle.

Lean Mixture: An air to fuel ratio above the stoichiometric ratio; too much air.

LEV: Low Emission Vehicle.

Limp-in or Limp-home: This term is used by many manufacturers to explain the drivability characteristics of a failed computer system. Many computer systems store information that can be used to get the vehicle to a repair facility. In this mode of operation, drivability is greatly reduced.

Liquified Natural Gas (LNG): Natural gas that has been compressed and then condensed into a liquid form by lowering its temperature below 271 degrees F. Can be used as a motor fuel. Octane level is from 107 to 110, depending on the propylene content.

Liquified Petroleum Gas (LPG): A fuel commonly known as propane consisting mostly of propane (C₃H₈), derived from the liquid components of natural gas stripped out before the gas enters the pipeline, and the lightest hydrocarbons produced during petroleum refining. Octane level is 107.

LNG: Liquified Natural Gas.

Logic Module: See Control Module.

LPG: Liquified Petroleum Gas.

M85: A blend of gasoline and methanol consisting of 85% methanol and 15% gasoline.

Measurements of Pressure: 1 PSI=2.06 Hg (mercury) = 27.72" H₂O (water column). At sea level atmospheric pressure is 29.92" Hg.

Methanol: Known as wood alcohol (CH₃OH), a light, volatile, flammable alcohol commonly made from natural gas. Volumetric energy content is about half that of gasoline, (implies range for the same fuel volume is about half that of gasoline, unless higher efficiency is obtained). Octane level of 101 allows use in high compression engines. Much lower vapor pressure (low evaporative emissions, but poor starting at low temperatures).

Misfire: Failure of the air/fuel mixture to ignite during the power stroke.

Mixer: Fuel introduction device that does not include a throttle plate.

MPC: Manifold Pressure Controlled fuel injection system. A fuel injection system that determines engine load based upon intake manifold pressure.

MPFI: Multi-Point Fuel injection. A fuel injection system that uses one injector per cylinder mounted on the engine to spray fuel near the intake valve area of combustion chamber.

MTBE: Methyl Tertiary Butyl Ether. Oxygenate add to gasoline to reduce harmful emissions and to improve the octane rating.

Multi-fuel System: A motor fuel system designed to operate on two different fuels, such as LPG and gasoline, or LPG and CNG, or CNG and gasoline.

Natural Gas: A gas formed naturally from buried organic material, composed of a mixture of hydrocarbons, with methane (CH₄) being the dominant component. Octane level of 120 to 130. Volumetric energy content at 3,000 psi is about one-fourth that of gasoline.

NGV: Natural Gas Vehicle.

Nox: See Oxides of Nitrogen.

Octane Rating: The measurement of the antiknock value of a motor fuel.

OEM: Original Equipment Manufacturer, the vehicle manufacturer.

OHG: A manufacturer of gaseous fuel systems.

Open-Loop: An operational mode during which control module memory information is used to determine air/fuel ratio, injection timing, etc., as opposed to "real" sensor input. This occurs during cold engine operation, or when a particular sensor malfunctions.

Orifice: A port or passage with a calibrated opening designed to control or limit the amount of flow through it.

Oscilloscope: An instrument that converts voltage and frequency readings into traces on a-cathode ray tube (also see Cathode Ray Tube).

OTR: Over the Road.

Oxides of Nitrogen: Chemical compounds of nitrogen bonded to various amounts of oxygen (Nox). A major pollution emission of the internal combustion engine. Formed under pressure and temperature above 2500 degrees F. A chief smog forming-agent.

Oxygen Sensor: An automotive fuel system that produces a signal in accordance with the oxygen content of the exhaust gas. (See Lambda Sensor).

Oxygenate: MTBE, ethanol and methanol. Oxygenates are added to gasoline to increase the oxygen content and therefore reduce exhaust emissions. U.S. Clean Air Act Amendments of 1990 provided the impetus for oxygenates.

Ozone: A radical oxygen molecule (O₃) that is found in the upper atmosphere and filters out ultraviolet radiation from the sun. Ground level ozone is formed by Nox, during the formation of photochemical smog.

Particulates: Microscopic pieces of solid or liquid substances such as lead and carbon that are discharged into the atmosphere by internal combustion engines.

PCA: Pacific Carburetion Assembly.

PGM-FI: Programmed Fuel Injection: This is Honda's fuel injection system used on Accord, Civic, Civic CRX and Prelude models.

Photochemical Smog: A combination of pollutants created which, when acted upon by sunlight, forms chemical compounds harmful to both animal and plant life. Appears, in severe cases, as heavy brown fog covering a city.

Positive Crankcase Ventilation (PCV): An automotive emission control system designed to reduce hydrocarbon emissions by routing crankcase fumes into the intake manifold rather than to the atmosphere.

Power Module: On Chrysler Motors vehicles, this module works in conjunction with the Logic Module. The power module is the primary power supply for the EFI system.

Pressure Differential: The differential between atmospheric pressure and intake manifold (referred to as vacuum) pressure.

Pressure Regulator: A device to control the pressure of fuel delivered to the fuel injector(s).

Primary Circuit: The low-voltage or input side of the ignition coil.

Propane: An odorless, colorless gas, C₃H₈, found in natural gas and petroleum. One of the five LP gases.

Propylene: An odorless, colorless gas, C₃H₆, found in natural gas and petroleum. One of the five LP gases.

Quarter Turn Valve: The manual shut-off valve on a CNG system, located between the fuel cylinders and the pressure regulator.

Railroad Commission of Texas: A state regulating agency that, among other responsibilities, regulates the oil and gas industry in the state of Texas. Establishes and enforces safety regulations for the use of both LP and natural gas.

Reactivity: Refers to the tendency of an HC in the presence of Nox and sunlight to cause a smog-forming reaction. The lighter the HC, the lower reactivity tends to be.

Regulator: An assembly used to reduce and control the pressure of a liquid or vapor.

Resistance: The opposition to the flow of current in an electrical circuit. Measured in ohms.

Rest Pressure: Fuel pressure maintained within the system after engine shutdown.

Rich Mixture: An air to fuel ratio below the stoichiometric ratio; too much fuel.

Rupture Disk: A device designed to vent CNG in the event that the cylinder pressure becomes excessive.

SAE: Society of Automotive Engineers.

Secondary Circuit: The high-voltage output side of the ignition coil.

SEFI or SFI: Sequential Electronic Fuel Injection or Sequential Fuel Injection. A fuel injection system, which uses a microcomputer to determine and control the amount of fuel, required by, and injected into, a particular engine in the same sequence as engine firing sequence.

Sensors: Devices that provide the control module with engine information as needed to properly control engine function.

Spark Line: The portion of an oscilloscope pattern that represents the time during which the air/fuel mixture is being burned in the combustion chamber.

Splice: An electrical term for the joining of two or more conductors at a single point.

Stoichiometric Ratio: An ideal fuel/air ratio for combustion in which all of the fuel and all of the oxygen will be burned.

Sulfur Oxides: Chemical compounds where sulfur is bonded to varying numbers of oxygens, produced by the combustion of gasoline or any other fuel that contains sulfur. As sulfur oxides decompose in the atmosphere, they combine with water to form sulfuric acid.

System Pressure: The fuel pressure maintained in the system during normal engine operation.

Tap: An electrical term for a type of splice where the original circuit is not interrupted.

TBI: Throttle Body Injection. Any of several injection systems that have the fuel injector(s) mounted in a centrally located throttle body, as opposed to positioning the injectors close to the intake ports.

Texas Natural Resources Conservation Commission (TNRCC): A state regulating agency that, among other responsibilities, regulates air quality in the state of Texas. Establishes and enforces emissions regulations for automobiles and other sources of pollution.

Throttle Body: Controls engine RPM by adjusting the engine manifold vacuum to the mixer. Consists of housing shaft, throttle liner and butterfly valve.

TLEV: Transitional Low Emission Vehicle.

Toluene: A liquid aromatic hydrocarbon C_7H_8 that resembles benzene but is less volatile, flammable, and toxic, is produced commercially from light oils from coke-oven gas and coal tar and from petroleum, and is used as an antiknock agent for gasoline.

TPI: Tuned Port Injection. A General Motors fuel injection system that uses tuned air intake runners for more precise delivery.

TPS: Throttle Position Sensor.

ULEV: Ultra Low Emission Vehicle.

Vacuum Control Solenoid (VSC): The electrically operated three-way valve used to select the proper vacuum signal for operation of the system on either LPG or gasoline.

Vacuum Lift: The use of intake manifold vacuum, controlled by a Vacuum Control Solenoid (VCS), to raise the air/gas valve assembly on carbureted and feedback-carbureted dual fuel applications.

Vaporization: A process in which liquid changes states into gas.

Venturi Air Valve Vacuum (VAVV): An amplified air valve vacuum signal coming from the venturi area of the mixer, directly exposed to airflow before the addition of vaporized LPG.

Volt/Ohmmeter (VOM): A combination meter used to measure voltage and resistance in an electrical circuit. Available in both analog and digital types. May be referred to as AVOM and DVOM.

Voltage: The electrical pressure that causes current to flow in a circuit. Measured in volts.

Voltage Drop: A lowering of the voltage in a circuit when resistance or electrical load is added.

Xylene: $C_6H_4(CH_3)_2$. Any of three toxic flammable oily isomeric aromatic hydrocarbons that are dimethyl homologues of benzene and are usually obtained from petroleum or natural gas distillates.

ZEV: Zero Emission Vehicle.

2.2 PRESSURE CONVERSION CHART

LPG and CNG are stored under high pressure. These high pressures must be reduced before the fuel enters the engine. Therefore it is very important to be familiar with the different types of pressure measurements used to test and trouble shoot problems with gaseous fuel systems. The following chart shows how different pressure measurements relate to each other.

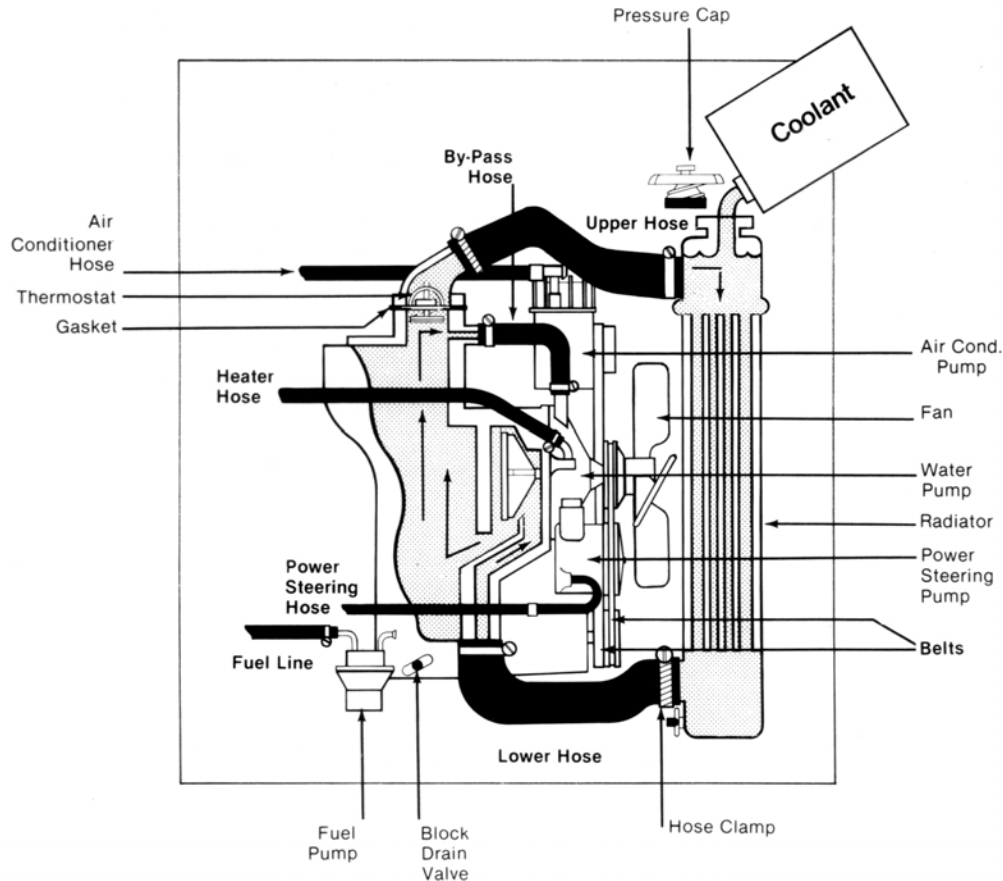
How To Use This Chart.

1. Find the type of measurement you **have** listed across the top of the chart.
2. Find the type of measurement you **want** listed in the column on the left side of chart.
3. Find the square on the chart where the two types of measurements intersect.
4. Multiply the measurement you have by the number in the square to get the measurement you want.

| Multiply This Measurement By Number In Box | | | | | |
|--|-----------------------------------|---------------------------------|---------------------------------|-----------------------------------|---------------------------------|
| To Get This Measurement | | Inches of Water Column | Ounces Per Square Inch | Inches of Mercury Column | Pounds Per Square Inch |
| | Inches of Water Column | | 1.731 | 13.7 | 27.7 |
| | Ounces Per Square Inch | .578 | | 7.85 | 16 |
| | Inches of Mercury Column | .074 | 0.128 | | 2.04 |
| | Pounds Per Square Inch | .036 | .0625 | 0.491 | |

2.3 COOLING SYSTEM REQUIREMENTS

It is very important that the cooling system on hard working engines be kept in top working condition regardless of the type of fuel being used. The following points should be kept in mind when servicing a gaseous-fueled engine or converting an engine to operate on gaseous fuel.



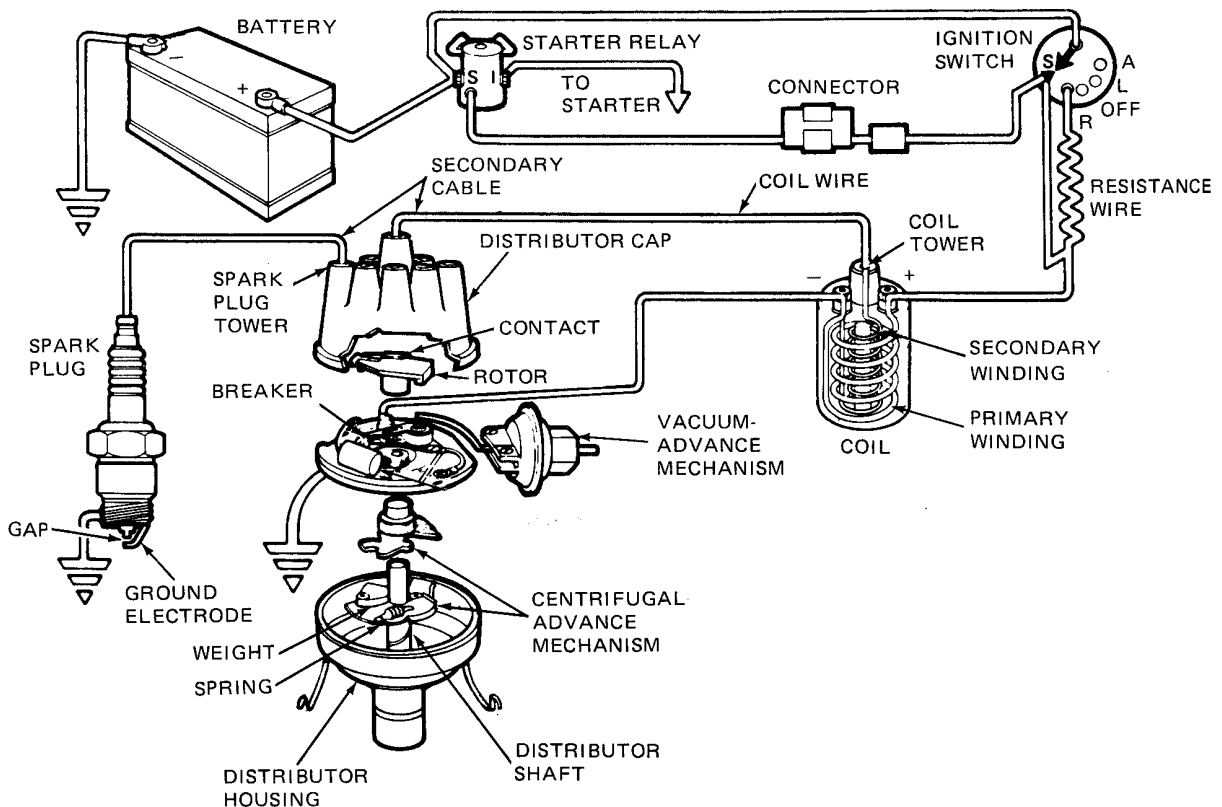
- **The cooling system must be full of coolant.** Air in the system may become trapped in the engine block and/or cylinder head causing hot spots and uneven cooling which may lead to detonation, preignition and backfires. Hot spots and uneven cooling may cause excessive stress on the engine block and cylinder head leading to cracks and damaged head gaskets. Cracks and damaged head gaskets may allow combustion gases to enter the cooling system making the problem even worse. Also air in the system may become trapped in the fuel regulator causing problems with fuel vaporization and may lead to regulator freezing.
- The position of the fuel regulator in relation to the top of the radiator is very important. **The fuel regulator must always be lower than the top of the radiator** because air in the system will seek the highest point. If the fuel regulator is higher than the radiator any air in the system will remain trapped in the fuel regulator and may lead to freezing of the regulator even though the radiator appears full.
- Engine coolant should be a **50/50 mix of water and antifreeze** and should test to at least **-35 degrees** even in warmer climates. During cold start and warm up the temperature of the regulator can drop below the freezing point of water. If antifreeze

is not used the fuel regulator may freeze up. Also antifreeze contains additives that reduce corrosion and deposits in the system. Deposits in the system reduce the amount of heat that can be transferred to the coolant. For example a 1-inch piece of cast iron with a 1/16-inch layer of mineral deposit has the same heat transferability of a 4 1/4-inch piece of clean cast iron.

- With gaseous fuels high engine operating temperatures are **not** required to help vaporize the fuel and since high operating temperatures reduce the efficiency of the engine it is recommended to use the coolest thermostat allowed by the engine manufacturer, preferably 160 degrees.

2.4 IGNITION SYSTEM REQUIREMENTS

The ignition system is one of the most important systems on an internal combustion engine. Operating an engine on gaseous fuels increases the demands made on the ignition system. When servicing the ignition system, the following points should be kept in mind.



Battery

It is important that the battery be kept clean and in top working order.

- Perform a **battery discharge test**. The battery must be able to hold a full charge to avoid starting problems and ignition misfires.
- Perform an **alternator output test**. If the alternator is not capable of charging the battery starting problems may occur.
- The battery must be **clean**. A dirty battery may suffer from surface discharge, which can rob a battery of starting power.
- The terminals must be **corrosion free**. Corrosion on the battery terminals will increase resistance in the circuit and can lead to hard starting, poor charging and a host of other problems.
- The battery cables must be in good condition with good **clean connections** to the starter or solenoid and ground. Poor battery cables can increase resistance in the circuit
- During cranking 12 volt battery must maintain **at least 9.6 volts**. As a general rule, a 1-volt drop in battery voltage will cause a loss of 5000 volts from the secondary output of the ignition coil.

Ignition Coil & Primary Wiring

It is important that the coil be in top working condition and that it be kept clean.

- **Dirt** and other foreign material can lead to arcing from the coil tower to ground.
- Also it is important that **soldered connectors** be used on the primary wiring not crimped on connectors.
- All connections should be **insulated** and protected by heat shrink tubing.
- Care should also be taken to ensure that the **coil polarity** is correct. With the primary wires disconnected from the coil and the ignition switch on (some engines may need to be cranked) one of the wires should have 12 volts. This wire must be connected to the positive coil terminal. The secondary voltage requirement may be increased 30-40% if the coil polarity is reversed.

Breaker Units

Breaker units can be of the mechanical or electronic type. Both types must be maintained in top operating condition.

- Electronic breaker units require little or no maintenance or adjustments.
- Mechanical breaker units (points & condenser) require **periodic maintenance** of the contact surfaces and adjustment of the point gap/dwell.
- Points that are not kept in good condition will **decrease available secondary voltage** and may lead to misfires, backfires and poor exhaust emissions.

Distributor Cap & Rotor

Again it is very important that the distributor cap and rotor be maintained in top condition.

- Any **build up and/or carbon tracking** inside the distributor cap can lead to cross firing which will cause misfires and/or backfires and increased exhaust emissions. This may be more noticeable under heavy load conditions because secondary voltage requirements will be higher.

- The same holds true for the ignition rotor, any **build up** can lead to misfires and/or backfires.

Secondary Ignition Wires

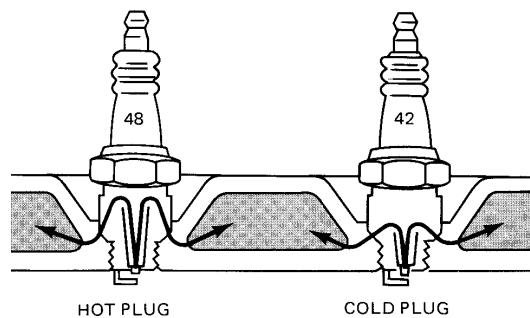
The secondary ignition wires are probably the weakest link in the ignition system. They are exposed to high temperatures, solvents and rough handling.

- It is very important that they are routed away from **sources of heat** such as exhaust manifolds and EGR valves.
- **Oil** from leaks can coat the wires and act as a solvent, which can break down the insulation.
- **Rotating parts and sharp edges** can also damage the insulation leading to short circuits which will cause misfires and/or backfires and increased exhaust emissions.
- When servicing requires that the wires be removed be very careful. **Do not pull on the wire to remove it**, grab the wire by the spark plug boot and pull gently with a twisting motion (special tools are available to remove the wires safely).
- **Dielectric grease** can be used as a lubricant and moisture-proofing agent when installing ignition wires.
- When replacing secondary ignition wires use wires with **high temperature silicone insulation**. These wires are more resistant to high underhood temperatures and solvents.

Spark plugs

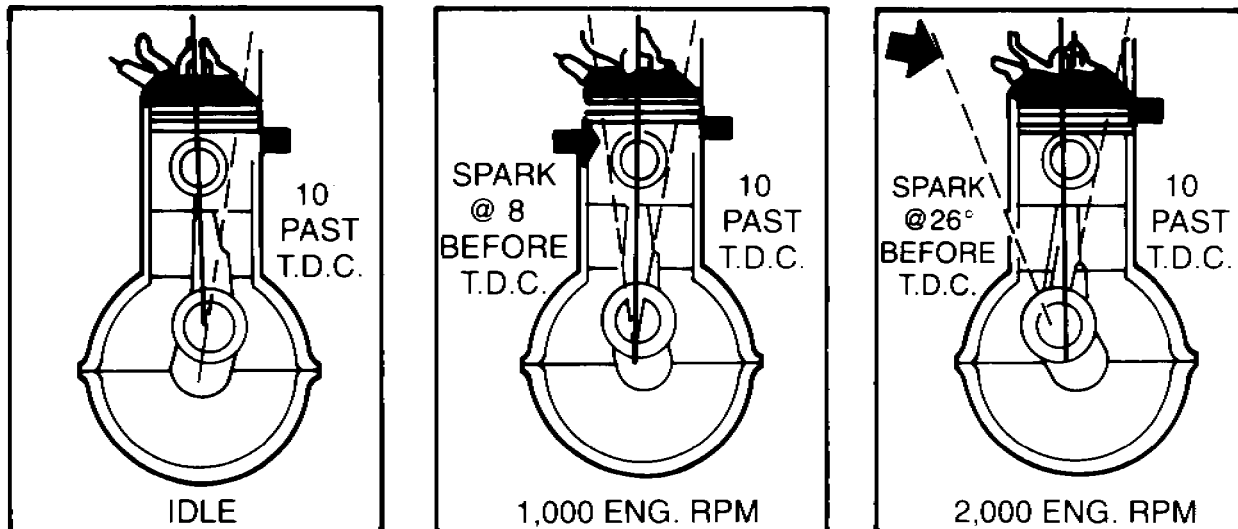
Spark plugs are probably the most important part of the ignition system and selecting the correct spark plug is critical.

- LPG produces **higher spark plug temperatures** than gasoline. Part of the reason for this is the fact that gasoline enters the engine as liquid droplets. When these liquid droplets vaporize they have a cooling effect on the combustion chamber valves and spark plug (this is referred to as "heat of vaporization").
- In **heavy-duty** applications it may be advisable to install spark plugs that are one heat range **colder** than the ones for gasoline.
- One way of choosing the correct spark plug heat range is to install the standard gasoline spark plug and run the engine for 100 hours. Remove and inspect the plugs. If the heat range is correct the plugs will be a light tan in color and the gap will only have increased from .001 inches to .003 inches. If the heat range is too hot the plug will be white in color and the gap will have increased more than .003 inches. In this case a colder plug should be installed and the 100-hour test procedure repeated.
- Care must be taken **not** to use a plug with a heat range that is **too cold**. Colder spark plugs require a higher secondary voltage than hotter ones. If the spark plug used is too cold misfires and/or backfires and increased exhaust emissions will result. Also fouling of the plugs may increase because they will not be hot enough to burn off contaminants.



2.5 IGNITION TIMING

Ignition timing refers to a specific crankshaft position when the spark plug fires measured in degrees of crankshaft rotation.



- **Top Dead Center (TDC)** equal to 0 degrees of crankshaft rotation is always used as the reference point. This is when the piston reaches its highest point of travel in the cylinder. This is the point of highest cylinder compression.
- **Before Top Dead Center (BTDC)** refers to a crankshaft position before the piston reaches TDC. This is the most commonly used measurement of ignition timing.
- **After Top Dead Center (ATDC)** refers to a crankshaft position after the piston has reached its highest point of travel in the cylinder and is now traveling back down the cylinder.

Methods Used To Change Ignition Timing (mechanical distributors).

- **Initial timing advance.** This refers to the position of the distributor housing and breaker unit in relation to the distributor shaft. Initial timing is set by turning the distributor housing. The distributor housing is turned against rotation to advance the timing and turned with rotation to retard timing.
- **Centrifugal timing advance.** This refers to the method used to advance timing as engine RPM increases usually consisting of weights and springs attached to the spinning distributor shaft. As engine speed increases centrifugal force causes the weights to travel outward from the axis of the distributor, overcoming spring pressure which is used to hold the weights in at low engine speed. As the weights travel outward they advance part of the breaker unit attached to the distributor shaft which advances timing.
- **Vacuum timing advance.** This refers to the method used to advance timing as engine load decreases, usually consisting of a diaphragm connected by a rod to the breaker plate and a spring assembly mounted in a chamber with one side of the chamber connected to manifold vacuum. At low engine vacuum (high load) the spring holds the diaphragm to one side of the chamber with no timing advance. As

engine load decreases and engine vacuum increases atmospheric pressure pushes the diaphragm against spring pressure. As the diaphragm moves it moves the breaker plate against the rotation of the distributor advancing the timing.

- For some applications with mechanical distributors aftermarket centrifugal advance springs are available for LPG and CNG operation. These springs allow the centrifugal advance to begin at a lower RPM, which is desirable with LPG and CNG fuels.

Methods Used To Change Ignition Timing (electronic distributors or DIS).

- Electronic distributors perform the same functions as a mechanical distributor. They supply advance with a combination of mechanical and electronic systems.
- DIS (Distributorless Ignition Systems) perform the same functions as a mechanical distributor but they supply advance with a fully electronic system.

Ignition Timing For Engines Designed For Gaseous Fuel Operation

Engines designed by the manufacturer to operate on LPG or CNG will have a more aggressive timing curve specified than a comparable engine designed to operate on gasoline. The reason for this is the fact that LPG burns slower than gasoline and CNG burns even slower than LPG. To compensate for this the ignition timing must be advanced.

Ignition Timing For Gasoline Engines Converted To Gaseous Fuel Operation

When converting an engine designed to run on gasoline contact the engine manufacturer for recommendations on a timing curve for the fuel being used. If the manufacturer has no recommendations consider the following "rule of thumb".

CAUTION – Because of the wide variety of applications, combustion chamber designs, compression ratios and altitudes it is impossible to say for instance "all LPG engines should have initial timing set at X# of degrees". Each engine design must have its timing curve calculated using the manufacturer's gasoline timing curve as a starting point.

LPG

- Ignition timing may be advanced 10% - 20% above the gasoline specification.
- Initial timing plus centrifugal advance timing should not be more than 28 degrees at 2500 RPM (or max governed no load RPM if less than 2500 RPM).
- If vacuum advance is used, initial timing plus centrifugal advance timing plus vacuum advance timing should not be more than 45 degrees total advance.

CNG

- Ignition timing may be advanced 20% - 30% above the gasoline specification.
- Initial timing plus centrifugal advance timing should not be more than 32 degrees at 2500 RPM (or max governed no load RPM if less than 2500 RPM).
- If vacuum advance is used, initial timing plus centrifugal advance timing plus vacuum advance timing should not be more than 45 degrees total advance.

2.6 CRANKCASE OIL REQUIREMENTS

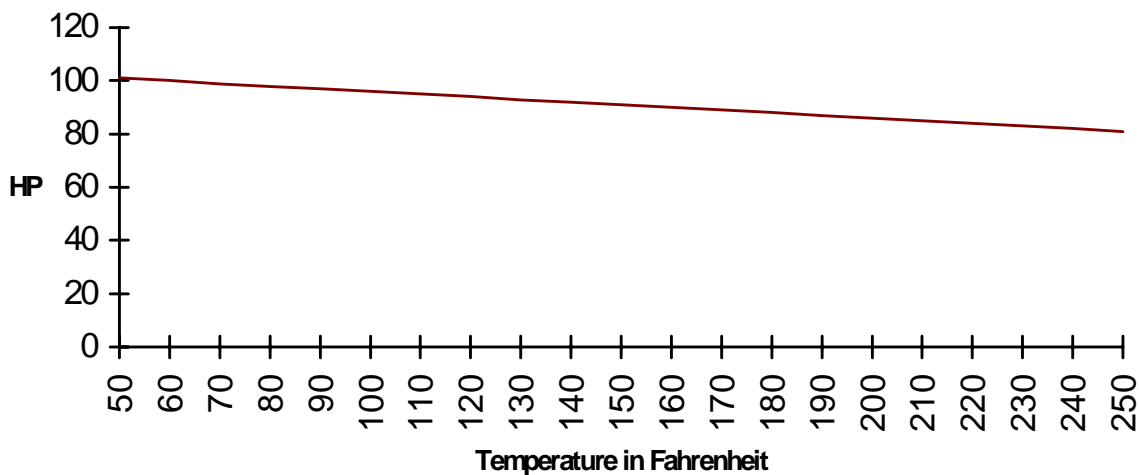
Always follow the engine manufacturer's recommendations for oil type and change intervals. Oil used in gaseous-fueled engines may remain cleaner than oil in gasoline or diesel engines but the affects of friction, heat and pressure cause oil to deteriorate and even though it looks clean it is worn out.

2.7 EFFECTS OF AIR TEMPERATURE ON POWER OUTPUT

The temperature of the air entering an engine is very important for two reasons.

1. Hot air entering an engine can lead to detonation and preignition, which will injure or destroy an engine in short order. The cooler the temperature of the incoming air the healthier it is for the engine.
2. As the temperature of air entering an engine increases it expands becoming less dense and lighter. This reduces the volumetric efficiency and therefore the horsepower output of the engine. For every 10-degree increase of engine intake air temperature the horsepower output drops 1%. Since underhood air temperature can easily reach 200 degrees it is very important that the engine air intake be ducted outside the engine compartment. As an example an engine that makes 100 HP breathing air at 60 degrees will only make 86 horsepower breathing air at 200 degrees. This decrease in power can be explained by the fact that an engine requires 7lbs. of air to make 1 horsepower for 1 hour. As air is heated it expands and becomes less dense and lighter (as in a hot air balloon). A greater volume of air is required to weight 7lbs. An engine running at rated full load RPM can only breath a fixed volume of air. The number of available pounds of air is reduced by using hot air (a 100 cubic inch displacement 4 stroke engine will only pass 100 cubic inches of air and fuel for every 2 revolutions of the crankshaft. The displacement is fixed by the bore and stroke. The displacement cannot increase to allow for the high temperature and lower density of the incoming air).

Intake Air Temperature vs Horse Power

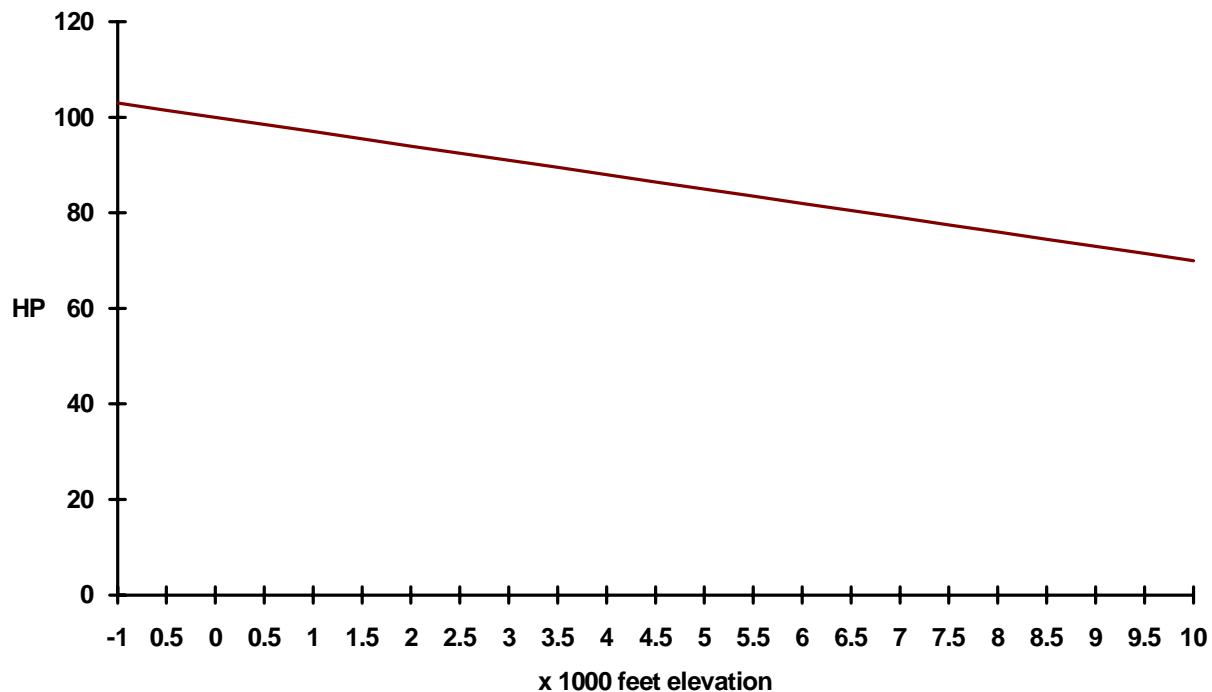


2.8 EFFECTS OF ALTITUDE ON POWER OUTPUT

The altitude at which an engine operates has a dramatic effect on power output. Since atmospheric pressure (14.7psi at sea level) drops as altitude increases air becomes less dense and lighter. Therefore it has the same effect on horsepower output as air temperature described in the previous section. The rate of horsepower decrease is 3% for each 1000 feet increase in altitude. As an example an engine that makes 100 horsepower in Washington, D.C. (elevation 30 feet) will only make about 85 horsepower in Denver Colorado (elevation 5280 feet).

An advantage to using gaseous fuels (LPG, CNG) over liquid fuel (gasoline) is that when altitude increases the density of air and gaseous fuels change at about the same rate, therefore the air fuel ratio remains unchanged. However with a liquid fuel, as altitude increases, air becomes less dense but the liquid fuel does not change therefore the air fuel mixture becomes richer (less pounds of air to a fixed amount of gasoline) and engine horsepower output decreases more than the 3% reduction (per 1000-feet) caused by the decrease in atmospheric pressure.

Altitude vs Horse Power



SECTION 3

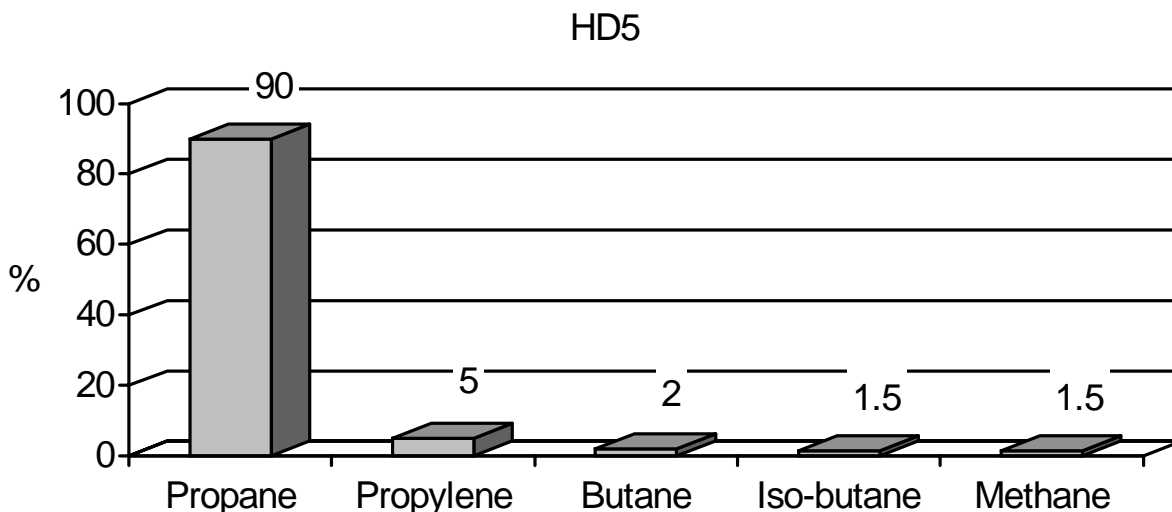
FUEL CHARACTERISTICS

3.1 WHAT IS LPG

LPG is "liquefied petroleum gas" commonly known as propane (C_3H_8), a combustible hydrocarbon based fuel. It comes from the refining of crude oil and natural gas. At normal pressure (29.92"HG) and temperatures above -44F/-45C Propane remains in it's gaseous form. At lower temperatures and/or higher pressures propane will become a liquid. Propane is colorless and odorless. For safety reasons propane is required to be odorized as to indicate positively, by distinct odor, the presence of gas in air down to a concentration of not over 1/5th the lower level of flammability (0.4% in air). This is achieved by adding 1.0#s of ethyl mercaptan, or 1.0#s of thiophane, or 1.4#s of amyl mercaptan per 10,000 gallons of LPG. There are currently three grades of propane available, HD5 for internal combustion engines, commercial propane and commercial propane/butane mix for other uses. The exact composition of propane varies slightly between different parts of the country and different refineries. Compared to gasoline the energy content of LPG is 74%.

The following table shows the approximate composition of HD5.

| PROPANE | | | | | |
|-------------------------|-----------|---------------------------|------------|-----------------------|-------|
| Propane (C_3H_8) | Propylene | Butane (C_4H_{10}) | Iso-Butane | Methane (CH_4) | Total |
| 90.0% min. | up to 5% | 2.0% | 1.5% | 1.5% | 100% |



3.2 WHAT IS CNG

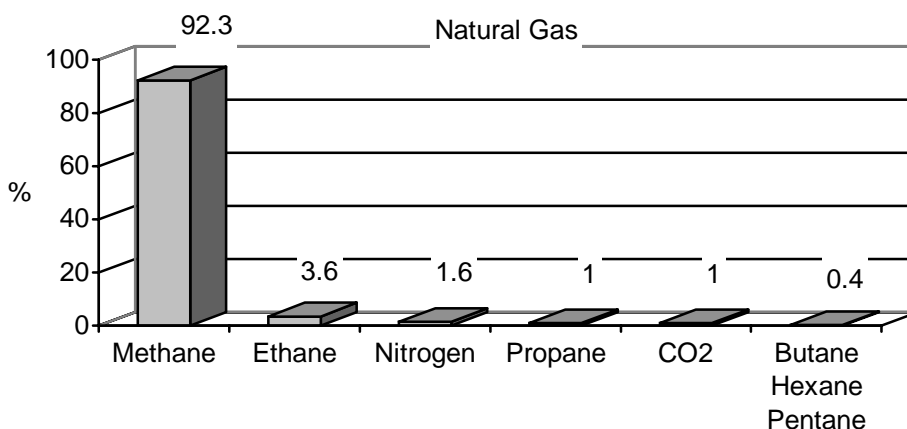
CNG is "compressed natural gas". Natural gas (CH_4) is a naturally occurring mixture of combustible hydrocarbon gases found in porous formations beneath the earth's surface. Natural gas is created by the decomposition of plant and animal remains, under great heat and pressure, over very long periods of time. Natural gas can be found as

- Nonassociated gas - free gas not in contact with significant amounts of crude oil in the reservoir.
- Associated gas - free gas in contact with crude oil in the reservoir.
- Dissolved gas - gas in solution with crude oil in the reservoir.

For safety reasons natural gas is required to be odorized as to indicate positively, by distinct odor, the presence of gas in air down to a concentration of not over 1/5th the lower level of flammability (1.0% in air). This is achieved by adding ethyl mercaptan, or thiophane, or amyl mercaptan to the natural gas. Compared to gasoline the energy content of CNG is 25%.

The exact composition of natural gas varies between different parts of the country and different refineries. The following table shows the approximate composition of natural gas.

| NATURAL GAS | | |
|----------------|---------------------------|------------|
| COMPONENT | | VOLUME = % |
| Methane | CH_4 | 92.3 |
| Ethane | C_2H_6 | 3.6 |
| Propane | C_3H_8 | 1.0 |
| Butanes | C_4H_{10} | 0.3 |
| Pentanes | C_5H_{12} | 0.1 |
| Hexanes | C_6H_{14} | 0.1 |
| Carbon Dioxide | CO_2 | 1.0 |
| Nitrogen | N_2 | 1.6 |
| Total | Natural Gas | 100 |



3.3 WHAT IS LNG

LNG is "liquefied natural gas". Basically natural gas (CH_4) that has been refrigerated to its saturation temperature of $-261^\circ\text{F}/-163^\circ\text{C}$ where it turns to a liquid at normal pressure. As natural gas turns from a gas to a liquid its volume is reduced by 600 times therefore the energy density of LNG is much higher than CNG. From a fuel storage, vehicle operating range, view point this is an advantage over CNG. The composition of LNG is the same as CNG. Compared to gasoline the energy content of LNG is 66%.

3.4 WHAT IS METHANOL

Methanol (CH_3OH) is an alcohol based fuel. It can be produced in several ways.

- Methanol can be produced from natural gas. But, methanol production from natural gas causes considerable energy loss. This process is an inefficient, nonviable method of production.
- Methanol can be produced from coal. But, methanol produced from coal yields higher carbon dioxide emissions. However coal reserves are much greater than oil or natural gas.
- Biomass and urban refuse can provide a long-term supply for the production of methanol. But, the amount of nonrenewable energy input required for the conversion of biomass to methanol is prohibitive.

Compared to gasoline the energy content of methanol is only 49%.

3.5 WHAT IS ETHANOL

Ethanol ($\text{C}_2\text{H}_5\text{OH}$) is an alcohol based fuel. There are basically two ways to produce ethanol.

- Ethanol can be produced by the fermentative method. This method is based on the fermentation of ethanol from corn, sugar, cellulosic and alternative crops.
- Catalytic hydrolysis of ethylene (a petroleum product) is the primary synthetic method.

Compared to gasoline the energy content of ethanol is 66%.

3.6 WHAT IS GASOLINE

Gasoline (C_8H_{16}) is a combustible hydrocarbon based fuel made up of over 200 hydrocarbons and additives. It comes from the refining of crude oil and some refineries can turn more than half of a 42 gallon barrel of crude oil into gasoline. Gasoline is available in many different grades depending on its intended use. For automobiles gasoline is usually available in three different grades, the difference being their octane number.

3.7 WHAT IS DIESEL

Diesel fuel ($\text{C}_{12}\text{H}_{26}$) is a combustible hydrocarbon based fuel used in compression ignition engines. It comes from the refining of crude oil and is available in many different grades with "D2" appearing to be the most popular. The energy content of diesel fuel compared to gasoline is 110%.

3.8 COMPARISON OF FUEL PROPERTIES

| | CNG | Methanol | LNG | Ethanol | Propane | Gasoline | Diesel |
|---|-------------------|-------------------------------|--------------------|----------------------------------|-------------------------------|--------------------------------|---------------------------------|
| Formula | CH ₄ | C ₃ H ₈ | CH ₄ | C ₂ H ₅ OH | C ₃ H ₈ | C ₈ H ₁₆ | C ₁₂ H ₂₆ |
| Research Octane # | 130 | 112 | 130 | 111 | 112 | 91-98 | N/A |
| Motor Octane # | 130 | 91 | 130 | 92 | 97 | 82-90 | |
| Cetane # | -10 | 3 | -10 | 8 | 5-10 | 8-14 | 40-60 |
| Boiling Point °F/°C | -259/-162 | N/A | -259/-162 | N/A | -44/-42 | (81-464)/ (27-240) | N/A |
| Energy Content (volume) (BTU/ft ³) / (kJ/L) | 213,300/ 7,875 | 425,000/ 15,688 | 569,200/ 21,013 | 570,000/ 21,027 | 637,500/ 25,535 | 862,100/ 31,825 | 950,400/ 35,082 |
| Energy vs Gasoline % | 25 | 49 | 66 | 66 | 74 | 100 | 110 |
| Stoich A/F Ratio (mass) | 17.3 | 6.5 | 17.3 | 9.0 | 15.7 | 14.7 | 15.0 |
| Autoignition Temperature °F/°C | 842/450 | N/A | 842/450 | N/A | 1,004/540 | 428/220 | 437/225 |
| Peak Flame Temperature °F/°C | 3,254/ 1,790 | N/A | 3,254/ 1,790 | N/A | 3,614/ 1,990 | 3,591/ 1,977 | 3,729/ 2,054 |
| Flammability Lower Limit (volume %) | 5.3 | 4.0 | N/A | N/A | 2.1 | 1.4 | N/A |
| Flammability Upper Limit (volume %) | 15.0 | 75.0 | N/A | N/A | 10.4 | 7.6 | N/A |

3.9 LPG PRESSURE VERSUS TEMPERATURE

It can be difficult to picture in our minds the effects of temperature and pressure on propane because the propane we deal with on a daily basis is always sealed inside a storage container, out of sight. To help us to understand propane better we will compare it to a substance that we are all familiar with, water. We will use an automotive cooling system to illustrate water under pressure at different temperatures. Liquid propane and water act very similar to temperature changes, the difference being the temperature at which events take place.

Table #1 lists the vapor pressure inside a propane container, at a particular temperature, containing some liquid but not more than 80% total capacity. This allows for a 20% vapor space.

| TABLE #1 | | | |
|-------------|--------|------------------------------------|------|
| TEMPERATURE | | VAPOR PRESSURE | |
| deg. F | deg. C | PSIG | kPa |
| 130 | 54 | 257 | 1794 |
| 110 | 43 | 197 | 1358 |
| 100 | 38 | 172 | 1186 |
| 90 | 32 | 149 | 1027 |
| 80 | 27 | 128 | 883 |
| 60 | 16 | 92 | 637 |
| 30 | -1 | 51 | 356 |
| 0 | -18 | 24 | 162 |
| -20 | -29 | 11 | 74 |
| -44 | -42 | propane begins to boil @ sea level | |
| -45 | -43 | 0 | 0 |

Table #2 lists the boiling point of water at a particular pressure.

| TABLE #2 | | | |
|-------------|--------|----------------------------------|-----|
| TEMPERATURE | | PRESSURE | |
| deg. F | deg. C | PSIG | kPa |
| 260 | 127 | 16 | 110 |
| 254 | 123 | 14 | 96 |
| 248 | 120 | 12 | 82 |
| 242 | 117 | 10 | 69 |
| 236 | 113 | 8 | 55 |
| 230 | 110 | 6 | 41 |
| 224 | 107 | 4 | 28 |
| 218 | 103 | 2 | 14 |
| 212 | 100 | water begins to boil @ sea level | |
| 211 | 99 | 0 | 0 |

Table #3 lists the similarities of water and propane.

| TABLE #3 | |
|---|--|
| WATER | PROPANE |
| Water is a clear liquid below 212 deg. F. | Propane is a clear liquid below -44 deg. F. |
| At sea level water begins to boil at 212 deg. F. | At sea level propane begins to boil at -44 deg. F. |
| When water boils it becomes water vapor (steam). | When propane boils it becomes propane vapor. |
| From a liquid to a vapor water expands 700 times its liquid volume. | From a liquid to a vapor propane expands 270 times its liquid volume. |
| A vehicle cooling system uses pressure to keep the water in its liquid form at temperatures above its normal boiling point. | A propane storage container uses pressure to keep the propane in its liquid form above its normal boiling point. |
| Below its boiling point water in liquid form expands when heated but does not vaporize. | Below its boiling point propane in liquid form expands when heated but does not vaporize. |
| Water in liquid form cannot be compressed. | Propane in liquid form cannot be compressed. |
| Water in vapor form can be compressed. | Propane in vapor form can be compressed. |
| Water in a vehicle cooling system takes on heat from the metal walls of the engine block. | Propane in a fuel storage container takes on heat from the metal walls of the container. |

How Can Propane Be Stored As A Liquid Above Its Boiling Point of -44 DEG. F.

We can increase the boiling point of liquid propane by applying pressure against it similar to the way a vehicle cooling system raises the boiling point of water by holding pressure in the system through the use of a radiator pressure cap. For example if we look at table #2 we see that at normal atmospheric pressure water boils at 212 deg. F. If we use a 10 psig rad cap to hold 10 psig against the water it's boiling point increases to 242 deg. F. Therefore the water remains liquid at 242 deg. F. Liquid propane reacts in much the same way to temperature and pressure as water, its just that propane's boiling point is much lower on the thermometer. For example if we look at table #1 we can see that if we had a bucket full of liquid propane and the temperature was below -44 deg. F the propane would remain a liquid at normal atmospheric pressure. The propane would look and act just like water does in its liquid form. If we raise the temperature of the propane in the bucket above -44 deg. F it would look and act just like water in a pot on the stove, it would boil and vaporize. The propane would continue to boil and vaporize until the bucket was empty. If we take that bucket of propane and we pour it into a propane container and seal it and the temperature is below -44 deg. F not much happens. The propane remains liquid. However if we raise the temperature of the container to 80 deg. F the propane will boil and vaporize. Since the propane is now in a sealed container with a fixed volume and we now know from table #3 that propane expands 270 times in volume when it changes from a liquid to a vapor, the propane

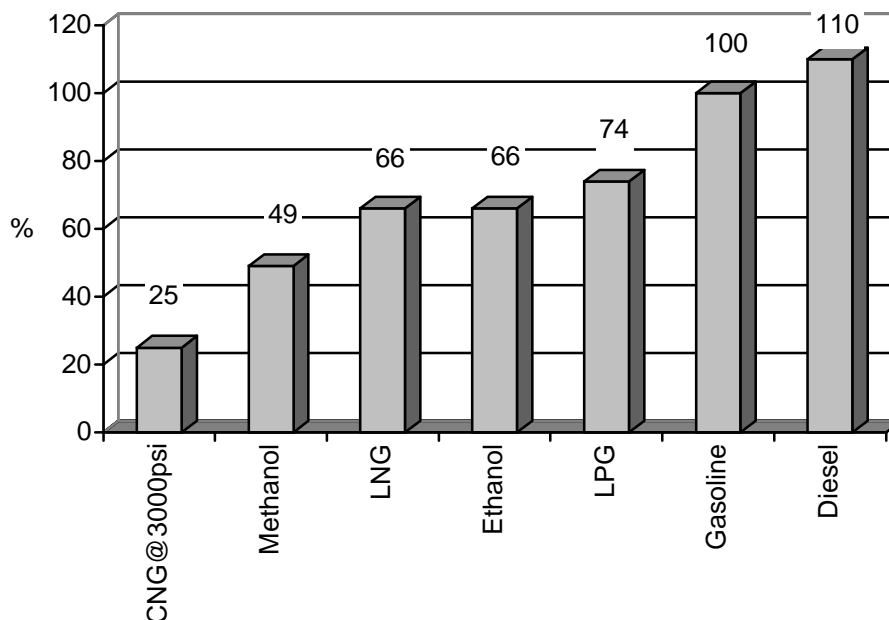
vapor begins to compress. As the propane vapor compresses the pressure inside the container will begin to increase. Table #1 shows that at 80 deg. F the vapor pressure inside the container should be 128 psig. Therefore the propane will continue to boil and vaporize, the vapor will continue to compress, the pressure will continue to increase until it reaches 128 psig. With 128 psig vapor pressure acting against the liquid propane the boiling point has been raised to slightly more than 80 deg. F. Therefore the propane will stop boiling. It is the vapor pressure that governs the boiling point of the liquid propane inside the container. In turn the amount of vapor pressure generated inside the container is governed by the ambient temperature outside the container. To review, liquid propane will boil above -45 deg. F unless pressure is held against it. The amount of vapor pressure required to stop the liquid propane from boiling depends on the ambient temperature outside the container.

Does The Amount Of Liquid Effect The Pressure Inside A Propane Storage Container?

No. An important fact to remember is that since the vapor pressure inside the propane container is governed by ambient temperature outside the container not the amount of liquid propane inside. A container that is 1/4 full at 80 deg. F will contain the same vapor pressure as a container that is 3/4 full at 80 deg. F. The vapor pressure is not generated by the amount of liquid in the tank. As long as there is some liquid and not more than 80% liquid inside the container, ambient temperature outside the container will govern the vapor pressure inside the container.

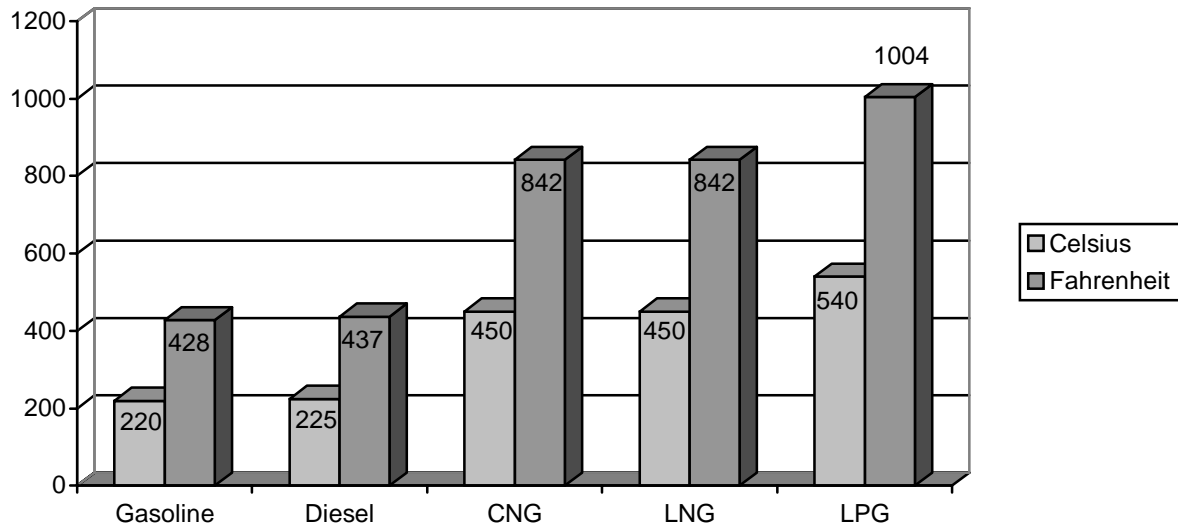
3.10 COMPARISON OF ENERGY CONTENT

Energy content per unit of fuel (energy density) is an important factor affecting range and power output of internal combustion engines. The following chart compares the energy content of alternate fuels to gasoline.



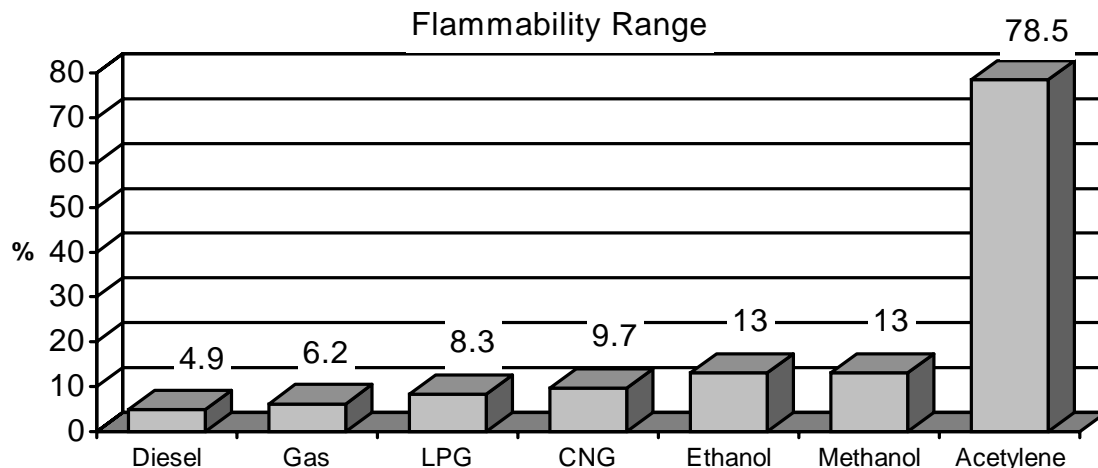
3.11 COMPARISON OF AUTO-IGNITION TEMPERATURE

The auto-ignition temperature is the temperature at which a fuel will ignite without the need for a spark or flame. In respect to auto-ignition temperature LPG, CNG and LNG are much safer than gasoline or diesel because the auto-ignition temperature is much higher. The following chart compares the auto-ignition temperature of various fuels.



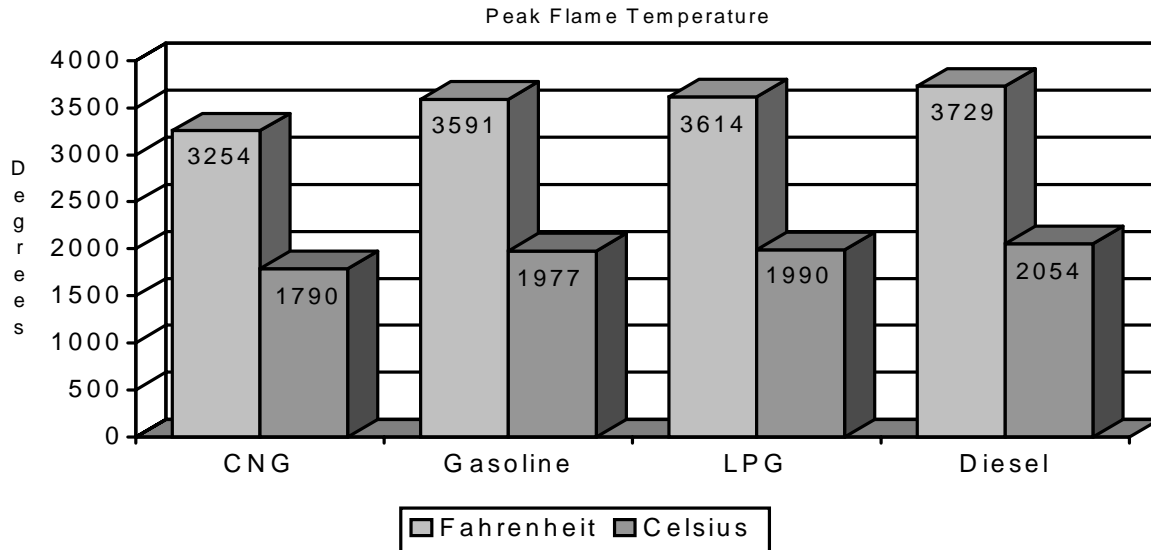
3.12 COMPARISON OF FLAMMABILITY RANGE

The flammability range is the distance from the leanest (LEL- Lower Explosion Limit) to the richest (UEL- Upper Explosion Limit) mixture of fuel and air that will burn. Fuels with narrower ranges are safer to work with but are less versatile because they offer less choice of air to fuel ratios. The following table compares the flammability range of various fuels.



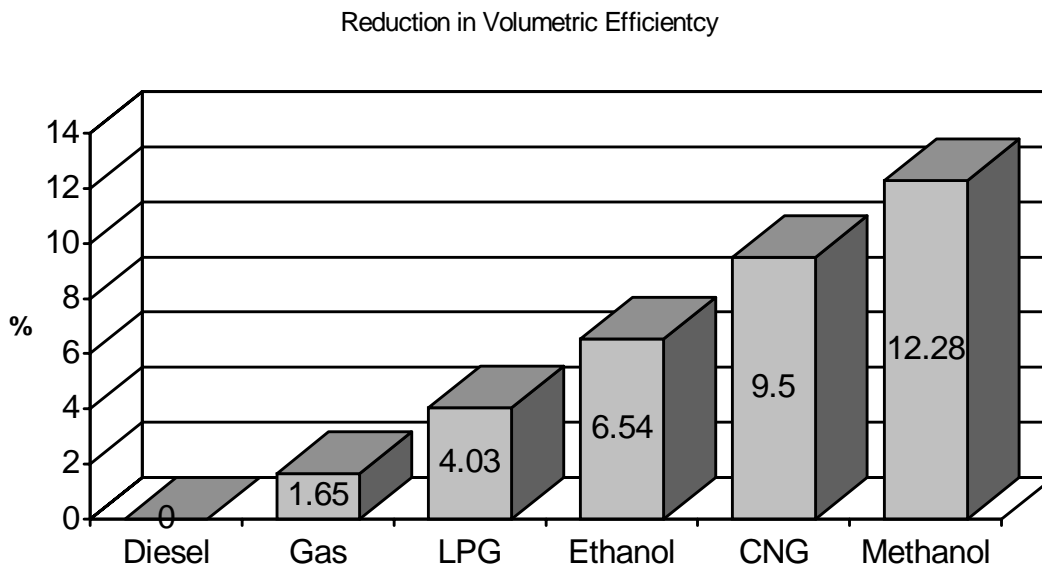
3.13 COMPARISON OF PEAK FLAME TEMPERATURE

The following chart compares the peak flame temperature of various fuels. You can see that CNG has a peak flame temperature of 1790C/3254F which is 187C/337F or 9.5% cooler than the peak flame temperature of gasoline at 1977C/3591F. The peak flame temperature of propane at 1991C/3614F is only 13C/23F or less than 1% higher than gasoline.



3.14 COMPARISON OF VOLUMETRIC EFFICIENCY

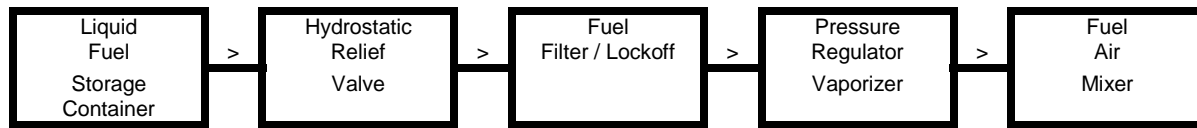
The amount of air entering an engine at a particular throttle angle and load is fixed. Any fuel added to the air before it enters the cylinder will displace an equal volume of air and will reduce the volumetric efficiency and power output of the engine. The table below illustrates the reduction of volumetric efficiency of various fuels.



SECTION 4

LPG FUEL SYSTEMS

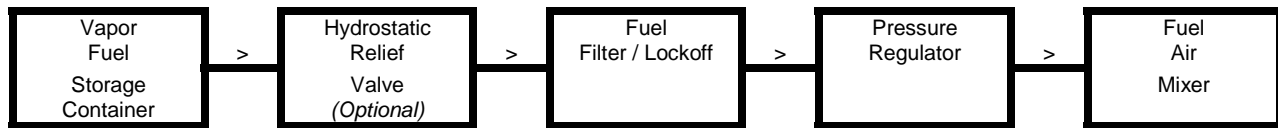
4.1 LIQUID WITHDRAWAL LPG SYSTEM THEORY OF OPERATION



- Propane is stored on-board the vehicle as a liquid under pressure in the fuel tank to a maximum volume of 80% of total water capacity (the pressure is created by ambient air temperatures above -45deg F). This leaves a minimum vapor space of 20% of total water capacity. The fuel tank liquid outlet draws liquid propane from the bottom of the tank. It is very important that the tank be mounted in the correct position. When the liquid outlet valve in the tank is opened liquid propane flows out of the tank through the service line, past the hydrostatic relief valve to the fuel filter lockoff.
- The purpose of the hydrostatic relief valve is to protect the service line from over pressurization when the service valve is closed and the fuel lockoff is closed. Some fuel tanks are equipped with the hydrostatic relief valve built into the service valve. These valves are marked "WITH RELEIF". The advantage to having the hydrostatic relief valve built into the service valve is that if the hydrostatic relief valve vents, the fuel is returned to the tank instead of being released into the atmosphere, even if the service valve is closed. This obviously is much safer.
- The fuel filter lockoff is normally closed. It requires a vacuum or electric signal from the engine cranking or running to open. This is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops (electric fuel lockoffs must have a vacuum or oil pressure safety switch in series with the power feed to the lockoff). When the fuel filter lockoff receives the desired vacuum or electric signal from the engine it opens and allows liquid propane at tank pressure to flow to the pressure regulator (some fuel lockoffs require a separate filter mounted upstream of the fuel lockoff, the Impco model VFF-30 fuel lockoff has an integral 10 micron filter).
- The Impco series of negative pressure regulators are normally closed, they require a vacuum signal from the air fuel mixer to allow fuel to flow. Again this is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops. When the pressure regulator receives the desired vacuum signal from the air fuel mixer it allows propane to flow. As the propane flows through the pressure regulator the pressure is reduced in two stages from tank pressure to slightly less than atmospheric pressure (it is very important that the outlet pressure of the regulator and the inlet pressure of the air fuel mixer be matched properly, this problem can be avoided by using a pressure regulator and air fuel mixer from the same manufacturer). As the pressure of the propane is reduced the liquid propane vaporizes and refrigeration occurs inside the pressure regulator. To replace heat lost to refrigeration and avoid regulator freezing Impco liquid propane pressure regulators are designed to be hooked up to the vehicle cooling system. The heat from the engine coolant replaces heat lost to the vaporization process.
- In the Impco series of air fuel mixers the fuel passage is normally closed. A vacuum signal from the engine cranking or running is required to draw fuel from the fuel

outlet. This again is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops. When the mixer receives the desired vacuum signal from the engine it draws a metered amount of propane vapor from the pressure regulator and blends it with air at the proper ratio to achieve peak engine performance over the complete operating range.

4.2 VAPOR WITHDRAWAL LPG SYSTEM THEORY OF OPERATION



- Propane is stored on-board the vehicle as a liquid under pressure in the fuel tank to a maximum volume of 80% of total water capacity (the pressure is created by ambient air temperatures above -45deg F). This leaves a minimum vapor space of 20% of total water capacity. The fuel tank vapor outlet draws propane vapor from the vapor space at the top of the tank. It is very important that the tank be mounted in the correct position. Incorrect mounting and/or over filling of the tank must be avoided as this may lead to liquid propane exiting through the vapor outlet of the tank. When the vapor service valve in the container is opened propane vapor flows out of the container through the service line, past the hydrostatic relief valve to the fuel filter lockoff.
- The hydrostatic relief valve protects the service line from over pressurization when the service valve is closed and the fuel lockoff is closed. Some fuel tanks are equipped with the hydrostatic relief valve built into the service valve. These valves are marked "WITH RELEIF". The advantage to having the hydrostatic relief valve built into the service valve is that if the hydrostatic relief valve vents, the fuel is returned to the tank instead of being dumped into the atmosphere, even if the service valve is closed. This obviously is much safer.
- The fuel filter lockoff is normally closed. It requires a vacuum or electric signal from the engine cranking or running to open. This is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops (electric fuel lockoffs must have a vacuum or oil pressure safety switch in series with the power feed to the lockoff). When the fuel filter lockoff receives the desired vacuum or electric signal from the engine it opens and allows propane vapor at tank pressure to flow to the pressure regulator (some fuel lockoffs require a separate filter mounted upstream of the fuel lockoff, the Impco model VFF-30 fuel lockoff has an integral 10 micron filter).
- The Impco series of negative pressure regulators are normally closed, they require a vacuum signal from the air fuel mixer to allow fuel to flow. Again this is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops. When the pressure regulator receives the desired vacuum signal from the air fuel mixer it allows fuel to flow. As the fuel flows through the pressure regulator to the air fuel mixer the pressure is reduced in two stages from tank pressure to slightly less than atmospheric pressure (it is very important that the outlet pressure of the regulator and the inlet pressure of the air fuel mixer be matched properly this

problem can be avoided by using a pressure regulator and air fuel mixer from the same manufacturer).

- In the Impco series of air fuel mixers the fuel passage is normally closed. A vacuum signal from the engine cranking or running is required to draw fuel from the fuel outlet. This again is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops. When the mixer receives the desired vacuum signal from the engine it draws a metered amount of propane vapor from the pressure regulator and blends it with air at the proper ratio to achieve peak engine performance over the complete operating range.

SECTION 5

CNG FUEL SYSTEMS

5.1 CNG SYSTEM THEORY OF OPERATION



- Natural gas (NG) is stored on-board the vehicle under pressure in the fuel storage cylinder (cylinder) as a compressed gas (CNG) to a maximum pressure of approximately 3600psi.
- When the valve in the fuel storage cylinder is opened CNG, at cylinder pressure, flows to the 1/4 turn valve (emergency shut off). As the name suggests the 1/4 turn valve requires only a 1/4 turn to open or close. The purpose of the 1/4 turn valve is to provide a means of quickly stopping fuel flow in case of a system malfunction. The 1/4 turn valve is mounted close to the cylinder and is normally left in the open position. A decal is usually attached to the exterior of the vehicle indicating the location of the " emergency shut off "
- From the 1/4 turn valve CNG, at cylinder pressure, flows to the multi-turn valve. The multi-turn valve is mounted in the engine compartment and provides a place to shut off the flow of CNG when disassembly and/or servicing of the fuel system and/or engine are required. A high pressure gauge is mounted on the cylinder side of the multi-turn valve to show cylinder pressure. An electronic fuel gauge sending unit may be mounted on the outlet side of the multi-turn valve. Also a fill connection is either directly mounted or remotely connected to the outlet side of the multi-turn valve.
- From the multi-turn valve CNG, at cylinder pressure flows to the High Pressure Regulator (HPR). The HPR reduces the pressure of the CNG in one stage from cylinder pressure to 150psi.
- From the HPR, CNG flows to the fuel filter lockoff. The fuel filter lockoff is normally closed. It requires a vacuum or electric signal from the engine cranking or running to open. This is a desirable safety feature because if the engine stops or is turned off fuel flow automatically stops (electric fuel lockoffs must have a vacuum or oil pressure safety switch in series with the power feed to the lockoff). When the fuel filter lockoff receives the desired vacuum or electric signal from the engine it opens and allows CNG to flow to the pressure regulator (some fuel lockoffs require a separate filter mounted upstream of the fuel lockoff, the Impco model VFF-30 fuel lockoff has an integral 10 micron filter).
- From the fuel filter lockoff CNG flows to the pressure regulator. As the CNG flows through the pressure regulator the pressure is reduced in two stages from HPR output pressure to slightly more than atmospheric pressure (it is very important that the outlet pressure of the regulator and the inlet pressure of the air fuel mixer be matched properly, this problem can be avoided by using a pressure regulator and air fuel mixer from the same manufacturer).
- From the pressure regulator NG flows to the air fuel mixer. In the Impco series of air fuel mixers the fuel passage is normally closed. A vacuum signal from the engine cranking or running is required to draw fuel from the fuel outlet. This again is a

desirable safety feature because if the engine stops or is turned off fuel flow automatically stops. When the mixer receives the desired vacuum signal from the engine it draws a metered amount of NG from the pressure regulator and blends it with air at the proper ratio to achieve peak engine performance over the complete operating range.

SECTION 6

LPG FUEL STORAGE

6.1 THE CONSTRUCTION OF LPG FUEL STORAGE CONTAINERS

LPG fuel storage containers for industrial and lift trucks are available in two styles:

1. Portable universal cylinders.

- These containers are constructed in accordance with the DOT-TC (United States Department of Transport – Transport Canada) code and/or specifications. In some cases they may be constructed in accordance with the ASME (American Society of Mechanical Engineers) code for a container of a similar size, designed for a similar service.
- Portable universal cylinders are used primarily on off-highway vehicles at locations that do not have on-site refueling. They can be removed from the vehicle or equipment and transported to a re-fueling site to be filled. These cylinders are called universal because they can be used in the vertical or horizontal position.
- When used in the horizontal position a round hole in the cylinder collar must be aligned with a locating pin on the mounting bracket.
- Cylinders may be exchanged indoors.
- **Cylinders must be stored outdoors in a secure area.**

2. Permanently mounted tanks.

- These containers are constructed in accordance with the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code (section VIII "Rules for the Construction of Unfired Pressure Vessels").
- These containers may also be constructed in accordance with the API-ASME (American Petroleum Institute-American Society of Mechanical Engineers) code.
- Permanently mounted tanks are primarily used on over the road vehicles where the vehicle can travel to a refueling station.

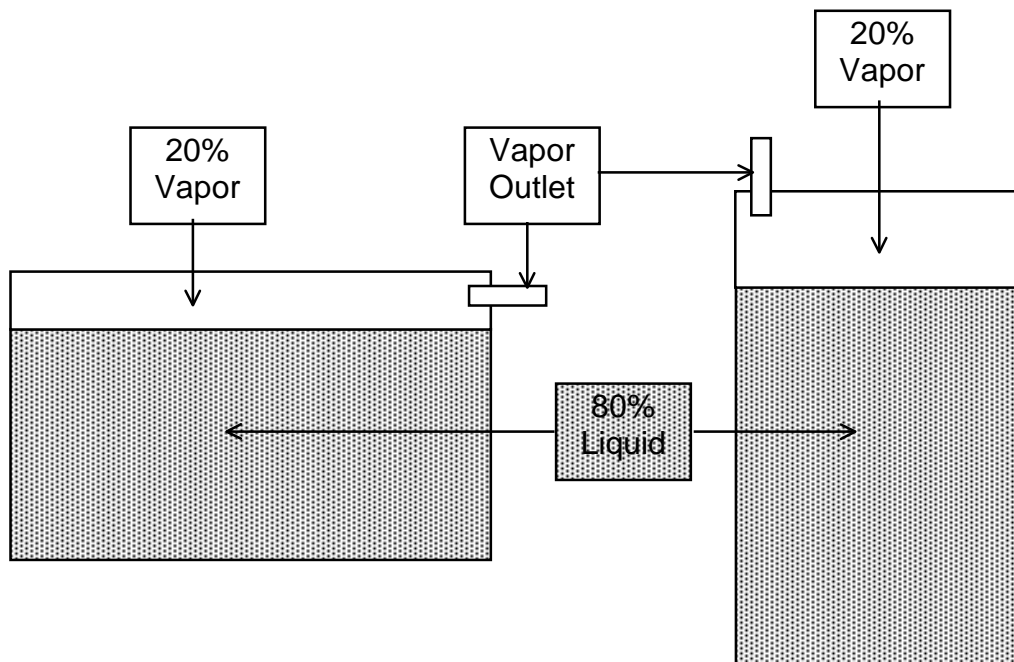
All openings in an LPG fuel container, except for the safety pressure relief port and the liquid contents gauge port must be protected by one of the following:

- A #54 drill size hole.
- A manual shutoff valve equipped with an excess flow valve. Any piping installed must have a rated flow higher than that of the excess flow valve in order for it to function properly.
- A double back-flow check valve
- A steel pipe plug (unused openings).

6.2 LPG VAPOR WITHDRAWAL

Vapor withdrawal LPG fuel containers are designed for fuel systems that require fuel to be supplied to the pressure regulator in vapor form. Since propane expands 270 times from a liquid to a vapor much less fuel can flow through the fuel line to the engine therefore vapor withdrawal systems are used primarily on small displacement engines. Inside the fuel container there is a dip tube attached to a vapor outlet port. This dip tube is designed in such a way that the open end is positioned in the vapor space above the 80% liquid level of the fuel container when the fuel container is positioned properly (see section "6-4 LPG Fuel Container Orientation" for details on cylinder positioning). It is also very important that the fuel container not be filled with liquid to more than 80% of total water capacity. Over filling and/or incorrect positioning of the fuel container may allow liquid propane to enter the vapor fuel system through the vapor outlet port of the fuel tank causing the fuel system to malfunction. Frost forming on the vapor pressure regulator may be an indication that the fuel tank is over filled/incorrectly positioned. On vapor withdrawal fuel systems the propane, stored as a liquid in the fuel container, is allowed to vaporize in the fuel container before entering the fuel system. Since propane absorbs heat when it vaporizes the surface area of the fuel container must be capable of supplying enough heat from the surrounding air to support the vaporization process. If the surface area of the fuel container is not large enough to support the vaporization process fuel pressure will drop and a reduction of engine power output may result. Frost forming on the outside of the tank may be an indication that the surface area of the container is not large enough to support the rate of vaporization.

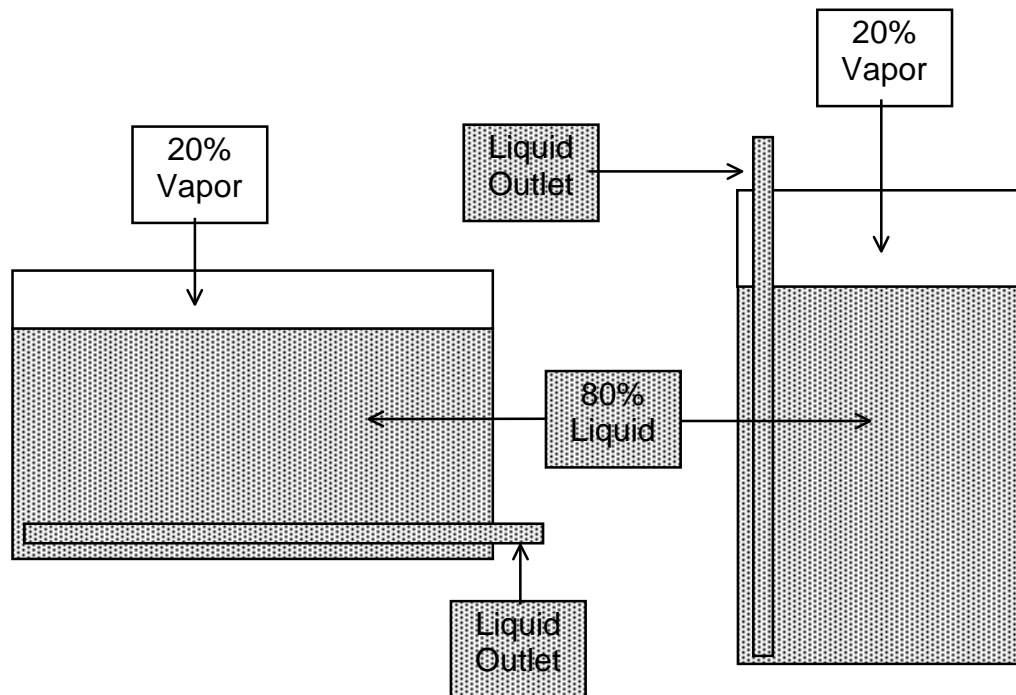
Schematic Of Lpg Vapor Withdrawal Container



6.3 LPG LIQUID WITHDRAWAL

Liquid withdrawal LPG fuel containers are designed for fuel systems that require fuel to be supplied to the pressure regulator in liquid form. Inside the fuel container there is a dip tube attached to a liquid outlet port. This dip tube is designed so that the open end reaches the bottom of the fuel container when the container is positioned properly (see section "6-4 LPG Fuel Container Orientation" for details on cylinder positioning). Incorrect positioning of the fuel container may allow propane vapor to enter the liquid propane fuel system through the liquid outlet port of the fuel container. A lack of engine power output and/or frost on the fuel container may be an indication that the fuel container is not positioned properly.

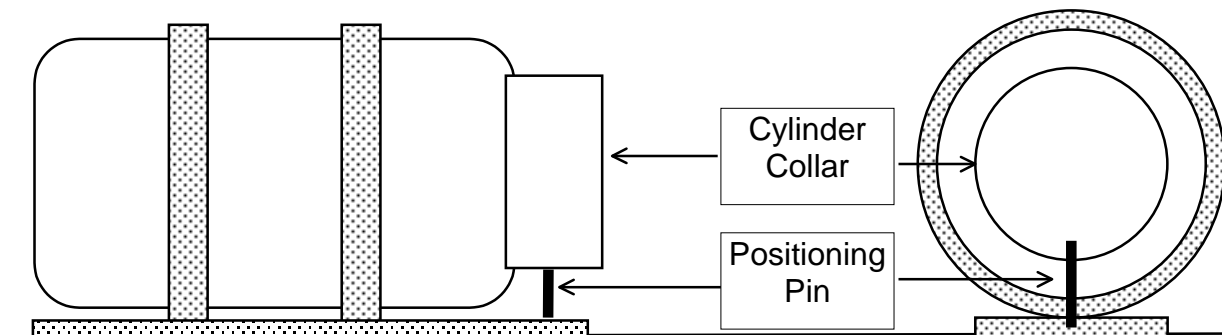
Schematic Of Lpg Liquid Withdrawal Cylinder



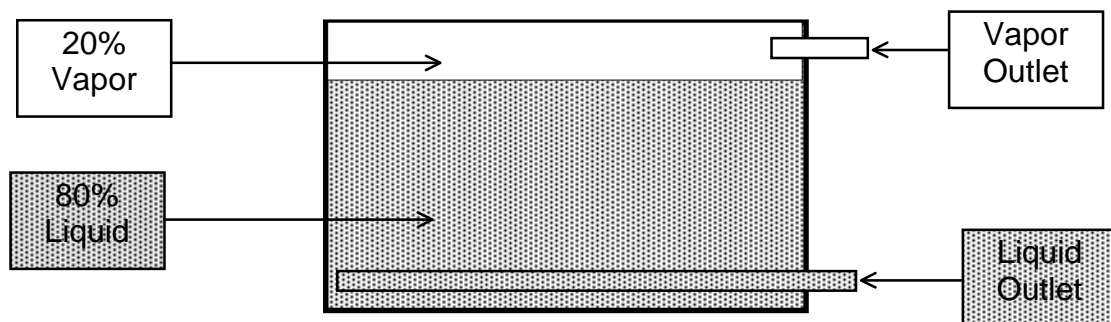
6.4 LPG FUEL CONTAINER ORIENTATION

Portable Universal Cylinders.

Portable universal cylinders are designed, to be mounted, in either the vertical or horizontal position. When positioning the cylinder in mounting brackets that are mounted vertically the exact position of the cylinder in the mounting brackets is not important. **When positioning the cylinder in mounting brackets that are mounted horizontally, cylinder position is very important.** The cylinder mounting bracket is equipped with a 1/2" diameter positioning pin that points upward at the valve end of the cylinder. This pin is designed to fit into a round hole in the cylinder collar. If the positioning pin is missing just remember that the 1/2" diameter round hole in the cylinder collar must point straight down. If the cylinder is not positioned properly the safety relief valve, fuel gauge, liquid outlet and/or vapor outlet may not function properly.

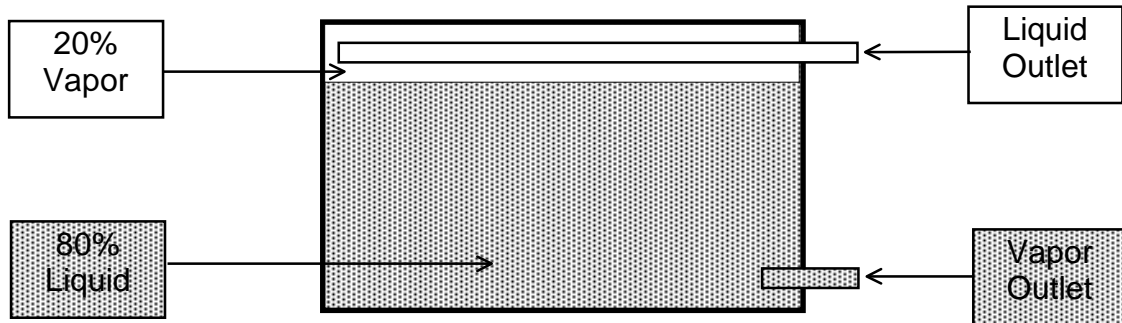


Schematic of LPG Cylinder in Correct Position.



Schematic of LPG Cylinder Positioned Incorrectly 180 Degrees Off.

*Notice the liquid propane exiting through the vapor outlet and propane vapor exiting through the liquid outlet.

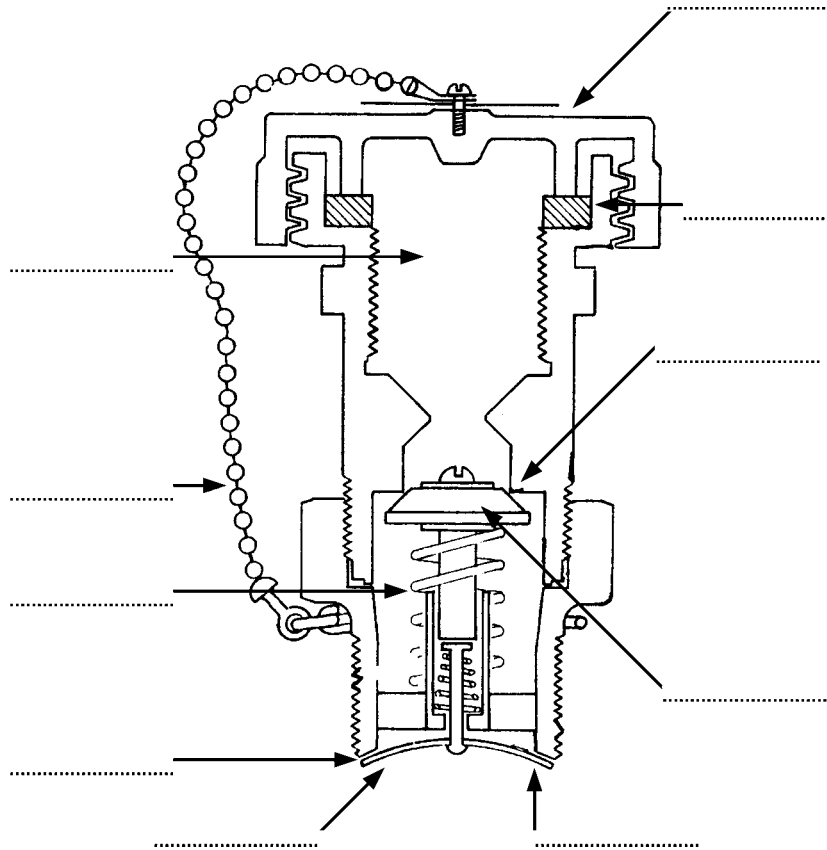
**Permanently Mounted Fuel Tanks**

Permanently mounted fuel tanks are designed to be mounted in one position only. Some models come equipped with mounting feet welded onto the tank, others are designed to use hoop type mounting brackets. Most fuel tanks will be equipped with some type of marking indicating the top of the tank. This marking must point straight up regardless of how or where the fuel tank is mounted. If the tank is not positioned properly the safety relief valve, fuel gauge, liquid outlet and/or vapor outlet may not function properly.

6.5 LPG CONTAINER VALVES AND FITTINGS

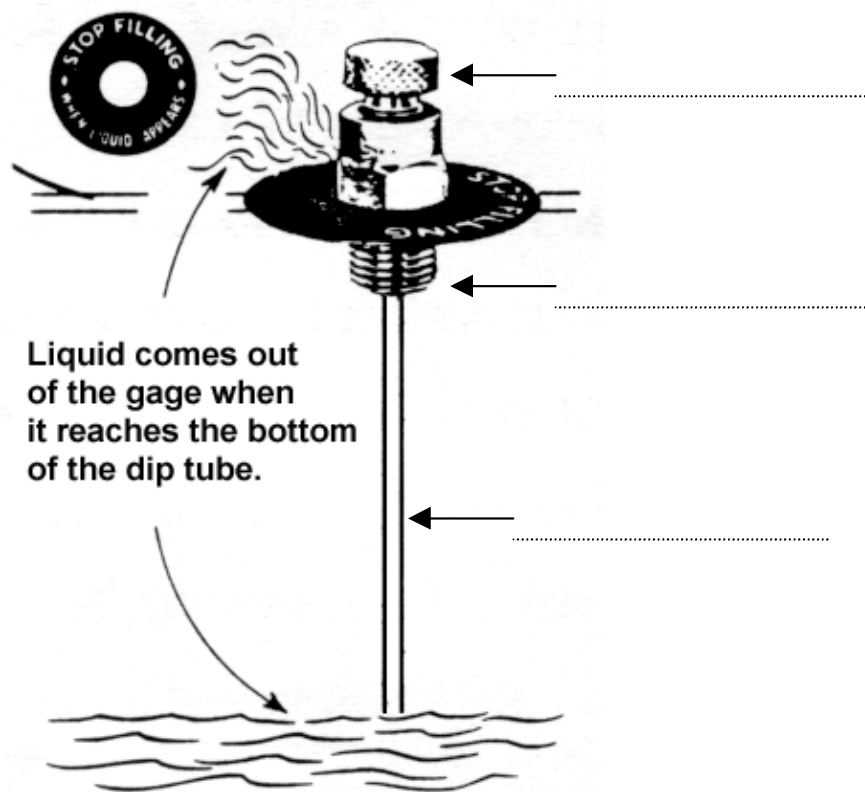
Liquid Fill Valve

The liquid fill valve is basically two one way backpressure check valves mounted in a machined brass assembly. The liquid fill valve has a 1" male pipe thread (1"npt) on the outlet side so that the liquid fill valve can be mounted in the liquid fill port of the fuel tank. The inlet side of the liquid fill valve is equipped with a male thread that allows the fuel dispenser nozzle to be securely fastened to the valve during refueling. The inlet side of the liquid fill valve is also equipped with a plastic cap on a small chain. This plastic cap should be securely fastened to the liquid fill valve between refueling to stop dirt and debris from contaminating the fill valve. The liquid fill valve operates by allowing propane to travel in one direction only, into the fuel tank. Once propane has entered the fuel tank the two back- pressure check valves prevent it from exiting the fuel tank through the fill valve. The back-pressure check valves are designed in such a way that pressure in the fuel tank acting on the back of the valve (back-pressure) adds to the valves own spring pressure and actually helps the valves to seal. The first back-pressure check valve provides a neoprene to metal seal and the second back-pressure check valve provides a metal to metal seal. An important safety feature of the liquid fill valve is a weakness ring machined into the brass assembly just above the two-backpressure check valves. This weakness ring is designed to shear in the case of a mishap. By shearing above the two back-pressure check valves the back-pressure check valves remain in the tank to stop the propane from escaping.



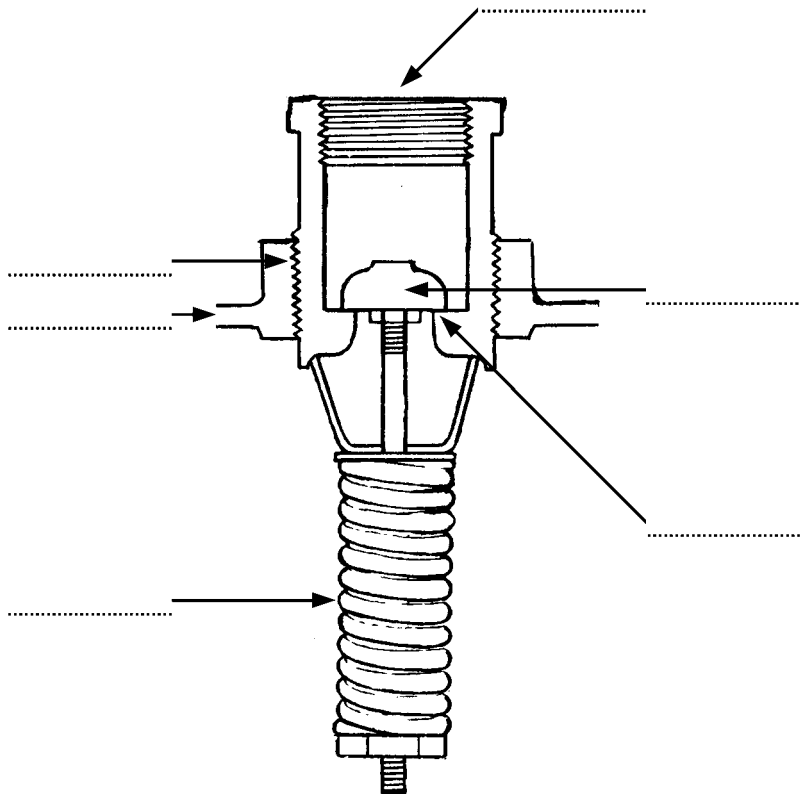
Fixed Tube Liquid Level Gauge

The fixed tube liquid level gauge is basically a manually operated valve with a dip tube attached on the tank side of the valve which reaches the 80% liquid volume level of the fuel tank. The fixed tube liquid level gauge has a 1/4" male pipe thread (1/4"npt) on the tank side of the valve which allows it to be installed in the fixed tube liquid level gauge port of the fuel tank. The outlet side of the valve is equipped with a small outlet port (#54 drill size hole). This outlet port is controlled by a small finger wheel which is turned counter clockwise to open and clockwise to close (always use fingers to open and close the valve never use a tool such as pliers or vise grips as this will damage the neoprene valve seat). The fixed tube liquid level gauge is normally closed, it is only used during refueling. After the refueling attendant has attached the fuel dispenser nozzle to the liquid fill valve he opens the fixed tube liquid level gauge and then starts to fill the fuel tank. While the level of propane in the fuel tank is below the 80% liquid volume level only a small amount of propane vapor can be heard exiting the fuel tank through the fixed tube liquid level gauge. When the propane in the fuel tank reaches the 80% liquid volume level liquid propane will be seen exiting the fixed tube liquid level gauge port as a jet of white mist (adequate protective apparel should always be worn when filling propane fuel tanks). At this point the propane tank is filled to the maximum allowable limit. The filling attendant should stop filling and then close the fixed tube liquid level gauge (propane fuel tanks should never be filled with liquid to more than 80% of total water capacity). It is important that the fuel tank be positioned properly during refueling for the fixed tube liquid level gauge to be accurate.



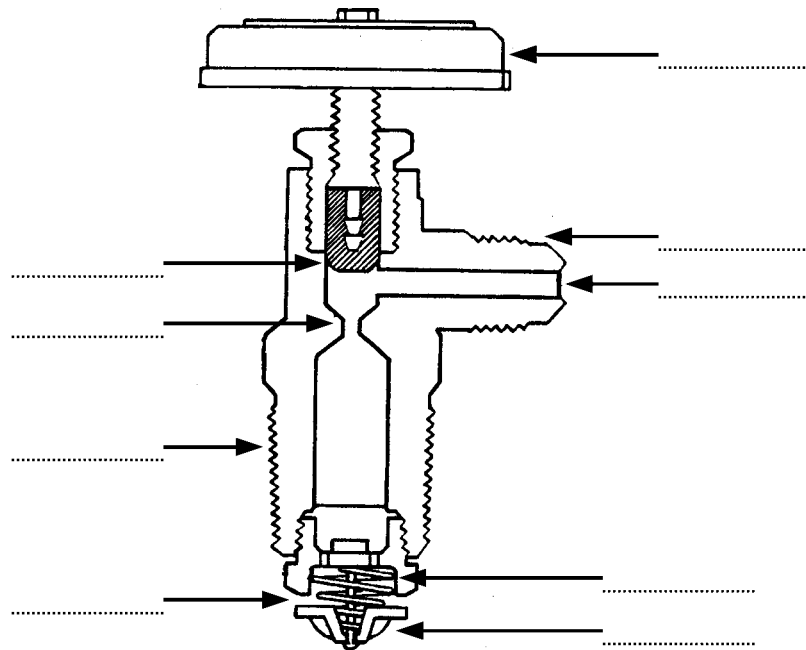
Safety Pressure Relief Valve

The safety pressure relief valve is a simple normally closed spring-loaded valve. The tank side of the safety pressure relief valve is equipped with a male pipe thread that allows it to be installed in the safety pressure relief valve port of the fuel tank. The safety pressure relief valve port of the fuel tank is connected to the vapor portion of the fuel tank, when the fuel tank is positioned properly. The outlet side of the safety pressure relief valve is covered by a protective cap designed to keep dirt and debris from contaminating the valve. The purpose of the safety pressure relief valve is to protect the fuel tank from over pressurization. The safety pressure relief valve is equipped with a calibrated spring, which keeps the valve closed until a certain pressure is reached inside the fuel tank. Portable fuel tank safety pressure relief valves are set to open at 375 psig. Permanently mounted fuel tank, pressure relief valves are set to open at 250 psig for tanks not in an enclosed area and 312 1/2 psig for tanks mounted in an enclosed area. If it is necessary to replace a safety pressure relief valve make sure you do not exceed the pressure rating stamped on the fuel tank. When the pressure inside the fuel tank exceeds the preset limit the safety pressure relief valve opens allowing propane vapor to escape, reducing the pressure inside the fuel tank. When the pressure in the tank falls below the opening pressure setting of the safety pressure relief valve the valve closes. When using a propane fuel tank in an enclosed area the safety pressure relief valve must have it's outlet connected to a suitable hose routed to discharge in a safe area.



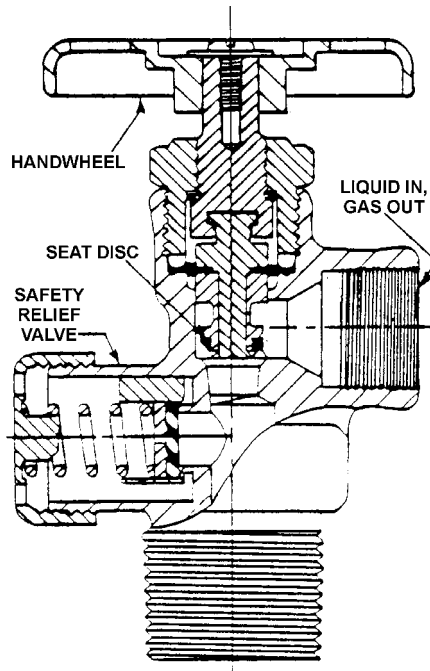
Liquid Service Valve

The liquid service valve is a simple manually operated valve. The liquid service valve is equipped with a hand wheel, which is turned counterclockwise to open and clockwise to close. The inlet side of the liquid service valve is equipped with a male pipe thread to allow it to be threaded into the liquid outlet port of the propane fuel tank. On permanently mounted tanks the outlet side of the liquid service valve is equipped with a male flair connection to allow it to be attached to the vehicle liquid fuel line (liquid service line). On portable fuel tanks the liquid service valve outlet is equipped with a 3/8" (3/8"npt) male pipe thread to allow attachment of a male quick connect coupler. When in the open position the liquid service valve allows liquid propane to flow out of the fuel tank to the fuel lockoff. When in the closed position the liquid service valve stops liquid propane from flowing out of the fuel tank. Built into the inlet side of the liquid service valve is a safety device known as an excess flow valve. If the liquid service valve and/or the vehicle liquid service line suffer a mishap, the excess flow valve is designed to shut off the flow of liquid propane from the tank when the flow exceeds the maximum flow rate of the liquid service valve. On engines operating on propane up to and including 550 cubic inch displacement the excess flow valve shall be sized up to a maximum of 2.0 US gallons/7.6 liters per minute flow rate. On engines over 550 cubic inch displacement the excess flow valve shall be sized up to a maximum of 3.2 US gallons/12.1 liters per minute flow rate. Some liquid service valves are equipped with an internal hydrostatic relief valve and are labeled "LIQUID WITH INTERNAL RELIEF". The internal hydrostatic relief valve is designed to protect the liquid service line between the liquid service valve and the fuel lockoff from over pressurization. The internal hydrostatic relief valve will have an opening pressure of no less than 375psig and no more than 500 psig. Internal hydrostatic relief valves are preferred over external hydrostatic relief valves because with the internal design propane is returned to the tank rather than dumped into the atmosphere when the relief valve opens.



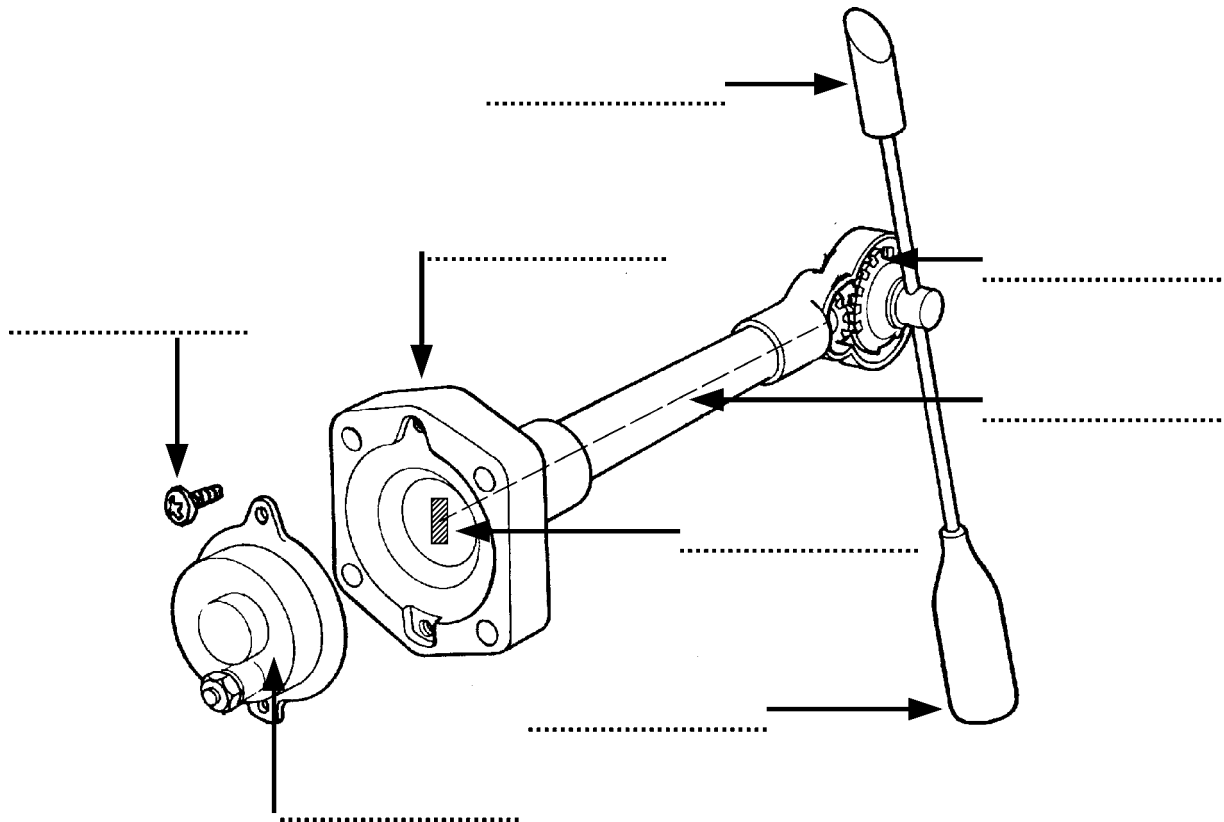
Vapor Service Valve

The vapor service valve is similar to the liquid service valve except that it has a female thread on the valve outlet designed to connect to a POL fitting. On small LPG cylinders where the vapor service valve is the only valve in the cylinder, filling takes place through the vapor service valve. A safety pressure relief valve is built into the vapor service valve on the container side of the valve seat.



Liquid Contents Gauge

The liquid contents gauge is used to indicate the amount of LPG in the Fuel storage container. The gauge uses a float, which rides on the top of the liquid LPG. As this float moves up and down with the level of LPG in the container it turns a shaft with the use of a ring and pinion gear set. A magnet is mounted to the opposite end of the shaft within the mounting flange. On the outside of the mounting flange there is mounted a site gauge or electric sending unit which incorporates a magnetic pointer and a scale from empty to full. This magnetic pointer aligns itself with the magnet attached to the shaft. As the shaft turns the pointer follows indicating the level of LPG in the container. Units incorporating an electric sending unit use a variable resistor to send a signal to a remote fuel gauge. The site gauge or electric sending unit may be changed with fuel in the tank by removing the two small retaining screws. **NEVER REMOVE THE FOUR LARGE FLANGE SECURING BOLTS UNLESS THE TANK HAS BEEN EVACUATED AND PURGED.** The liquid contents gauge is not legal for filling.



6.6 LPG CONTAINER SERVICE PROCEDURES

Service procedures for LPG containers are limited to the following:

- Visual inspection. Inspect the container for dents, gouges and rust.
- Leak test. Spray an approved leak test solution over the entire container and watch for bubbles. Bubbles indicate a leak.
- Welding is **not** allowed on the pressure vessel.
- Before removing any fitting from the container it must be evacuated and purged.

6.7 LPG CONTAINER INSTALLATION TIPS

- LPG containers must be mounted within the perimeter of the vehicle.
- If mounted underneath, between the axles, they must not be the lowest part of the vehicle with the suspension (if any) fully depressed.
- If mounted underneath behind the rear axle they must not be below a line drawn from where the rear wheels touch the ground to the bottom of the rear of the vehicle.
- If mounted within 8 inches of any source of heat, a heat shield must be installed. This heat shield should not touch the source of heat or the container. LPG containers should be positioned so that the safety relief valve does not point at the operator or any heat source or source of ignition.

SECTION 7

CNG FUEL STORAGE

7.1 THE CONSTRUCTION OF CNG FUEL STORAGE CONTAINERS

CNG containers are constructed to the following specifications:

- Containers shall be fabricated of steel, aluminum or composite material.
- The container shall be designed to be suitable for CNG service and shall be permanently marked "CNG" by the manufacturer.
- **Cylinders** shall be manufactured, inspected, marked, tested, retested, equipped, and used in accordance with U.S. Department of Transport (DOT) or Transport Canada (TC) regulations, exemptions, or special permits, or ANSI/AGA NGV2, *Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers*, specifically for CNG service and shall have a rated service pressure of not less than 3600 psi @ 70 degrees F (21.1 degrees C).
- **Pressure vessels** shall be manufactured, inspected, marked and tested in accordance with *Rules for the Construction of Unfired Pressure Vessels*, Section VIII, Division 1 or 2, or *ASME Boiler and Pressure Vessel Code*, Section X, and shall be suitable for CNG service. Adherence to applicable *ASME Boiler and Pressure Vessel Code* interpretations and addenda shall be considered as compliance with the *ASME Boiler and Pressure Vessel Code*.
- Welding in the field is **not** permitted on the pressure vessel.

7.2 CNG CONTAINER ORIENTATION

Since compressed natural gas is not stored in liquid form the orientation of the container is not important.

7.3 CNG CONTAINER VALVES & FITTINGS

The CNG container has only one opening. Into this opening is fitted a multi-turn valve that has a burst disc incorporated into its design. The burst disc is designed to rupture if the pressure in the container reaches an unsafe level. Once the burst disc ruptures it must be replaced.

7.4 CNG CONTAINER SERVICE PROCEDURES

Service procedures for CNG containers are limited to the following:

- Visual inspection. Inspect the container for dents, gouges and rust.
- Leak test. Use an approved electronic leak detector or spray an approved leak test solution over the entire container and watch for bubbles. Bubbles indicate a leak.
- Welding in the field is **not** allowed on the pressure vessel.
- Before removing the multi turn valve from the container it must be evacuated and purged.

7.5 CNG CONTAINER INSTALLATION TIPS

- CNG containers must be mounted within the perimeter of the vehicle.
- If mounted underneath, between the axles, they must not be the lowest part of the vehicle with the suspension (if any) fully depressed.
- If mounted underneath behind the rear axle they must not be below a line drawn from where the rear wheels touch the ground to the bottom of the rear of the vehicle.

- If mounted within 8 inches of any source of heat, a heat shield must be installed. This heat shield should not touch the source of heat or the container.
- Since CNG containers have no built in valve protection for the multi-turn valve, the containers should be positioned with the valve inboard or a substantial protective shield should be installed.
- CNG containers should be positioned so that the burst disc does not point at the operator or any heat source or source of ignition.
- CNG containers must have an insulator such as nylon or neoprene installed between the container and the container bracket to protect the container.

SECTION 8

LPG FUEL TRANSFER LINES

8.1 LPG FUEL TRANSFER LINE DESCRIPTION

LPG fuel transfer lines can be made from pipe, tube and/or hose. The specifications for each are listed below. The most popular LPG fuel transfer line is "Type III black with hydraulically swedged fittings attached".

Pipe

Pipe shall be wrought iron or steel (black or galvanized), brass, or copper and shall comply with the following:

- Wrought iron pipe: ASME B36.10M Welded and Seamless Wrought Steel Pipe.
- Steel pipe: ASTM A53, Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless.
- Steel pipe: ASTM A106, Specification for Seamless Carbon Steel Pipe for High-Temperature Service.
- Brass pipe: ASTM B43, Specification for Seamless Red Brass Pipe, Standard Sizes.
- Copper pipe: ASTM B42, Specification for Seamless Copper Pipe, Standard Sizes.

For LPG vapor in excess of 125psig (0.9 mPa) or for LPG liquid, the pipe shall be schedule 80 or heavier.

For LPG vapor at pressures of 125psig (0.9 mPa) or less, the pipe shall be Schedule 40 or heavier.

Tubing

Tubing shall be steel, brass or copper and shall comply with the following:

- Steel tubing: ASTM A539, Specification for Electric-Resistance-Welded Coiled Steel Tubing For Gas Fuel Oil Lines, with a minimum wall thickness of 0.049".
- Copper tubing: Type K or L, ASTM B88, Specification for Seamless Copper Water Tube.
- Copper tubing: ASTM B280, Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service Work.
- Brass tubing: ASTM B135, Specification for Seamless Brass Tube.

Pipe and Tube Fittings.

Cast iron pipe fittings such as ells, tees, crosses, couplings, unions, flanges or plugs shall not be used. Fittings shall be steel, brass, copper, malleable iron or ductile iron and shall comply with the following:

- Pipe joints in wrought iron, steel, brass or copper pipe shall be permitted to be screwed, welded or brazed. Tubing joints in steel, brass, or copper tubing shall be flared, brazed or made with approved gas tubing fittings.
- Fittings used with LPG liquid, or with LPG vapor at operating pressures over 125psig/0.9 mPa, where working pressures do not exceed 250 psig/1.7mPa, shall be suitable for a working pressure of at least 250psig/1.7mPa.
- Fittings for use with LPG vapor at pressures in excess of 5psig/34.5kPa, and not exceeding 125 psig/0.9mPa, shall be suitable for a working pressure of 125psig/0.9mPa
- Brazing filler material shall have a melting point in exceeding 1,000F/538C.

Hose, Hose Connections, and Flexible Connectors.

Hose, hose connections, and flexible connectors used for conveying LPG liquid or vapor at pressures in excess of 5psig/34.5kPa, shall be fabricated of materials resistant to the action of LPG both as a liquid and/or vapor and shall be of wire braid construction. The wire braid shall be of stainless steel. The hose shall comply with the following:

- Hose shall be designed for a working pressure of 350psig//240mPa, with a safety factor of 5 to 1 and shall be continuously marked "LP-GAS", "PROPANE", "350 PSI WORKING PRESSURE", and the "MANUFACTURERS NAME OR TRADEMARK". Each installed piece of hose shall contain at least one such marking.
- Hose assemblies after the application of connections shall have a design capability to withstand a pressure of not less than 700psig/4.8mPa. If a test is performed, such assemblies shall not be leak-tested at pressures higher than the working pressure of the hose.
- Hose used for vapor service at 5psig/34.5kPa or less shall be constructed of material resistant to the action of LPG.
- Hose and quick connectors for pressures above 5psig/34.5kPa service pressure shall be approved for this application by the authority having jurisdiction

8.2 LPG FUEL TRANSFER LINE SERVICE PROCEDURE

Field service of LPG fuel transfer lines is limited to visual inspection, leak testing and replacement.

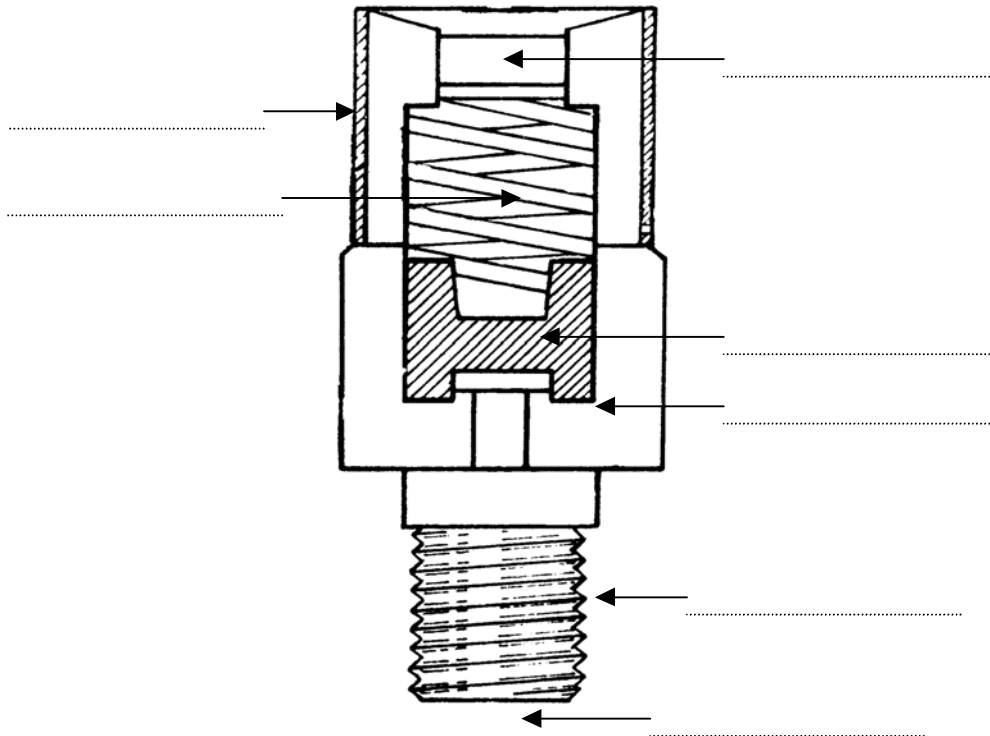
- First perform a visual inspection, if damage is found replace the line.
- Perform a leak test by applying an approved leak test agent to the entire fuel line, watch for bubbles, this indicates a leak. If a leak is found replace the line.

8.3 LPG FUEL TRANSFER LINE INSTALLATION TIPS

- Fuel transfer lines shall be installed, supported and secured in such a way as to lower the chance of damage from expansion, contraction, vibration, strains, impact and/or wear.
- Fuel transfer lines should be supported every 24" by a nylon/rubber covered metal line clamp.
- Where fuel transfer lines pass through sheet metal or structural members a rubber grommet or equivalent protection shall be installed.
- Where liquid service lines of two or more individual containers are connected together, a spring loaded back flow check valve or equivalent shall be installed in each of the liquid lines before the point where the lines come together to prevent the flow of LPG from one container to the other.
- Fuel transfer lines shall be tested and proven free of leaks at not less than normal operating pressure.
- There shall be no fuel connection between a tractor and a trailer.
- A hydrostatic relief valve must be installed in each fuel transfer line between shutoff's to protect the line from over pressurization.

8.4 HYDROSTATIC RELIEF VALVE THEORY OF OPERATION

The hydrostatic relief valve is a simple spring-loaded valve that is normally closed. A hydrostatic relief valve must be present in all fuel transfer lines between shutoffs. The Hydrostatic relief valve must have a dust cap covering the outlet to prevent contamination of the valve. The purpose of the hydrostatic relief valve is to protect the fuel transfer line from over pressurization. The hydrostatic relief valve shall have an opening pressure of not less than 400psig/2.8mPa and not more than 500psig/3.5mPa.



8.5 HYDROSTATIC RELIEF VALVE SERVICE PROCEDURES

The hydrostatic relief valve is not serviceable in the field. However it can be checked for leakage, using an approved leak test product. Apply the leak test product to the whole hydrostatic relief valve and any connections associated with it (follow leak test product manufacturers instructions if applicable). Do not remove the dust cap from hydrostatic relief valve to leak test, moisture trapped beneath the dust cap may cause corrosion and may lead to a malfunction of the valve. A hydrostatic relief valve that is missing the dust cap should be replaced. As with any safety device, if in doubt change it.

8.6 HYDROSTATIC RELIEF VALVE INSTALLATION TIPS

Installation shall be made in accordance with the manufacturer's recommendations and, in the case of listed and/or approved equipment, it shall be installed in accordance with the listing or approval. In addition, the hydrostatic relief valve should be positioned in such a way that the outlet does not point toward the operator or any sources of ignition. If multiple tanks are connected together the hydrostatic relief valve must be located down steam from the spring loaded back-flow check valves.

SECTION 9

CNG FUEL TRANSFER LINES

9.1 CNG FUEL TRANSFER LINE DESCRIPTION

- Pipe, tubing, fittings, gaskets and packing material shall be compatible with the fuel under the service conditions.
- Pipe, tubing, fittings and other piping components shall be capable of withstanding a hydrostatic test of at least four times the rated service pressure without structural failure.
- Natural gas piping shall be fabricated and tested in accordance with ANSI/ASME B31.3, *Chemical Plant and Petroleum Refinery Piping*.
- Aluminum or copper pipe, tubing, or fittings shall not be used between the fuel container and the first stage pressure regulator.
- Hose and metallic hose shall be constructed of or lined with materials that are resistant to corrosion and the actions of natural gas.
- Hose, metallic hose, flexible metal hose, tubing, and their connections shall be suitable for the most severe pressures and temperatures expected under normal operating conditions with a burst pressure at least four times the service pressure.
- Prior to use, hose assemblies shall be tested by the manufacturer or it's designated representative at a pressure at least twice the service pressure.
- Hose and metallic hose shall be distinctly marked by the manufacturer's permanently attached tag or by distinct markings indicating the manufacturers name or trademark, applicable service identifier, and design pressure.

Vehicle Fueling Connection.

- The vehicle fueling connection devices shall be listed in accordance with ANSI/AGA NGV1, *Standard for Compressed Natural Gas Vehicles (NGV) Refueling Connection Devices*. The use of adapters shall be prohibited.

9.2 CNG FUEL TRANSFER LINE SERVICE PROCEDURES

Field service of CNG fuel transfer lines is limited to visual inspection, leak testing and replacement.

- First perform a visual inspection, if damage is found replace the line.
- Perform a leak test by applying an approved leak test agent to the entire fuel line, watch for bubbles, this indicates a leak. If a leak is found replace the line.

9.3 CNG FUEL TRANSFER LINE INSTALLATION TIPS

- Fuel transfer lines shall be installed, supported and secured in such a way as to lower the chance of damage from expansion, contraction, vibration, strains, impact and/or wear.
- Fuel transfer lines should be supported every 24" by a nylon/rubber covered metal line clamp.
- Where fuel transfer lines pass through sheet metal or structural members a rubber grommet or equivalent protection shall be installed.
- Fuel transfer lines shall be tested and proven free of leaks at not less than normal operating pressure.
- There shall be no fuel connection between a tractor and a trailer.
- Loops must be made in stainless steel lines between chassis/body members.

SECTION 10

FUEL LOCKS & FILTERS

10.1 WHY ARE FUEL LOCKS REQUIRED

As with gasoline or diesel fuel systems a fuel filter is required on LPG and CNG systems to remove contaminants from the fuel that would otherwise damage the system. Since LPG and CNG are stored under pressure in the fuel storage container no fuel pump is required to deliver the fuel to the engine. For safety reasons it is necessary to provide a means of automatically stopping the fuel flow to the engine when the engine stops or is turned off. This is accomplished by using a fuel lockoff operated by engine vacuum, or by an electric lockoff using a vacuum or oil pressure safety switch.

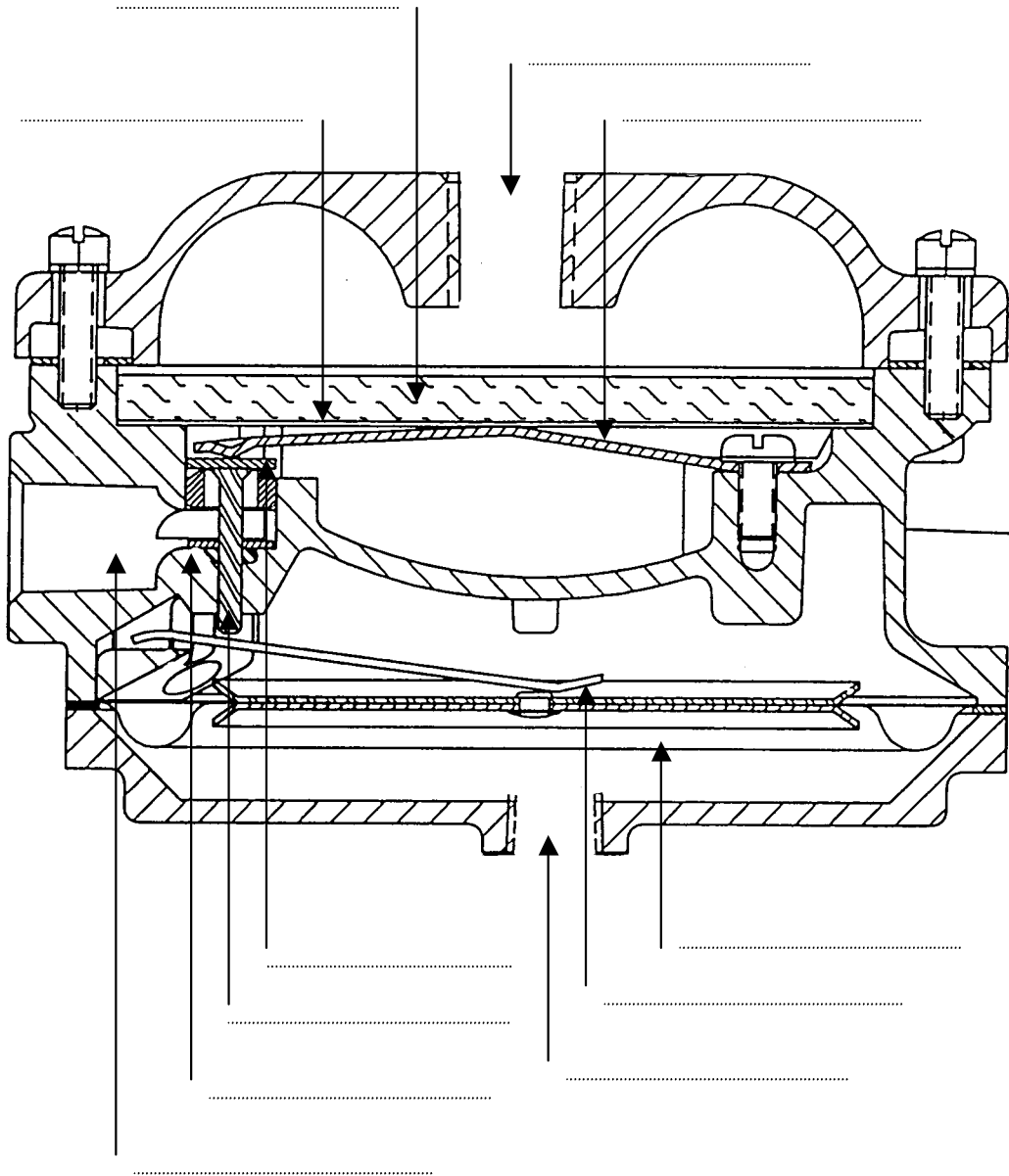
10.2 VACUUM FUEL LOCK THEORY OF OPERATION

- IMPCO vacuum fuel locks are normally closed.
- They use air valve vacuum from the air fuel mixer to open the fuel lock.
- If the engine stops or is turned off, engine vacuum dissipates and the fuel lockoff closes automatically, this is a desirable safety feature.
- When the engine is cranking or running air valve vacuum is transmitted from the mixer to the lockoff through a 3/16-inch vacuum hose.
- The vacuum acts upon a diaphragm assembly, atmospheric pressure forces it inward against the valve operating lever.
- As the valve operating lever is depressed it moves the valve operating pin.
- As the valve operating pin moves it lifts the valve off of its seat.
- This allows propane to flow through the lockoffs 10 micron filter and on to the pressure regulator.

Impco VFF-30 Vacuum Fuel Lockoff



Impco Model VFF-30 Fuel Lock



10.3 VACUUM FUEL LOCK SERVICE PROCEDURES

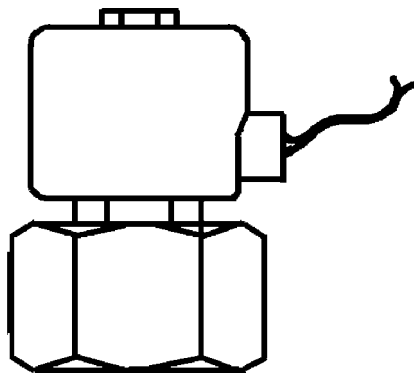
- The IMPCO VFF30 vacuum fuel filter lockoff is fully field serviceable.
- A repair kit is available (RK-VFF30) which includes all the wear parts necessary to rebuild the unit. Each part is also available individually.
- To test a unit for external leakage, apply an approved leak test solution to the entire outer surface and watch for leaks.
- To test a unit for internal leakage remove the vacuum hose from the port marked VAC.
- Apply an approved leak test agent to your finger tip and lightly place finger over port marked VAC.
- Position your finger so that any LPG leaking internally and escaping out of the vacuum port will create small bubbles around your fingertip.
- If bubbles are found the pin and o-ring need replacing.

10.4 VACUUM FUEL LOCK INSTALLATION TIPS

- Lockoffs with filter elements should be positioned so that the filter can be changed as easily as possible.
- Vacuum lockoffs should be positioned so that the atmospheric vent is not restricted.
- Vacuum lockoffs should be positioned so that debris will not enter the atmospheric vent.
- Vacuum lockoffs should be connected to air valve vacuum, not manifold vacuum.

10.5 ELECTRIC FUEL LOCK THEORY OF OPERATION

- Electric fuel lockoffs are normally closed.
- They use current from the vehicles electrical system to open the fuel lock and allow fuel to flow to the engine.
- Since there can be current flow in a circuit on the vehicle even when the vehicle is not running electric fuel lockoffs must have a safety switch wired in series with the circuit which controls the lockoff.
- The safety switch is normally open.
- It only closes when the engine is cranking or running.
- Therefore if the engine stalls the safety switch opens the circuit and the fuel flow is stopped automatically regardless of key position.



10.6 ELECTRIC FUEL LOCK SERVICE PROCEDURES

Filter elements are available for electric lockoffs equipped with filters. Otherwise electric lockoffs are not field serviceable, only a leak test may be performed.

- Apply an approved leak test agent to the valve portion of the electric lockoff and watch for leaks. If a leak is found replace lockoff.

10.7 ELECTRIC FUEL LOCK INSTALLATION TIPS

- Wiring connections on electric lockoffs should be adequately protected from the elements.
- A safety switch must be used with electric fuel locks.

SECTION 11

PRESSURE REGULATORS

11.1 LPG PRESSURE REGULATOR THEORY OF OPERATION

IMPCO LPG pressure regulators are classified as two stage, negative pressure regulator/vaporizers because they reduce fuel pressure in two stages, convert the fuel from a liquid to a vapor and meter the output in relation to a negative pressure signal from the air fuel mixer.

- Propane liquid, at tank pressure, enters the regulator through the fuel inlet port.
- Propane liquid then flows through the primary valve, which is held normally open by the primary spring(s), and into the primary/heat exchanger chamber of the regulator.
- A small port connects the primary/heat exchanger chamber and the primary diaphragm chamber.
- The secondary valve at the outlet of the primary/heat exchanger chamber is held normally closed by the secondary spring. Therefore the pressure in the primary/heat exchanger chamber and the primary diaphragm chamber begins to rise from atmospheric pressure.
- When the pressure in the primary/heat exchanger chamber and primary diaphragm chamber reaches 1.5 psi it causes the primary diaphragm and lever assembly to pivot, against primary spring pressure, closing off the primary valve.
- Since the fuel pressure has been reduced from tank pressure to 1.5 psi the fuel vaporizes. As propane vaporizes it takes on heat from the primary/heat exchanger chamber of the regulator. This heat is replaced by engine coolant, which is piped through the heat exchanger section of the regulator.
- Fuel will not flow through the regulator to the engine until a negative pressure signal is received from the air fuel mixer.
- When the engine is cranking or running, a negative pressure signal is generated by the air fuel mixer.
- This negative pressure signal travels through the vapor fuel connection between the air fuel mixer and the regulator secondary diaphragm chamber.
- The negative pressure signal acts upon the lower side of the secondary diaphragm allowing atmospheric pressure above to move the diaphragm down.
- As the secondary diaphragm moves down it causes the secondary lever to pivot against the secondary spring.
- As the secondary lever pivots it lifts the secondary valve off of its seat allowing vaporized fuel to flow from the primary/heat exchanger chamber, through the secondary chamber, and on to the air fuel mixer.
- Since fuel has now exited the primary/heat exchanger chamber the pressure in the chamber will drop allowing the primary valve to reopen. This creates a balanced condition between the primary and secondary chambers allowing for a constant flow of fuel to the air fuel mixer. Although the flow of fuel is constant the amount of fuel flowing will vary depending on how far the secondary valve opens in response to the negative pressure signal from the air fuel mixer.
- Impco pressure regulators equipped with a blue secondary spring (example model JB or EB) require negative 1.5 inches of water column (wc) to begin opening the secondary valve. Pressure regulators equipped with an orange secondary spring (example model JO or EO) require negative 0.5 inches of water column (wc).

- The amount of fuel flowing from the regulator is directly related to the strength of the negative pressure signal generated by the air fuel mixer.
- The strength of the negative pressure signal developed by the air fuel mixer is directly related to the amount of air flowing through the air fuel mixer into the engine.
- Therefore the larger the quantity of air flowing into the engine, the larger the amount of fuel flowing to the air fuel mixer.
- This design in conjunction with the profile of the gas valve in the air fuel mixer allows for a consistent air fuel mixture over the complete operating range of the engine.

| IMPCO Pressure Regulator Horsepower Rating | |
|---|-----------|
| Model | HP Rating |
| J | 100 |
| Cobra | 100 |
| L | 325 |
| E | 325 |

11.2 LPG PRESSURE REGULATOR SERVICE PROCEDURES

IMPCO pressure regulators have proven to be very reliable and require very little maintenance due to the robustness of their design and the small number of moving parts. Only periodic disassembly for the purpose of inspection and cleaning is required. The time interval between inspections varies with the quality of the fuel being used. A quick pressure test is all that is required to verify proper regulator operation. Repair kits are available from Impco if required. These kits contain complete instructions and all wear parts necessary to rebuild an Impco pressure regulator.

****NOTE USE ONLY GENUINE IMPCO REPLACEMENT PARTS.**

On-Vehicle Pressure Test

- Shut off fuel supply at fuel storage container and run engine out of fuel.
- Remove the primary test port plug (see diagram).
- Connect the ITK-1, 0-5 psi gauge to the primary test port.
- Remove secondary test port plug.
- Install the ITK-1, 0-10 inch wc (water column) gauge.
- Slowly open fuel storage container valve.
- Start engine.
- Note gauge pressure readings.
- Primary pressure should be approximately 1.5 psi.
- Secondary pressure on regulators with a blue spring should be negative 1.5 wc.
- Secondary pressure on regulators with an orange spring should be negative 0.5 wc.
- Flip throttle several times then allow engine to idle.
- Gauge readings will fluctuate and then should return to normal as engine idles and pressures stabilize.
- If pressure readings differ from those stated above the regulator should be disassembled and inspected as outlined below in *"Regulator Disassembly, Inspection and Cleaning"*.

Regulator Disassembly, Inspection and Cleaning

- Shut off fuel supply at fuel storage container and run engine out of fuel.
- Disconnect fuel inlet and outlet lines.
- Drain cooling system or clamp hoses.
- Remove regulator.
- Disassemble regulator
- Clean primary and secondary valves with soap and warm water and inspect for wear. Replace if required
- Clean primary and secondary diaphragms with soap and warm water and inspect for wear. Inspect primary diaphragm lever for straightness. Replace if required.
- Always replace the coolant chamber gasket.
- Clean regulator castings with parts cleaning solvent and inspect. It is very rare for the castings to require replacement.
- Reassemble regulator.
- Use an anti-sieze compound on screws.
- Use an approved pipe sealant on fittings.
- Bench test regulator

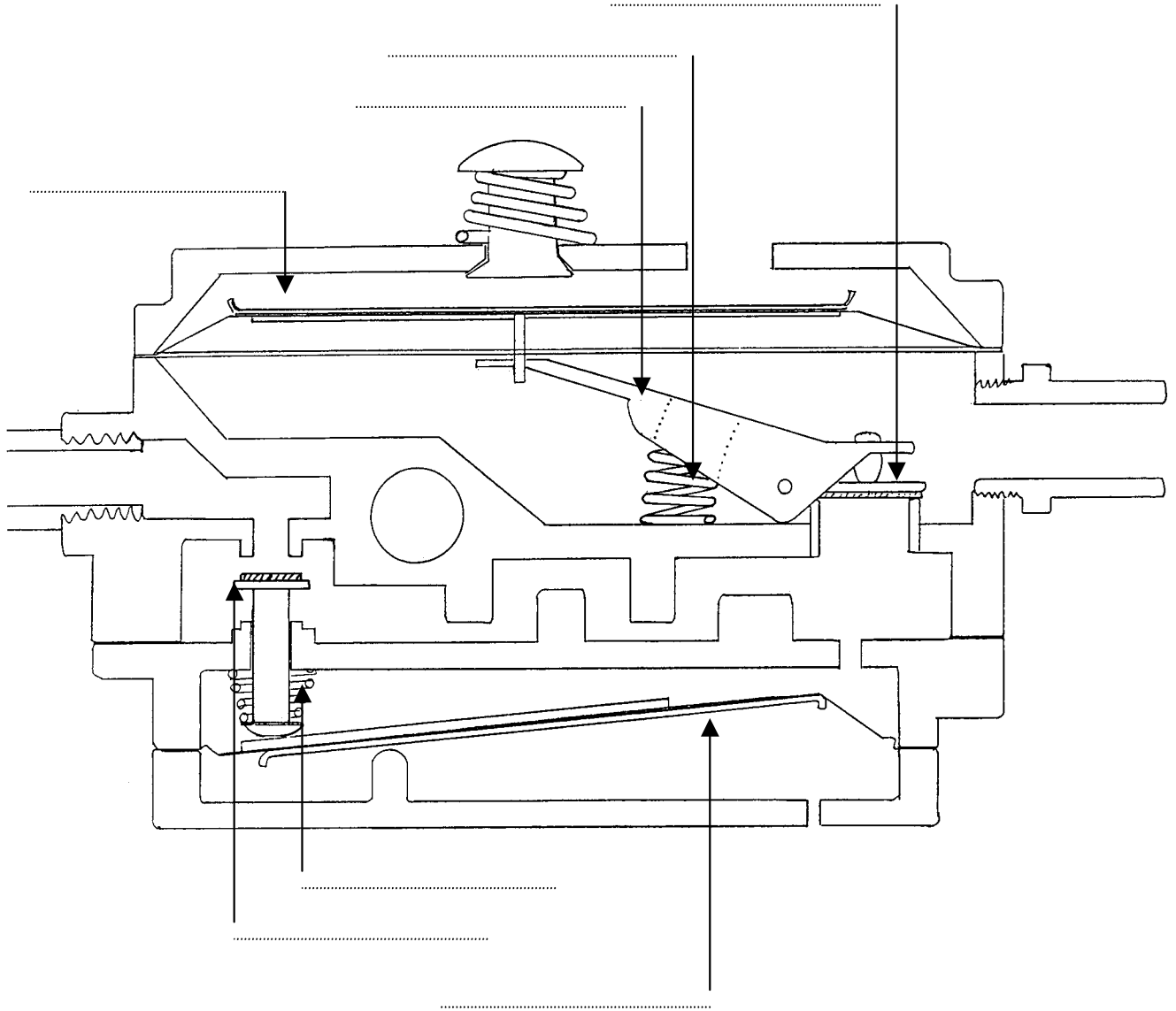
Regulator Bench Test

- Remove the primary test port plug.
- Connect the ITK-1, 0-5 psi gauge to the primary test port.
- Connect compressed air to the fuel inlet.
- Pressurize the regulator.
- Note reading on pressure gauge.
- Gauge reading should be approximately 1.5 psi.
- There should be no air escaping from the regulator outlet.
- If air is escaping from the regulator outlet check the secondary diaphragm, secondary valve and seat.
- Slowly push primer button several times and release.
- Gauge will fluctuate but should return to approximately 1.5 psi.

| |
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| 11.3 LPG PRESSURE REGULATOR INSTALLATION TIPS |
|--|

- Mount regulator below top of radiator. Air in the cooling system will seek the highest point. The regulator must not be the highest point. Air trapped in the regulator may cause it to freeze.
- Mount regulator with fuel outlet pointing down. This allows for any heavy ends, such as butyl oil, that may be present in the fuel, to drain from the regulator. If any heavy ends are allowed to accumulate in the regulator they may interfere with the movement of the diaphragms.
- Mount regulator to a solid surface. Fuel lines and coolant lines must not be used to support regulator.
- Mount regulator as close as practical to the air fuel mixer. Since the regulator requires a negative pressure signal from the air fuel mixer to operate, mounting them close together will ensure short cranking time when starting the engine.

IMPCO Model J Regulator



11.4 CNG HIGH PRESSURE REGULATOR

The IMPCO HPR-3600 CNG high-pressure regulator is a single stage regulator. It is mounted between a ¼ turn emergency shut off valve and a vacuum or electric fuel lockoff. The HPR-3600 is not field serviceable.

- The primary function of the HPR-3600 is to accept fuel at storage container pressure, up to 3600 psi, and reduce it to an outlet pressure of 150 psi plus or minus 20 psi. This is necessary because of the high storage pressure of CNG.
- The regulator is heated by engine coolant to eliminate freezing of any moisture that may be present in the natural gas during pressure reduction.
- The regulator is equipped with a pressure relief valve, which will release pressure if it exceeds approximately 400 psi. This protects the low-pressure components downstream.
- The pressure relief valve is pressure actuated only. No temperature actuation is provided.
- The pressure relief valve will reset after opening and reducing the pressure. It does not have to be replaced after operation.
- Since the HPR-3600 is heated by engine coolant it must be mounted below the top of the radiator to avoid air being trapped in the regulator.

11.5 CNG PRESSURE REGULATOR THEORY OF OPERATION

IMPCO CNG pressure regulators are classified as two stage, positive pressure regulators because they reduce fuel pressure in two stages, and supply fuel to the air fuel mixer under a slight positive pressure.

- Natural gas (NG) at HPR output pressure enters the regulator through the fuel inlet port.
- NG then flows through the primary valve, which is held normally open by the primary spring(s), and into the primary chamber.
- A small port connects the primary chamber and the primary diaphragm chamber.
- NG then flows through the secondary valve, which is held normally open by the secondary spring, and into the secondary diaphragm chamber.
- NG then flows out of the regulator and on to the air fuel mixer through the dry gas hose.
- Since the gas jet in the mixer is normally closed pressure starts to back up from the air fuel mixer.
- When the pressure in the secondary chamber reaches positive 4.5 inches wc the secondary diaphragm moves upward against secondary spring pressure and closes the secondary valve.
- The pressure in the primary chamber continues to build until it reaches 1.5 psi.
- 1.5 psi in the primary chamber will cause the primary diaphragm to pivot against the primary spring and close the primary valve.
- The regulator will remain like this until the engine is cranked and started.
- As the engine begins to turn over a negative pressure developed by the air fuel mixer lifts the air gas valve assembly.
- As the gas valve moves out of the gas jet it allows NG to flow from the secondary side of the regulator into the intake air stream.

- The pressure in the secondary side of the regulator now lowers allowing the secondary valve to open.
- As the secondary valve opens pressure in the primary side of the regulator lowers allowing the primary valve to open and let NG into the regulator.
- As the engine starts and runs the primary and secondary sides of the regulator balance and supply a smooth and consistent flow of fuel to the engine.

11.6 CNG PRESSURE REGULATOR SERVICE PROCEDURES

IMPCO pressure regulators have proven to be very reliable and require very little maintenance due to the robustness of their design and the small number of moving parts. Only periodic disassembly for the purpose of inspection and cleaning is required. The time interval between inspections varies with the quality of the fuel being used. A quick pressure test is all that is required to verify proper regulator operation. Repair kits are available from Impco if required. These kits contain complete instructions and all wear parts necessary to rebuild an Impco pressure regulator.

****NOTE USE ONLY GENUINE IMPCO REPLACEMENT PARTS.**

On-Vehicle Pressure Test

- Shut off fuel supply at fuel storage container and run engine out of fuel.
- Remove the primary test port plug.
- Connect the ITK-1, 0-5 psi gauge to the primary test port.
- Remove secondary test port plug.
- Install the ITK-1, 0-10 inch wc (water column) gauge.
- Slowly open fuel storage container valve.
- Start engine.
- Note gauge pressure readings.
- Primary pressure should be approximately 1.5 psi.
- Secondary pressure should be approximately positive 4.5 inches wc.
- Flip throttle several times then allow engine to idle.
- Gauge readings will fluctuate and then should return to normal as engine idles and pressures stabilize.
- If pressure readings differ from those stated above the regulator should be disassembled and inspected as outlined below in *"Regulator Disassembly, Inspection and Cleaning"*.

Regulator Disassembly, Inspection and Cleaning

- Shut off fuel supply at fuel storage container and run engine out of fuel.
- Disconnect fuel inlet and outlet lines.
- Remove regulator.
- Disassemble regulator
- Clean primary and secondary valves with soap and warm water and inspect for wear. Replace if required
- Clean primary and secondary diaphragms with soap and warm water and inspect for wear. Replace if required.

- Clean regulator castings with parts cleaning solvent and inspect. It is very rare for the castings to require replacement.
- Reassemble regulator.
- Use an anti-sieze compound on screws.
- Use an approved pipe sealant on fittings.
- Bench test regulator

Regulator Bench Test

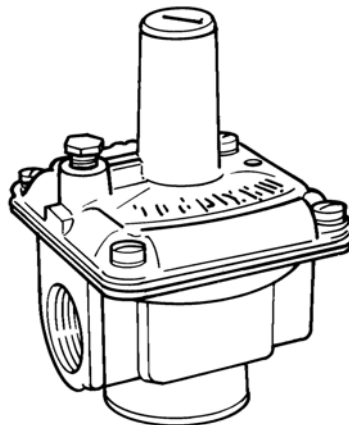
- Remove the primary test port plug.
- Connect the ITK-1, 0-5 psi gauge to the primary test port.
- Connect the ITK-1, 0-10 inch wc gauge to the secondary test port.
- Install a plug in the regulator outlet with a pressure bleed hole approximately .125 inches.
- Connect compressed air to the fuel inlet.
- Pressurize the regulator.
- Note reading on pressure gauges.
- The primary pressure should be approximately 1.5 psi.
- The secondary pressure should be approximately positive 4.5 inches wc.
- There should be a steady stream of air escaping from the regulator outlet, pressure bleed hole.

11.7 CNG PRESSURE REGULATOR INSTALLATION TIPS

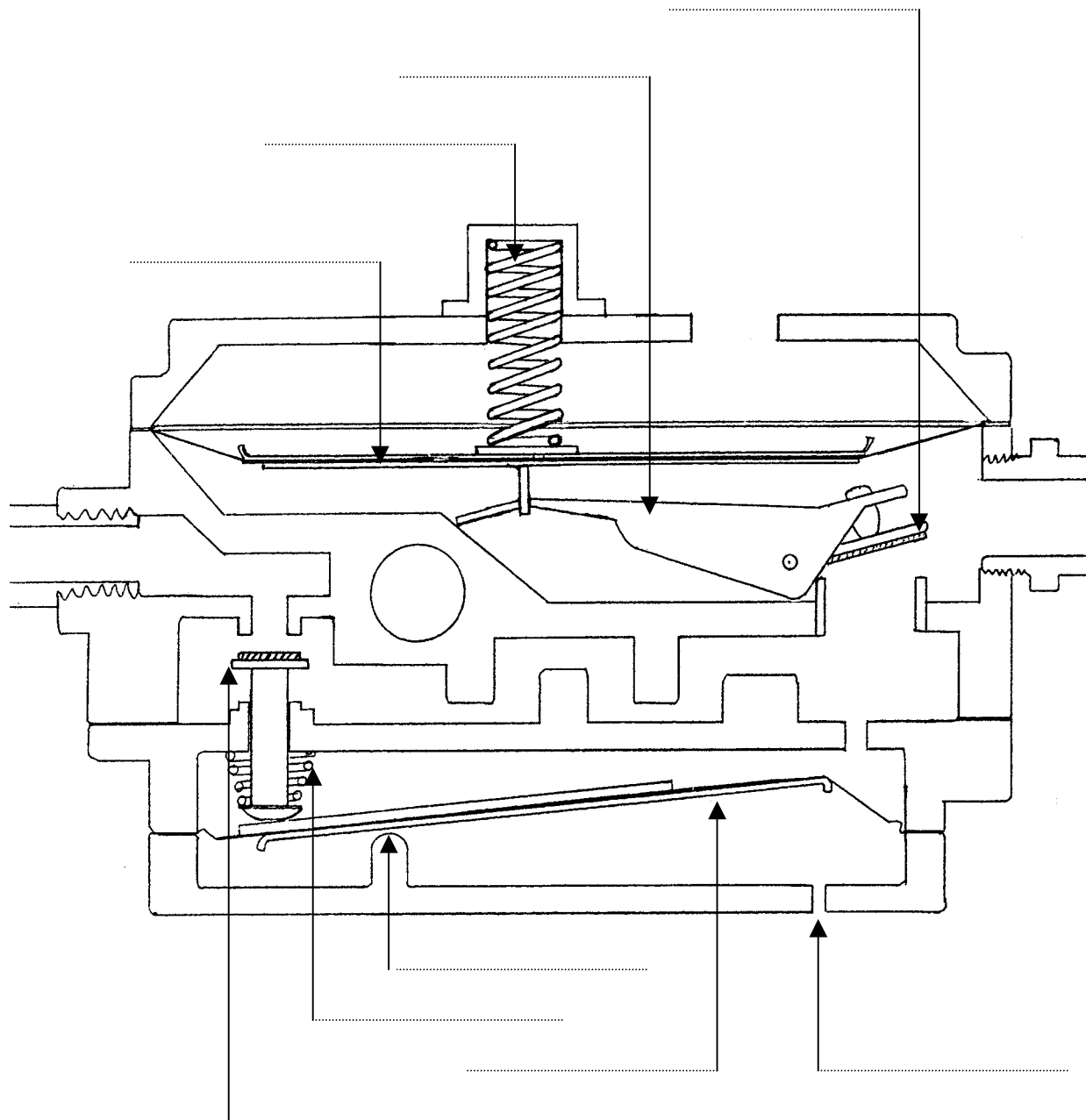
- Mount regulator to a solid surface. Fuel lines must not be used to support the regulator.
- Mount regulator as close as practical to the air fuel mixer.

11.8 IMP SERIES PRESSURE REDUCTION VALVES

IMP pressure reduction valves are designed for stationary engine applications using dry fuel, primarily natural gas. They can be used in positive or negative fuel output systems with only a small modification.



IMPCO Model PJ Regulator



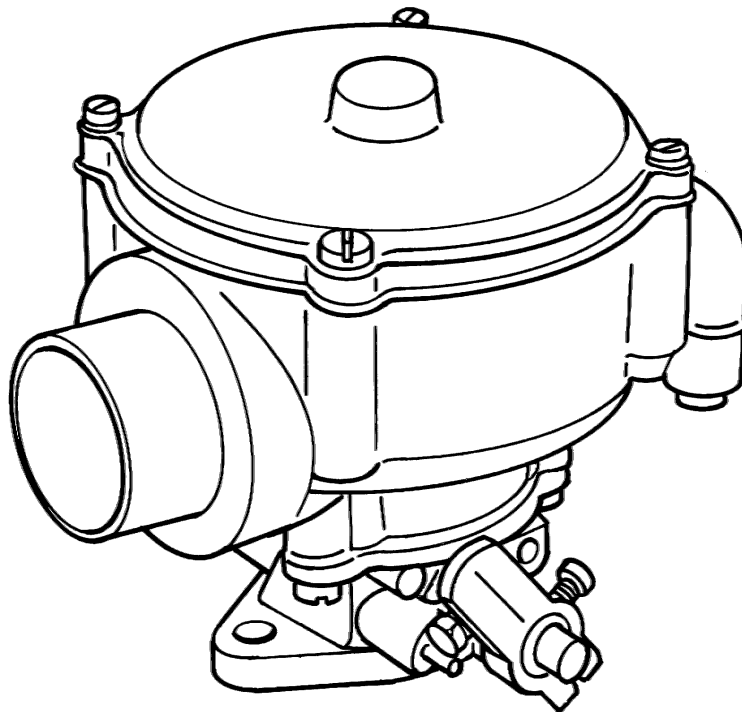
SECTION 12

AIR FUEL MIXERS

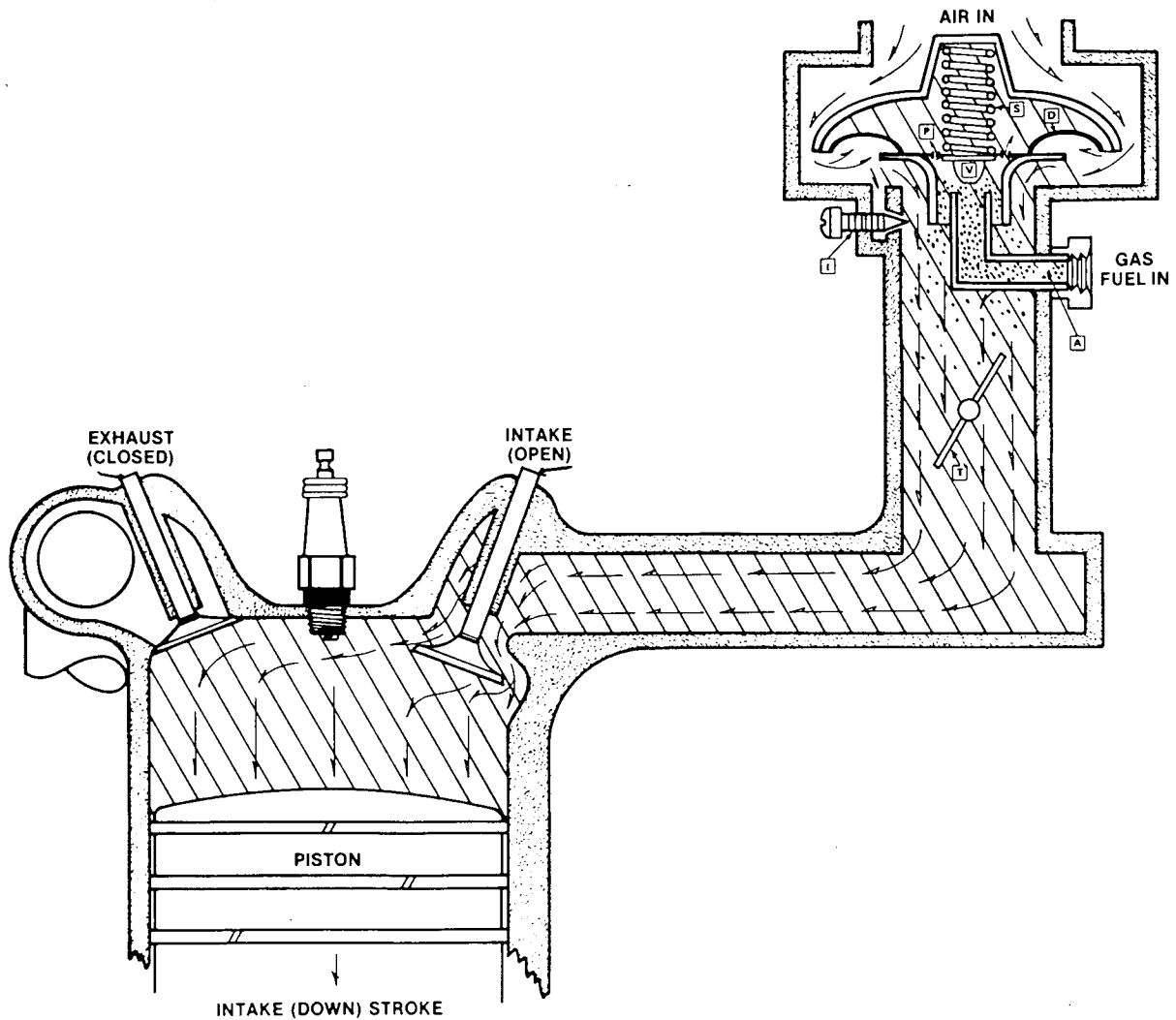
12.1 AIR VALVE MIXER THEORY OF OPERATION

The air-gas valve mixer is mounted in the intake air stream above the throttle plates and is designed to create a slight pressure drop (negative pressure) as air is drawn through it in to the engine. This negative pressure signal is communicated to the upperside of the diaphragm through passages in the air-gas valve assembly (the air-gas valve assembly is mounted in the center of and supported by the diaphragm). Atmospheric pressure acting on the underside of the diaphragm forces it upward against the metering spring. The metering spring is calibrated to generate about negative 6-inches of water column at idle and up to about negative 14-inches of water column at wide open throttle. The amount of negative pressure generated is a direct result of throttle position and the amount of air flowing through the mixer. As the diaphragm rises it lifts the tapered gas metering valve off of its seat and exposes the fuel outlet to the negative pressure generated within the mixer. This allows the negative pressure signal to travel to the secondary chamber of the pressure regulator and act upon the underside of the secondary diaphragm. Atmospheric pressure above the diaphragm forces it down against the secondary metering spring and opens the secondary valve allowing fuel to flow to the air-gas valve mixer. The tapered shape of the gas-metering valve is designed to maintain the correct air/fuel ratio over the entire operating range of the engine.

Impco CA 100 Air Fuel Mixer



Air Valve Mixer Theory of Operation



12.2 AIR VALVE MIXER SERVICE PROCEDURES

With a minimum of moving parts and a robust design Impco air fuel mixers require only periodic inspection and cleaning.

- Remove the diaphragm cover.
- Remove the air gas valve assembly.
- Clean the carburetor throat with a spray type cleaning solvent.
- Inspect carburetor throat and fuel outlet for wear
- Replace mixer body if worn.
- Clean air gas valve assembly with soap and water.
- Inspect diaphragm for wear and/or holes.
- Replace diaphragm if worn or damaged.
- Inspect air gas valve for wear.
- Check gas valve information chart for proper gas valve application (see below).
- Replace air gas valve if worn.
- Reassemble air fuel mixer.

12.3 AIR FUEL MIXER, GAS VALVE INFORMATION

55 Series Carburetors

| Air-Gas Valve # | Description |
|------------------------|--------------------|
| AV1-14925 | Standard |
| AV1-14926 | Lean idle |

100 and 125 Series Carburetors

| Air-Gas Valve # | Description |
|------------------------|---|
| AV1-14 | Standard, w/ hydrin diaphragm, for LPG |
| AV1-14-2 | Lean, w/ hydrin diaphragm, for LPG |
| AV1-14-3 | Standard, w/ silicone diaphragm, for LPG |
| AV1-14-4 | Lean, w/ silicone diaphragm, for LPG |
| AV1-14-9 | W/ hydrin diaphragm & ball check valve ass'y, for 1 & 2 cylinder engines, for LPG |
| AV1-1447 | Standard, for feedback, w/ hydrin diaphragm (47 on gas valve) |
| AV1-1447-2 | Standard, for feedback, w/ silicone diaphragm (47 on gas valve) |
| AV1-1447-4 | Dual-fuel, for vacuum-lift CA125M-10, w/ hydrin diaphragm, (47 on gas valve) |
| AV1-1447-4-2 | Dual-fuel, for vacuum-lift CA125M-10, w/ silicone diaphragm (47 on gas valve) |
| AV1-14-220 | Rich, for non-feedback |
| AV1-14-220-2 | Rich, for non-feedback, w/ silicone diaphragm |

| | |
|-------------|---|
| CV1-14 | Special lean, w/ hydrin diaphragm |
| CV1-14-2 | Special lean, w/ silicone diaphragm |
| DG-AV1-14 | For digester gas, w/ hydrin diaphragm |
| DG-AV1-14-2 | For digester gas, w/ silicone diaphragm |
| EV1-14 | W/ 42 valve |
| EV1-14-2 | W/ 42 valve, w/ silicone diaphragm |

200 and 225 Series Carburetors

| Air-Gas Valve # | Description |
|------------------------|---|
| AV1-12 | Standard (16 on gas valve), w/ hydrin diaphragm |
| AV1-12-2 | Standard (16 on gas valve), w/ silicone diaphragm |
| AV1-12-3 | For 1 & 2 cylinder engines (16 on gas valve), w/ hydrin diaphragm & ball check ass'y |
| AV1-12-3-2 | For 1 & 2 cylinder engines (16 on gas valve), w/ silicone diaphragm & ball check ass'y |
| AV1-12-5 | For vacuum-lift CA225M-10, LPG (16 on gas valve), w/ hydrin diaphragm |
| AV1-12-5-2 | For vacuum-lift CA225M-10, LPG (16 on gas valve), w/ silicone diaphragm |
| AV1-1245 | Standard feedback (45 on gas valve), w/ hydrin diaphragm |
| AV1-1245-2 | Standard feedback (45 on gas valve), w/ silicone diaphragm |
| AV1-12-220 | Rich, for non-feedback, w/ hydrin diaphragm |
| AV1-12-220-2 | Rich, for non-feedback, w/ silicone diaphragm |
| DG-AV1-12 | For digester gas (550-750 BTU; 14 on gas valve), w/ hydrin diaphragm |
| DG-AV1-12-2 | For digester gas (550-750 BTU; 14 on gas valve), w/ silicone diaphragm |
| LH-AV1-12 | For low heat gas (750-950 BTU; 14 on gas valve), w/ hydrin diaphragm |
| LH-AV1-12-2 | For low heat gas (750-950 BTU; 14 on gas valve), w/ silicone diaphragm |
| LG-AV1-12-3 | For low heat gas (750-950 BTU; 14 on gas valve), for 1 & 2 cylinder engines, w/ hydrin diaphragm & ball check valve ass'y |
| CV1-12 | For natural gas (17 on gas valve), w/ hydrin diaphragm |
| CV1-12-2 | For natural gas (17 on gas valve), w/ silicone diaphragm |
| CV1-12-4 | For natural gas (17 on gas valve), for 1 & 2 cylinder engines, w/ hydrin diaphragm & ball check valve ass'y |
| CV1-12-4-2 | For natural gas (17 on gas valve), for 1 & 2 cylinder engines, w/ silicone diaphragm & ball check valve ass'y |

425 Series Carburetors

| Air-Gas Valve # | Description |
|-----------------|---|
| AV1-16 | Standard (19 on gas valve), w/ hydrin diaphragm |
| AV1-16-2 | Standard (19 on gas valve), w/ silicone diaphragm |
| AV1-1637 | For use w/ EC1, rich (37 on gas valve), w/ hydrin diaphragm |
| AV1-1637-2 | For use w/ EC1, rich (37 on gas valve), w/ silicone diaphragm |
| AV1-1644 | Lean cruise (4x4 on gas valve), for 370+ cid engines, w/ hydrin diaphragm |
| AV1-1644-2 | Lean cruise (4x4 on gas valve), for 370+ cid engines, w/ silicone diaphragm |
| AV1-1651 | Standard feedback (51 on gas valve), w/ hydrin diaphragm |
| AV1-1651-2 | Standard feedback (51 on gas valve), w/ silicone diaphragm |

12.4 AIR VALVE MIXER INSTALLATION TIPS

IMPCO air fuel mixers are very versatile. They can be installed in a variety of positions. The following points should be used as a guide.

- Impco mixers can be attached to the throttle body and mounted to the intake manifold similar to the gasoline carburetor.
- Impco mixers can be mounted remotely in the air intake stream ahead of the throttle body.
- Intake air for the mixer must be ducted from outside the engine compartment.
- The fuel hose from the regulator must be as short as practically possible.

12.5 SELECTING THE CORRECT CARBURETOR SIZE

Air-Flow Capacities

It is important to size correctly the airflow capacity of the IMPCO conversion carburetor to the engine airflow requirement. Specifying the correct IMPCO carburetor is vital because a carburetor too small for a given engine limits horsepower. Up to a specific RPM, normal torque is obtained. Beyond that point, as the carburetor limits airflow, torque falls off, with consequent diminishing of performance. A carburetor excessively large for an engine may cause starting troubles. Idle will not be stable, and fuel mixture will not be consistent. As a general rule, the airflow capacity of the carburetor should be reasonably close to the airflow requirement of the engine being converted. However, the type of service the engine performs is a necessary consideration in selecting the appropriate carburetor (or mixer). Keep in mind the following:

- Engines, which are never operated at wide-open throttle, give the best performance and service with under carburetion. Lift trucks are typical of this situation.
- Engines with a degree of under carburetion are easier to start and will develop the low-end torque required in these types of service.

Chart for Determining Engine Air-flow Requirements

The chart gives engine airflow requirements for some common displacements at various RPM's. Find the air-flow requirement for the engine you are working with at the point where size and speed (CID and RPM) intersect. It is generally sufficiently close to use in selecting the correct IMPCO carburetor.

Maximum Engine RPM

| L i t e r s | C i d | 6 0 0 | 8 0 0 | 1 0 0 | 1 2 0 | 1 4 0 | 1 6 0 | 1 8 0 | 2 0 0 | 2 2 0 | 2 4 0 | 2 6 0 | 2 8 0 | 3 0 0 | 3 2 0 | 3 4 0 | 3 6 0 |
|----------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1.0 | 61 | 11 | 14 | 18 | 21 | 25 | 28 | 32 | 35 | 39 | 42 | 46 | 49 | 53 | 56 | 60 | 64 |
| 1.25 | 77 | 13 | 18 | 22 | 27 | 31 | 36 | 40 | 47 | 49 | 54 | 58 | 62 | 67 | 71 | 76 | 80 |
| 1.5 | 92 | 16 | 21 | 27 | 32 | 37 | 43 | 48 | 53 | 59 | 64 | 69 | 75 | 80 | 85 | 91 | 96 |
| 1.75 | 107 | 19 | 25 | 31 | 37 | 43 | 50 | 56 | 62 | 68 | 74 | 81 | 87 | 93 | 99 | 105 | 112 |
| 2.0 | 122 | 21 | 28 | 35 | 42 | 49 | 56 | 65 | 71 | 78 | 85 | 92 | 99 | 106 | 113 | 120 | 127 |
| 2.25 | 137 | 24 | 32 | 40 | 48 | 55 | 63 | 71 | 79 | 87 | 95 | 103 | 111 | 119 | 127 | 135 | 143 |
| 2.5 | 152 | 26 | 35 | 44 | 53 | 62 | 70 | 79 | 88 | 97 | 106 | 114 | 123 | 132 | 141 | 150 | 159 |
| 2.75 | 167 | 29 | 38 | 48 | 58 | 68 | 78 | 87 | 97 | 107 | 116 | 126 | 136 | 145 | 155 | 165 | 175 |
| 3.0 | 182 | 31 | 42 | 52 | 63 | 73 | 84 | 94 | 105 | 115 | 126 | 136 | 147 | 157 | 168 | 178 | 189 |
| 3.25 | 197 | 34 | 46 | 57 | 68 | 80 | 91 | 103 | 114 | 125 | 137 | 148 | 160 | 171 | 182 | 194 | 205 |
| 3.5 | 212 | 37 | 49 | 61 | 74 | 86 | 98 | 110 | 123 | 135 | 148 | 160 | 172 | 184 | 197 | 209 | 221 |
| 3.75 | 227 | 39 | 52 | 65 | 78 | 91 | 104 | 117 | 130 | 143 | 156 | 169 | 182 | 195 | 208 | 221 | 234 |
| 4.0 | 242 | 42 | 56 | 70 | 84 | 98 | 112 | 126 | 140 | 154 | 168 | 182 | 196 | 210 | 224 | 238 | 252 |
| 4.25 | 257 | 45 | 60 | 74 | 89 | 104 | 119 | 134 | 149 | 164 | 179 | 193 | 209 | 223 | 238 | 253 | 268 |
| 4.5 | 272 | 47 | 63 | 78 | 94 | 110 | 126 | 141 | 157 | 173 | 188 | 204 | 220 | 235 | 251 | 267 | 283 |
| 4.75 | 287 | 50 | 66 | 83 | 99 | 116 | 133 | 149 | 166 | 183 | 199 | 216 | 232 | 249 | 266 | 282 | 299 |
| 5.0 | 302 | 52 | 70 | 87 | 105 | 122 | 140 | 157 | 175 | 192 | 210 | 227 | 245 | 262 | 280 | 297 | 315 |
| 5.25 | 317 | 55 | 73 | 91 | 110 | 128 | 146 | 165 | 183 | 201 | 220 | 238 | 256 | 274 | 293 | 311 | 329 |
| 5.5 | 332 | 58 | 77 | 96 | 115 | 134 | 154 | 173 | 192 | 211 | 230 | 250 | 269 | 288 | 307 | 326 | 346 |
| 5.75 | 347 | 60 | 80 | 100 | 121 | 141 | 161 | 181 | 201 | 221 | 241 | 261 | 281 | 301 | 322 | 342 | 362 |
| 6.0 | 362 | 63 | 84 | 104 | 125 | 146 | 167 | 188 | 209 | 230 | 251 | 272 | 293 | 313 | 334 | 355 | 376 |
| 6.25 | 377 | 65 | 87 | 109 | 131 | 153 | 174 | 196 | 218 | 240 | 262 | 283 | 305 | 327 | 349 | 371 | 392 |
| 6.5 | 392 | 68 | 91 | 113 | 136 | 159 | 182 | 204 | 227 | 250 | 272 | 295 | 318 | 340 | 363 | 386 | 409 |
| 6.75 | 407 | 71 | 94 | 118 | 142 | 165 | 189 | 212 | 236 | 260 | 283 | 307 | 330 | 354 | 378 | 401 | 425 |
| 7.0 | 422 | 73 | 98 | 122 | 146 | 171 | 195 | 220 | 244 | 268 | 293 | 317 | 342 | 366 | 390 | 415 | 439 |
| 7.25 | 437 | 76 | 101 | 126 | 152 | 177 | 202 | 228 | 253 | 278 | 304 | 329 | 354 | 379 | 405 | 430 | 455 |
| 7.5 | 452 | 79 | 105 | 131 | 157 | 183 | 200 | 236 | 262 | 288 | 314 | 341 | 367 | 393 | 419 | 445 | 472 |
| 7.75 | 467 | 81 | 108 | 135 | 162 | 189 | 216 | 243 | 270 | 297 | 324 | 351 | 378 | 405 | 432 | 459 | 486 |
| 8.0 | 482 | 84 | 112 | 139 | 167 | 195 | 223 | 251 | 279 | 307 | 335 | 363 | 391 | 418 | 446 | 474 | 502 |

Formulas for Determining Cubic-Feet-per-Minute (CFM) Air-flow Requirements

Determining specific airflow requirement for any engine requires only the application of the following formulas.

| Application Conversion Table | | |
|-------------------------------------|------------------------|-------------------------------|
| If You Have | Do this | To Get |
| Cubic centimeter displacement (CC) | x .06102 | Cubic inch displacement (CID) |
| Cubic centimeter displacement (CC) | x .001 | Liter displacement |
| Liter displacement | x 61.02 | Cubic inch displacement (CID) |
| Liter displacement | x 1000 | Cubic centimeter displacement |
| Cubic inches per minute (CIM) | ÷ 1728 or x .000578 | Cubic feet per minute (CFM) |
| Cubic feet per minute (CFM) | x 28.32 | Liters per minute |

Naturally Aspirated Carbureted Engines

$CID \times RPM \div 1728 \div 2 \times 0.85 = CFM \text{ Required (four stroke engines)}$

$CID \times RPM \div 1728 \times 0.85 = CFM \text{ Required (two stroke engines)}$

The engine airflow requirement determined by this formula is at 85 percent of volumetric efficiency.

1. Determine the cubic inch displacement (CID) of the engine from the identification plate or the user's manual.
2. Multiply the CID figure by the RPM figure corresponding to the maximum engine speed at wide-open throttle.
3. Divide this CIM (cubic inches per minute) figure by 1728 to obtain CFM (cubic feet per minute).
4. Divide the result by 2, for 4 stroke engines.
5. Multiply the figure you obtain by 0.85 (for 85% volumetric efficiency).
6. This figure is the precise airflow requirement for the engine, accurate to one cubic foot/minute.

Example:

$150 \text{ CID} \times 2500 \text{ RPM} = 375,000 \text{ CIM (cubic inches per minute)}$

$375,000 \div 1728 = 217 \text{ CFM (2 stroke engines)}$

$217 \div 2 = 108.5 \text{ CFM (4 stroke engines)}$

$108.5 \times 0.85 = 92 \text{ CFM (at 85\% volumetric efficiency)}$

Fuel Injected Engines

$CID \times RPM \div 1728 = CFM \text{ Required (2 stroke engines)}$

$CID \times RPM \div 1728 \div 2 = CFM \text{ Required (4 stroke engines)}$

Due to improved intake manifold design, use 100% of volumetric efficiency for fuel injected engines, do not multiply by 0.85.

Turbocharged Engines (with mixer upstream of turbocharger)

$CID \times RPM \div 1728 \div 2 \times \% \text{ boost pressure} = \text{CFM Required (four stroke engines)}$.

$CID \times RPM \div 1728 \times \% \text{ boost pressure} = \text{CFM Required (two stroke engines)}$.

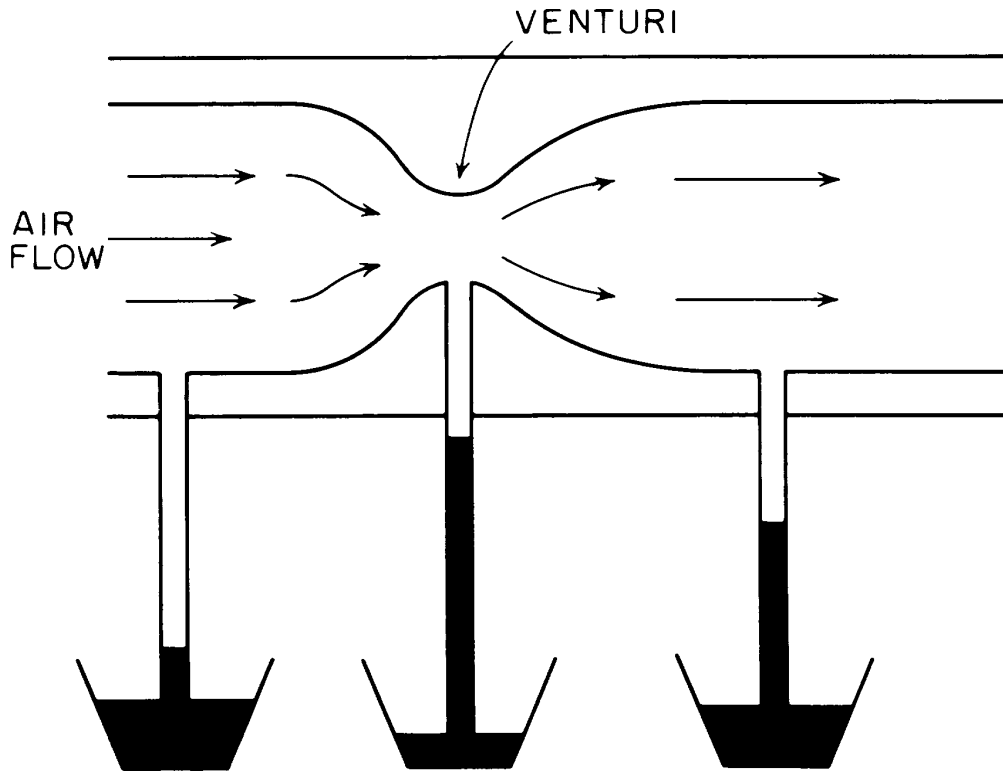
Normal air inlet pressure to the engine at sea level is 14.7 PSI (one atmosphere). Adding a turbocharger merely increases the inlet pressure. For example, 6PSI boost equates to 14.7 PSI plus 6 PSI for a total inlet pressure of 20.7 PSI. 20.7 PSI equals 140% of one atmosphere at sea level. Here is how this works using the above formula.

- One atmosphere equals 14.7 PSI (100%).
- 6 PSI boost equals 40% of 14.7 PSI
- Total inlet pressure equals 20.7 PSI (140%)
- Therefore you must multiply the naturally aspirated CFM requirement by 1.40 to obtain the turbocharged CFM requirement.

| Vehicle Engine Applications | | | |
|------------------------------------|------------------|---------------------|-----------------|
| Model | Rated Horsepower | Cubic Feet / Minute | Liters / Minute |
| 55 | 56 | 91 | 2577 |
| 55-500 | 67 | 108 | 3059 |
| 100 | 106 | 170 | 4814 |
| 125 | 126 | 202 | 5721 |
| 175 | 130 | 210 | 5947 |
| 200 | 172 | 276 | 7816 |
| 225 | 205 | 329 | 19,740 |
| 300A-1, 300A-20 | 217 | 348 | 20,880 |
| 300A-50, 300A-70 | 270 | 432 | 25,920 |
| 425 | 287 | 460 | 27,600 |

12.6 VENTURI MIXER THEORY OF OPERATION

The venturi mixer is a very simple design with no moving parts. It is placed in the intake air stream between the air cleaner and the throttle body. The design of the venturi creates a slight negative pressure as air is drawn through it. This negative pressure is used to draw fuel from the regulator into the intake air stream.



SECTION 13

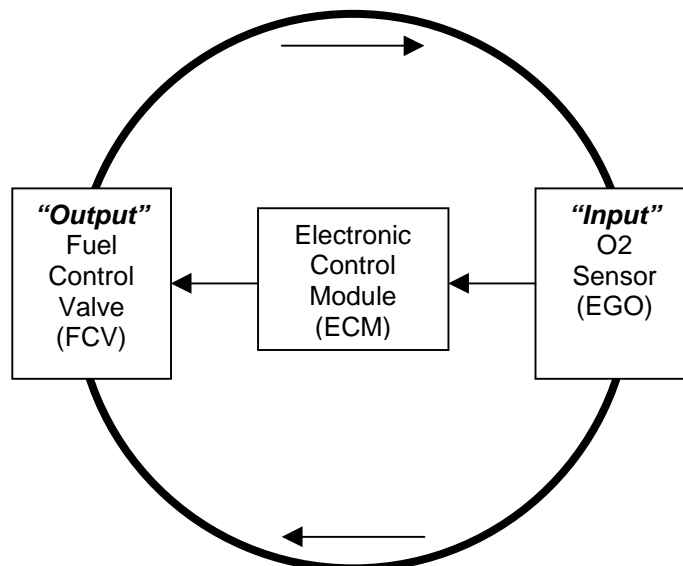
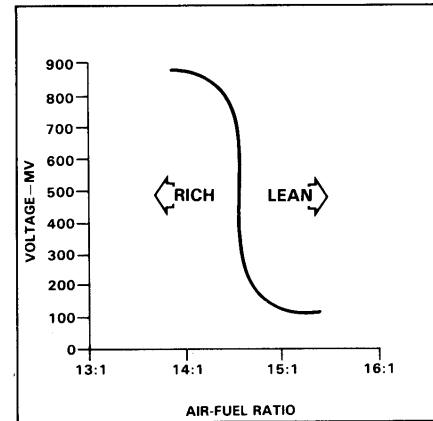
CLOSED LOOP AIR/FUEL MIXTURE CONTROL

13.1 CLOSED LOOP THEORY OF OPERATION

IMPCO has designed and manufactured advanced electronic closed-loop air/fuel ratio controllers for use with LPG, CNG and LNG fuel systems. These controllers may use engine manifold absolute pressure sensors (MAP), exhaust gas oxygen sensors (EGO) and engine RPM input. Information from the sensors is used to regulate the air/fuel mixtures, correcting for proper air/fuel ratios on different system configurations and in different operating modes.

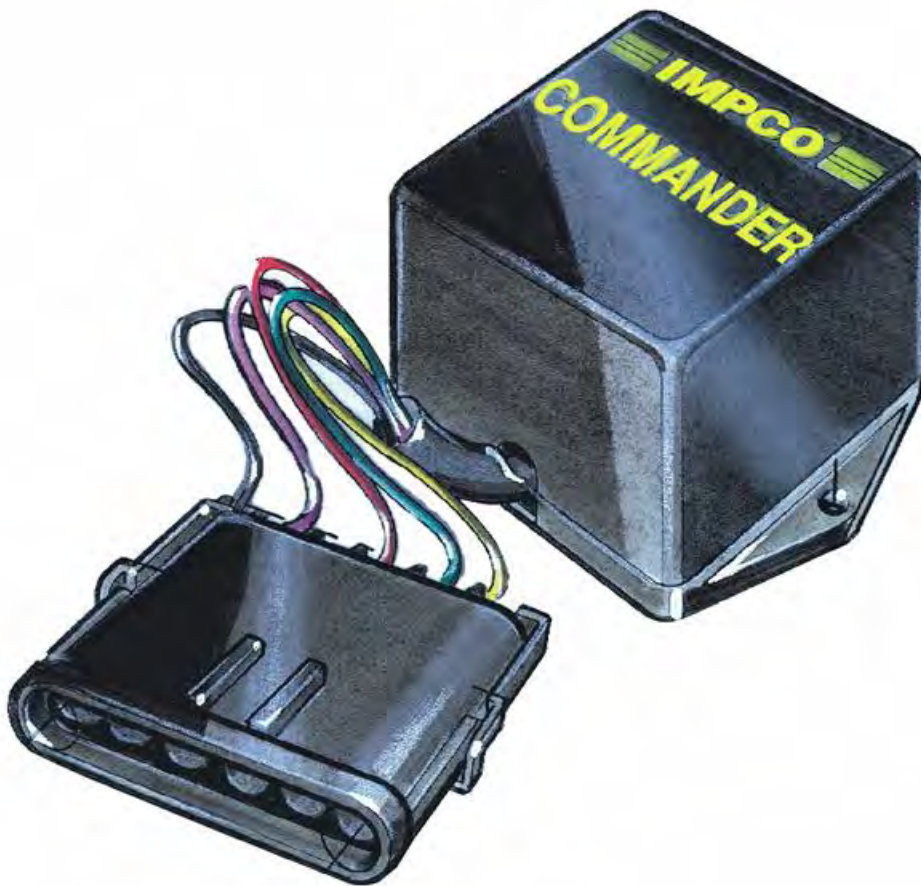
The fuel control valve(s) (FCV) meter air valve vacuum (AVV) into the atmospheric reference side (top) of the secondary regulator diaphragm. The atmospheric vent orifice allows for the depletion of vacuum over the diaphragm and a controlled bleed for dynamic response of the diaphragm.

When the EGO sends a voltage signal above 500 mv. the controller interprets that the fuel mixture is rich. The controller will increase the duty cycle of the FCV allowing more AVV to act on the top side of the secondary regulator diaphragm, which causes a reduction in regulator output pressure. As the regulator output pressure is reduced the air/fuel ratio becomes leaner. When the EGO sensor sends a voltage signal less than 500 mv. it signals to the controller that the mixture is now lean. The controller will decrease the duty cycle of the FCV lowering the amount of AVV acting on the top side of the secondary regulator diaphragm, which causes an increase in regulator output pressure. As regulator output pressure is increased the air/fuel ratio becomes richer. The closed loop fuel controller is constantly targeting stoichiometric or ideal air/fuel mixture. The IMPCO electronic closed loop system utilizes a feedback (FB) mixer. FB mixers are engineered rich and the air/fuel mixture is pulled back lean by manipulating the regulator output pressure with the variable vacuum signal from the FCV. The more vacuum the lower the fuel pressure.



13.2 IMPCO COMMANDER, DIGITAL, CLOSED-LOOP AIR/FUEL RATIO CONTROLLER

The COMMANDER is a low cost advanced digital, closed-loop air/fuel ratio controller for gaseous fuels. The COMMANDER provides an overall reduction in engine exhaust emissions. The COMMANDER's compact, rugged construction provides for an ideal underhood application. The package is hermetically sealed to combat harsh operating environments. The small electronic module controls fuel pressure based on engine speed and rich/lean status from the exhaust gas oxygen sensor (EGO). The COMMANDER's 8-bit microprocessor reads and computes this data 100 times per second, which gives a precise stoichiometric air/fuel ratio. The COMMANDER delivers excellent exhaust emissions, drivability and fuel economy at a reasonable cost. The COMMANDER kit includes the required electrical parts to convert IMPCO open-loop fuel systems to closed-loop feedback control.



SECTION 14

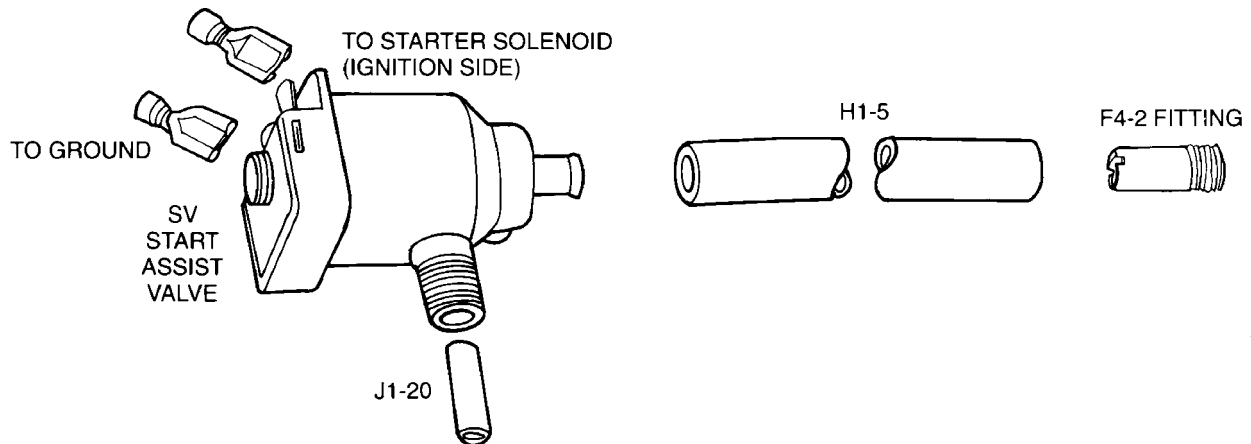
ACCESSORY COMPONENTS

14.1 START VALVE (SV) THEORY OF OPERATION

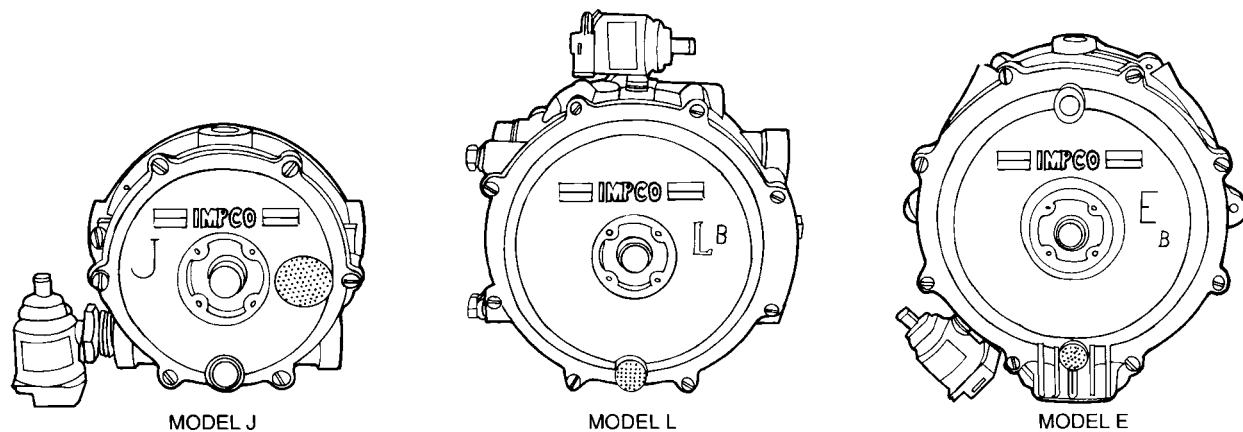
The start valve (SV) is an electrically operated solenoid, which is normally closed. It is wired into the start circuit so that it opens during engine cranking only. The SV is mounted in the secondary test port of the regulator and connected to an air valve vacuum port on the mixer. It is designed to richen the air fuel ratio during cranking to allow for easy engine starts.

- When the engine is off or running the SV is closed.
- When the engine is cranked an electrical signal from the start circuit opens the SV allowing fuel to flow to the engine richening the air fuel ratio.
- A selection of restrictors is available to custom tailor the amount of fuel enrichment for different size engines.

IMPCO SV (start valve)



SV Mounting Location



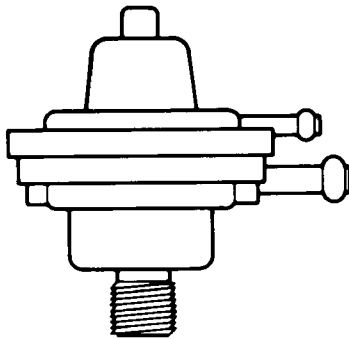
14.2 VACUUM POWER VALVE (VPV) THEORY OF OPERATION

The vacuum power valve (VPV) is a vacuum operated valve, which is normally open. The VPV is designed to richen the air fuel ratio when the engine is under high load to boost power output. The VPV is mounted in the secondary test port of the regulator and is connected to an air valve vacuum port on the mixer and manifold vacuum.

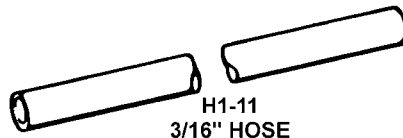
- When engine load is low and manifold vacuum is high the VPV is held closed by the strong manifold vacuum signal.
- When the engine load is high and manifold vacuum is low the weak manifold vacuum signal allows the VPV to open and richen the air fuel ratio.
- A selection of restrictors is available to custom tailor the amount of fuel enrichment for different size engines.

Vacuum Power Valve (VPV)

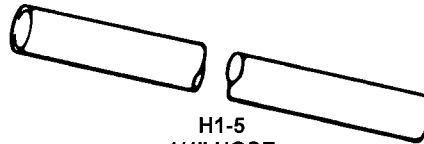
VACUUM POWER VALVE (VPV)



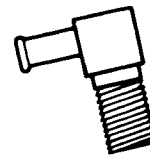
RESTRICTOR



H1-11
3/16" HOSE



H1-5
1/4" HOSE



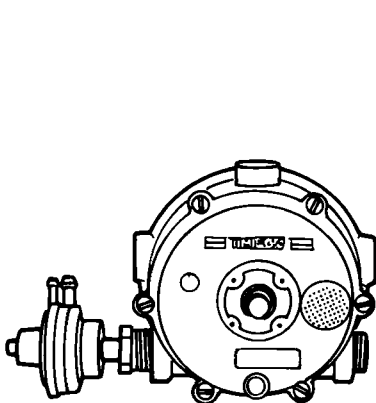
F4-8 FITTING
(IN MANIFOLD VACUUM PORT)



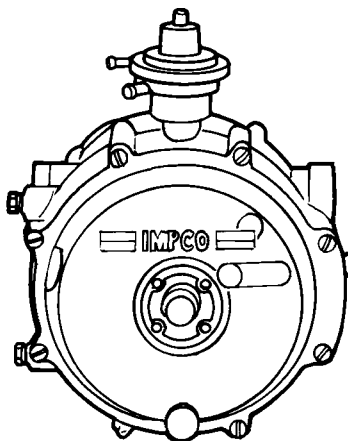
F4-2 FITTING
(IN AIR VALVE VACUUM PORT)

J1-20-2 (.050") RESTRICTOR, 4-CYLINDER APPLICATIONS
J1-20-3 (.075") RESTRICTOR, 6-CYLINDER APPLICATIONS
J1-20-4 (.100") RESTRICTOR, 8-CYLINDER APPLICATIONS

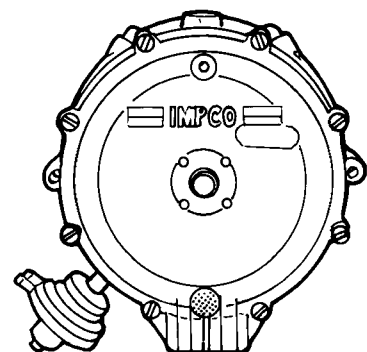
VPV Mounting Location



MODEL J



MODEL L



MODEL E

SECTION 15

TEST EQUIPMENT

15.1 U-TUBE WATER MANOMETER

The U-tube water manometer is a highly accurate yet very convenient pressure measurement tool. It is designed to measure slight positive and negative pressures. It rolls up compactly into a small coil and is stored in its circular metal case. It can and should be used to measure or calibrate other face type gauges.

Taking a Reading

- Connect the manometer to the source of pressure, vacuum or differential pressure.
- When the pressure is applied, add the number of inches one column travels up to the amount the other column travels down to obtain the pressure reading.

U-Tube Water Manometer



15.2 ITK-1 PRESSURE GAUGE KIT

The IMPCO ITK-1 pressure gauge kit is designed for testing and troubleshooting Impco gaseous fuel systems. The kit contains the following:

- 0-160 psi gauge – For measuring fuel container pressure or on dual fuel systems it may be used to measure gasoline fuel system pressure
- 0-5 psi gauge – For measuring Impco pressure regulator, primary pressure.
- 0-10" w.c. gauge – For measuring Impco pressure regulator, secondary pressure.
- G2-2 lever gauge – For correct adjustment of the Impco pressure regulator, secondary lever.
- Assorted fittings
- Hose
- Instructions

ITK-1 Pressure Gauge Kit



15.3 FSA-1 FUEL SYSTEM ANALYZER

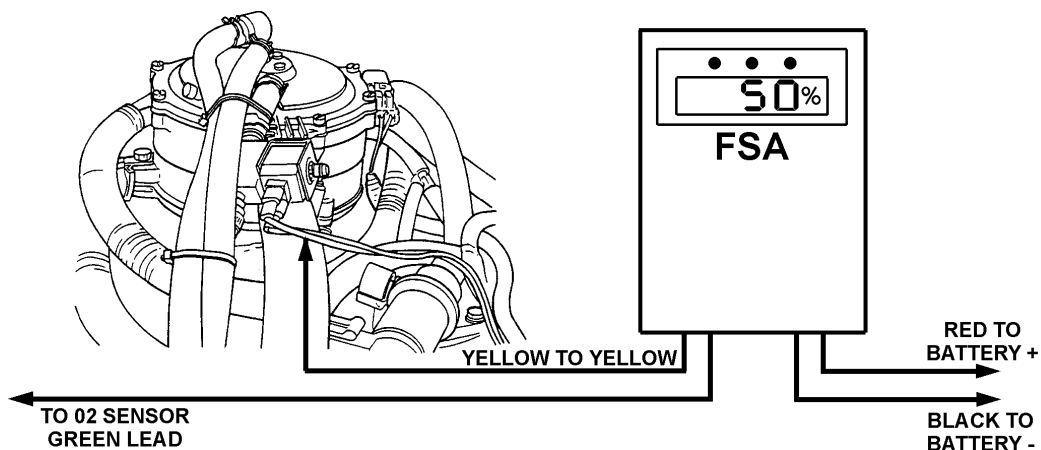
The IMPCO FSA-1 is designed for testing and adjusting feedback carburetion systems. The FSA-1 includes the following:

- FSA-1 Fuel System Analyzer
- Detailed instructions

FSA-1 Wire Connections.

- Connect the FSA black to battery ground.
- Connect the FSA red to battery positive.
- Connect the FSA green to oxygen sensor signal out.
- Connect the FSA yellow to the yellow lead at the fuel control valve.

FSA-1 Fuel System Analyzer

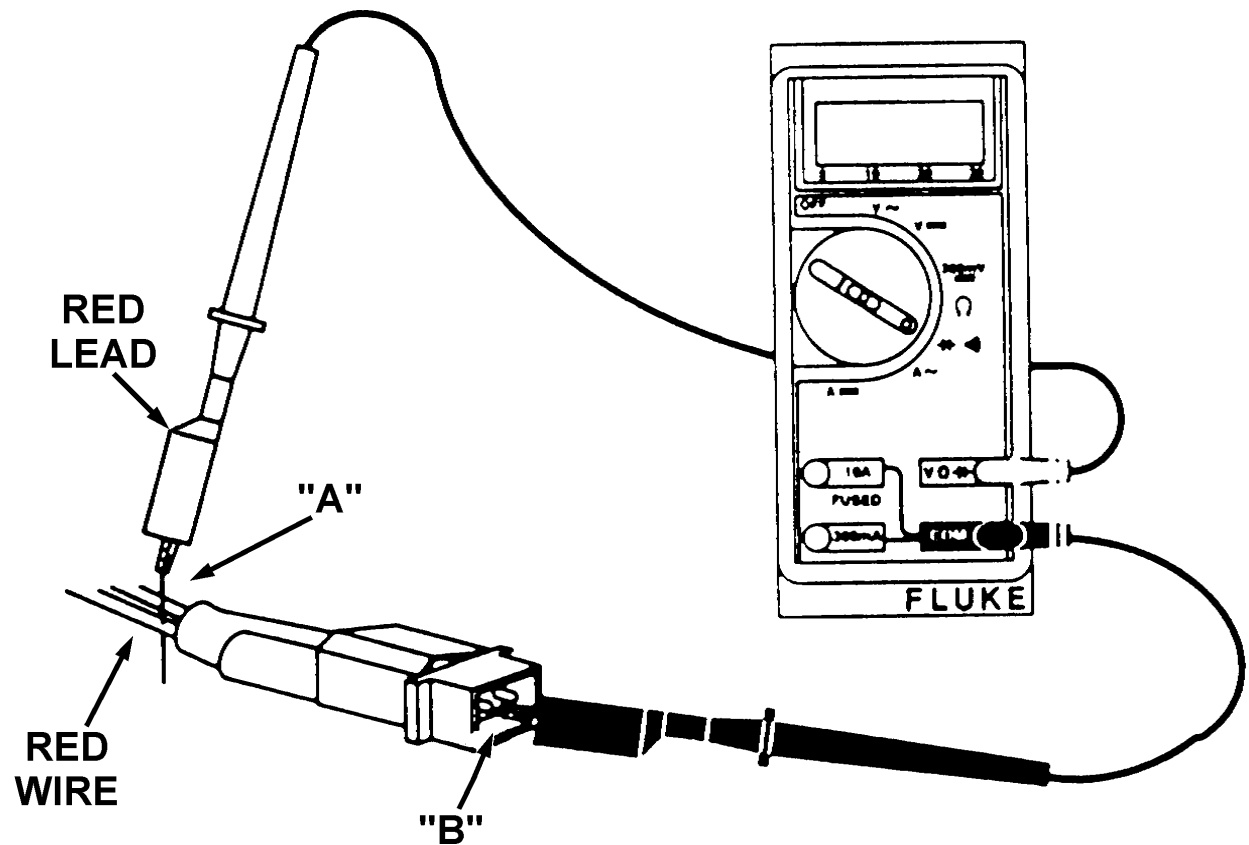


15.4 DVOM DIGITAL VOLT OHM METER

The DVOM is a standard diagnostic tool. It is used for measuring various types of electrical signals. Some important characteristics of a DVOM are:

- High-impedance safe for sensitive circuits
- Very accurate
- Fluke, Rotunda 77 & 88 types standard in the industry
- Filtered adjustable sample rates

DVOM Digital Volt Ohm Meter



SECTION 16 FUEL SYSTEM SET-UP, ADJUSTMENT, TROUBLESHOOTING & SERVICE PROCEDURES

Preface: These adjustments have been prepared to provide the technician with the proper procedure when adjustments to the IMPCO fuel system are required. However, the technician must understand why adjusting and tuning the system is critical for proper operation of the gaseous fuel system.

- Improper adjustment of the fuel system could result in extremely high levels of carbon monoxide (CO) and hydrocarbons.
- It is not possible to accurately adjust any IMPCO system without the use of calibrated emissions analyzing equipment. It is impossible to detect moderate levels of CO without this equipment.
- The following instructions apply to carburetion, which is in serviceable condition. It is impossible to properly adjust a fuel system that has faulty gas valves, faulty diaphragms, faulty regulators or plugged fuel and air filters.
- It is important that the technician who will make these adjustments have a good understanding of the entire fuel system. If you experience difficulty in making these adjustments, contact your local IMPCO distributor for assistance before proceeding.

Preliminary Checks

The following checks must be performed before making adjustments to the air/fuel mixture.

Part #1 - Engine Off & Cold Checks:

1. Check fuel system for leaks.
2. Check fuel container level, must be enough for testing (not more than 80% full).
3. Clean battery external surface.
4. Check battery cables
5. Clean battery cable connections.
6. Check battery voltage.
7. Clean ground connection to Chassis/engine block.
8. Clean positive connection to solenoid/starter.
9. Clean ground connection between starter and engine block.
10. Clean & inspect radiator cooling fins.
11. Check coolant level.
12. Check coolant strength.
13. Check for internal radiator deposits/clogging.
14. Check coolant hoses.
15. Check fan.
16. Check water pump.
17. Check V-belts.
18. Check ignition switch and wiring.
19. Check primary ignition wire connections and polarity.
20. Check ignition coil.
21. Check secondary ignition wires.
22. Check ignition distributor cap.
23. Check ignition rotor.

24. Check breaker unit (points & condenser or pick-up coil).
25. Check distributor shaft & housing.
26. Check spark plug for proper heat range and gap (refer to OEM specifications).
27. Check alternator wiring connections.
28. Check voltage regulator connections.
29. Check for cold air intake.
30. Check air filter.
31. Check air intake hoses.
32. Check fuel container position.
33. Check fuel line.
34. Check fuel filter.
35. Check electric fuel lock wiring.
36. Check vacuum fuel lock vacuum hose.
37. Check/clean pressure regulator.
38. Check and clean mixer & air/gas valve.
39. Check cylinder valve clearance.
40. Check cylinder compression.
41. Check for oil leaks.

Part #2 - Engine Running & Hot Checks:

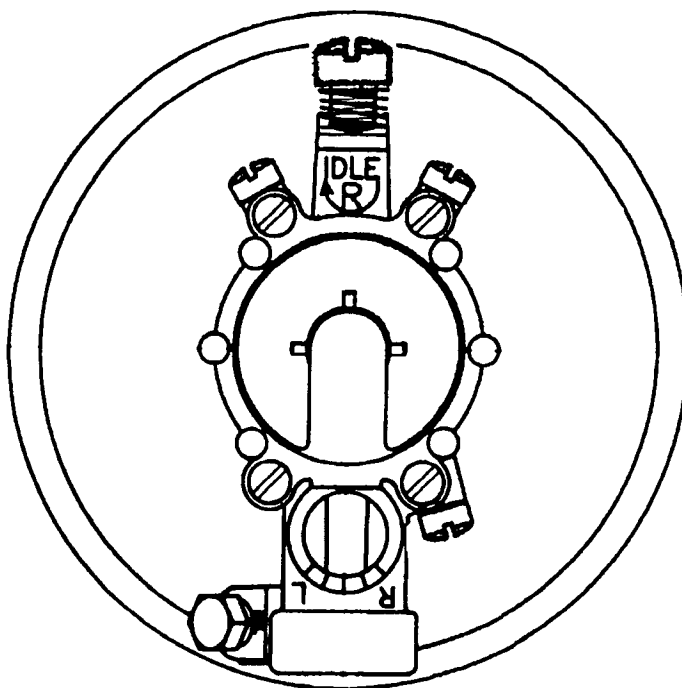
1. Check engine thermostat operation.
2. Check charging system output.
3. Check breaker point dwell (if so equipped).
4. Check for vacuum leaks at the carburetor and manifold.
5. Check vapor fuel line for leaks and check hose & clamp condition.
6. Check initial ignition timing.
7. Check centrifugal ignition timing.
8. Check vacuum ignition timing.
9. Check fuel lock operation.
10. Check regulator primary pressure.
11. Check regulator secondary pressure.
12. Check idle air/fuel mixture.
13. Check full load air/fuel mixture.

16.1 IDLE MIXTURE ADJUSTMENT

Adjustment procedures for IMPCO carburetor and mixer models CA50, CA55, CA100, CA125, and CA225.

1. Run engine and allow it to warm to its normal operating temperature.
2. Install the emissions analyzer sampling tube into the exhaust pipe, upstream of any catalyst.
3. Adjust engine idle RPM to the OEM specifications. To do this, turn the screw located on the throttle stop in to increase idle speed, and out to decrease idle speed.
4. Adjust the idle mixture using an exhaust emissions analyzer. Turning the idle mixture screw out will lean the mixture; turning it in will richen the mixture. Turn the idle mixture screw out slowly until engine speed slows down. Begin turning idle mixture screw in in one-half turn increments, pausing after each turn to allow the analyzer to read the sample (about 30-45 seconds).
5. Set the mixture at $0.75\% \pm 0.25$ CO for propane, $0.50\% \pm 0.25$ CO for natural gas. You may have to reset the idle speed as it may increase or decrease by this adjustment. If you are unable to adjust below the 1% CO level you may need to inspect the mixer. The body may be worn or the gas valve may need replacing. If you are unable to richen the mixture, you may want to check for vacuum leaks or re-inspect the mixer body for wear.

IMPCO CA125 & CA225 Mixture Adjustment Location



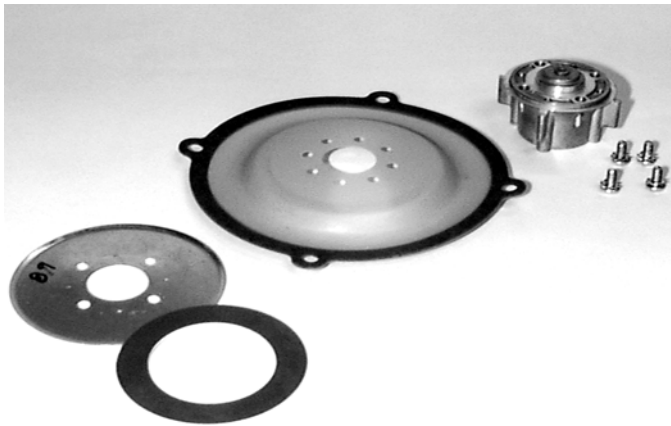
16.2 MIXTURE CONTROL SHIMS

IMPCO carburetor models CA100, CA125 and CA200, CA225 are designed with a limited external idle adjustment to comply with emission requirements as applied to forklift and automotive vehicles.

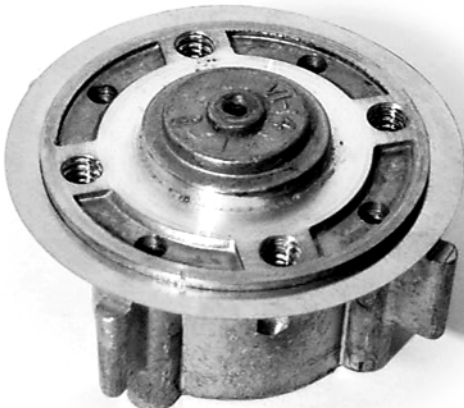
Because of variations in positive crankcase vents, exhaust gas recirculation devices, etc. between types and makes of engines, the limited external adjustment has not always been adequate. Impco has received numerous requests for a system to permit a wider range of idle mixture adjustment.

To accomplish this purpose without changing the range of external idle adjustment, the R1-29 spacer rings for the CA100 and CA125 carburetors and the R1-30 for the CA200 and CA225 carburetors are now available. Designed to lean the mixtures approximately two air/fuel ratios, they allow the idle mixture screw to be turned in towards the closed position for desired air-fuel mixtures in those engines tending to idle on the rich side.

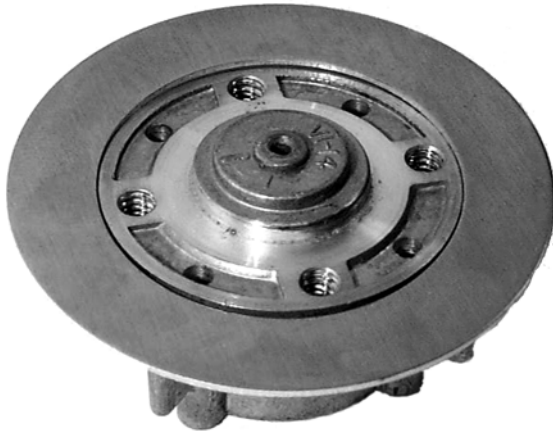
1. Completely disassemble the air-gas valve assembly (AV1-14 shown).



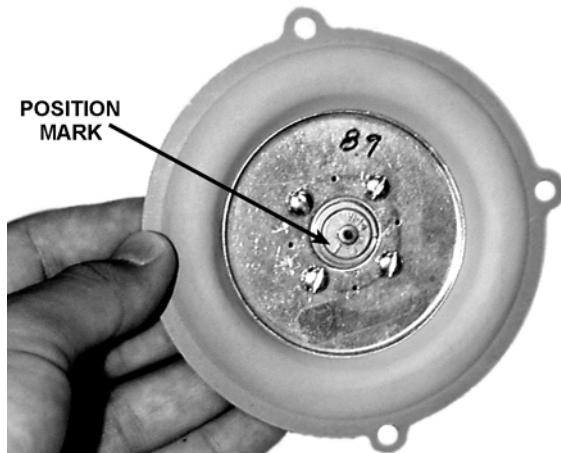
2. Place spacer ring on air valve as shown.



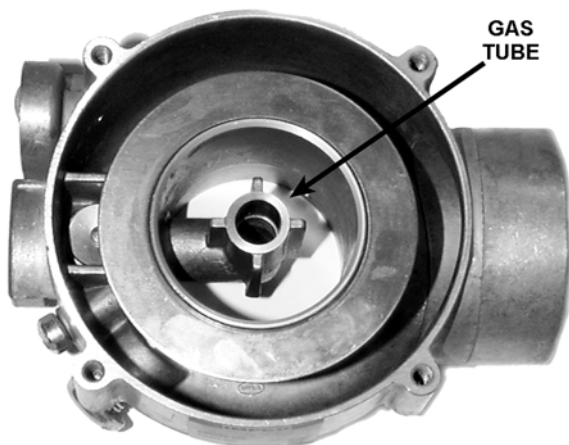
3. Assemble floating ring over spacer ring.



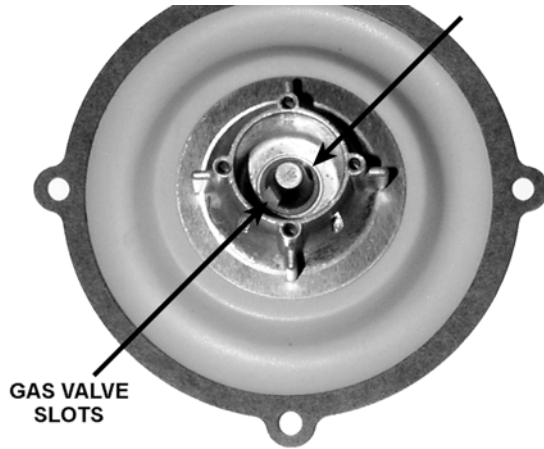
4. Air-gas valve assembled with position mark pointing between two mounting tabs in outer diameter of diaphragm (AV1-14).



5. The reason for assembling the parts as in Fig. 4 is the gas tube leading to the jet.



6. Shown inside air valve cup is the gas metering valve. By assembling the air-gas valve as shown, the gas valve slots are at right angles to the gas inlet. Gas flows out of slots over each side of gas tube for more efficient mixing of gas and air before it leaves the carburetor.



7. Proper assembly showing position mark pointing to idle screw (gas inlet) side of mixer body.



8. Install air valve spring.



9. Install cover and tighten screws snugly. Excess torque on these screws is unnecessary.



16.3 POWER MIXTURE ADJUSTMENT

Adjustment procedures for Impco carburetor and mixer models CA50, CA55, CA100, CA125 and CA225.

1. To adjust the power mixture, accelerate to full throttle and introduce a maximum load to the engine (depending on the equipment you are working on, this could be a hydraulic, electrical or a transmission stall). With the sample tube still in the exhaust pipe, move the power valve to a maximum lean setting. The engine should lose power, and CO should drop. At that point, begin turning the power valve towards the rich position. Move the pointer on the valve 1/4-turn between the marks on the body (wiggle valve slightly after each adjustment as the power valve is mounted in rubber and may cause settling after each adjustment).
2. Set the mixture at $0.75\% \pm 0.25$ CO for propane, $0.50\% \pm 0.25$ CO for natural gas.
3. Once you have reached your desired setting on the power valve, allow the engine to return to an idle. You may need to readjust the idle setting as adjusting the power valve may affect the idle settings. Refer to steps #3, #4 and #5 for idle mixture setting.

16.4 TROUBLESHOOTING PROCEDURES

This checklist is your guide to the most probable causes of an engine performance complaint when the malfunction is due to carburetion.

The troubleshooting approach is designed to diagnose problems in vehicles that have performed properly in the past and where time and/or wear have created the troublesome condition.

Locating a problem in a propane engine is done in exactly the same way as with a gasoline engine. Consider all parts of the ignition and mechanical systems as well as the fuel system. It is recommended that you systematically check potential causes of a particular complaint in every possible area before making changes or adjustments to the carburetion equipment. Utilize the troubleshooting sections of pertinent manufacturers' service manuals to correct or eliminate difficulties other than carburetion.

Every possible cause of poor performance cannot be covered, so if doing the work prescribed does not correct the problem a more extensive checkout and diagnosis will have to be made.

Don't stop after replacing a failed part. Find out what caused the part to go bad and eliminate the cause of the failure.

Quick Checks for a Stalled Engine

- A. Fuel in tank?
- B. Fuel getting to engine? (Look for signs of frost on lines or components.)
- C. Spark at spark plugs?
- D. Gasoline fuel bowl still full after switch to LPG? (Bi-fuel only)

Quick Check of IMPCO System

With the air cleaner and carburetor air/gas valve and cover removed, it is a simple matter to check the pressure regulator and fuelock for leaks.

- A. Open fuel valve on container and check carburetor open gas jet for leakage. If fuelock and converter are operating properly, no fuel will leak through.
- B. Press primer button on front of pressure regulator to open gas regulator valve. A small amount of gas will pass through the jet as the system is emptied back to the fuelock. If the fuelock is operating properly, the gas flow will cease as soon as the fuel downstream of the fuelock is exhausted.
- C. Next, remove the vacuum hose to the VFF30 fuelock from the fitting at the source of vacuum. With the primer button depressed, suck lightly on the fuelock vacuum hose. Fuel should flow immediately and stop flowing when suction is relieved. These checks should indicate each component is operating properly.

Troubleshooting Guide

Of the problems listed below, find the one(s), which most accurately match the problem you're experiencing. See information regarding the probable cause, and the probable solution.

| Problem | Probable Cause | Probable Solution |
|-----------------------|---|---|
| Will Not Start | Fuel container empty | Fill fuel container <ul style="list-style-type: none"> Do not exceed 80% of liquid capacity. |
| | Liquid valve closed | Open liquid valve slowly |
| | Excess flow valve closed | Reset excess flow valve <ul style="list-style-type: none"> close liquid valve wait for click sound open valve slowly |
| | Plugged fuel line | Remove obstruction from fuel line <ul style="list-style-type: none"> close liquid fuel valve using caution, disconnect fuel line clear obstruction with compressed air re-connect fuel line leak test |
| | Clogged fuel filter | Repair/replace as required <ul style="list-style-type: none"> close liquid fuel valve using caution, disconnect fuel line remove/replace filter open liquid fuel valve leak test |
| | Lack of priming | Check primer <ul style="list-style-type: none"> test primer operation check idle air/fuel ratio (lean?) Install primer if required |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> no holes in hose clamps must be tight watch for kinked and/or pinched and/or collapsed hose |
| | Fuel lock malfunction | Vacuum fuel lock <ul style="list-style-type: none"> check vacuum hose and fittings see IMPCO LPG Quick Test check diaphragm for damage Electric fuel lock <ul style="list-style-type: none"> check circuit wiring check safety switch see IMPCO LPG Quick Test |
| | Pressure regulator malfunction | Test pressure regulator operation <ul style="list-style-type: none"> use IMPCO ITK-1 test kit install primary pressure gauge install secondary pressure gauge crank engine and observe readings on pressure gauges (note secondary spring color) compare readings to IMPCO specifications if readings are out of spec repair/replace pressure regulator |

| Problem | Probable Cause | Probable Solution |
|---------------------------|---|--|
| Will Not Start | Carburetor malfunction | Check carburetor <ul style="list-style-type: none"> remove air/gas valve assembly clean air/gas valve and carb throat check diaphragm for holes/damage check air/gas valve for wear/damage repair/replace as required |
| | Incorrect idle air bypass adjustment | Check idle air bypass adjustment <ul style="list-style-type: none"> install lean idle shims readjust idle air/fuel mixture |
| | Incorrect idle air/fuel mixture | Check air/fuel mixture <ul style="list-style-type: none"> see section 16.1 |
| | Air filter plugged | Check air filter <ul style="list-style-type: none"> clean/replace as required |
| | No spark | Check for spark <ul style="list-style-type: none"> follow manufacturer's instructions repair/replace as required |
| Difficult to Start | Fuel container almost empty | LPG vapor from liquid outlet <ul style="list-style-type: none"> Fill fuel container Do not exceed 80% of liquid capacity. |
| | Excess flow valve closed | Reset excess flow valve <ul style="list-style-type: none"> close liquid valve wait for click sound open valve slowly |
| | Clogged fuel filter | Repair/replace as required <ul style="list-style-type: none"> close liquid fuel valve run engine out of fuel remove/replace filter open liquid fuel valve leak test |
| | Plugged fuel line | Remove obstruction from fuel line <ul style="list-style-type: none"> close liquid fuel valve using caution, disconnect fuel line clear obstruction with compressed air re-connect fuel line leak test |
| | Lack of priming | Check primer <ul style="list-style-type: none"> test primer operation check idle air/fuel ratio (lean) Install primer if required |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> no holes in hose clamps must be tight watch for kinked and/or pinched and/or collapsed hose |
| | Incorrect idle air bypass adjustment | Check idle air bypass adjustment <ul style="list-style-type: none"> install lean idle shims readjust idle air/fuel mixture |
| | Incorrect idle air/fuel mixture | Check air/fuel mixture <ul style="list-style-type: none"> see section 16.1 |

| Problem | Probable Cause | Probable Solution |
|-------------------------------|---|---|
| Difficult to Start | Pressure regulator malfunction | Test pressure regulator operation <ul style="list-style-type: none"> • use IMPCO ITK-1 test kit • install primary pressure gauge • install secondary pressure gauge • crank engine and observe readings on pressure gauges (note secondary spring color) • compare readings to IMPCO specifications • if readings are out of spec repair/replace pressure regulator |
| | Air filter clogged | Check air filter <ul style="list-style-type: none"> • clean/replace as required |
| Won't Run Continuously | Fuel container almost empty | LPG vapor from liquid outlet <ul style="list-style-type: none"> • Fill fuel container • Do not exceed 80% of liquid capacity |
| | Excess flow valve closed | Reset excess flow valve <ul style="list-style-type: none"> • close liquid valve • wait for click sound • open valve slowly |
| | Clogged fuel filter | Repair/replace as required <ul style="list-style-type: none"> • close liquid fuel valve • run engine out of fuel • remove/replace filter • open liquid fuel valve • leak test |
| | Plugged fuel line | Remove obstruction from fuel line <ul style="list-style-type: none"> • close liquid fuel valve • using caution, disconnect fuel line • clear obstruction with compressed air • re-connect fuel line • leak test |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> • no holes in hose • clamps must be tight • watch for kinked and/or pinched and/or collapsed hose |
| | Pressure regulator freezes | Check level in cooling system <ul style="list-style-type: none"> • must be full Check coolant strength <ul style="list-style-type: none"> • -35F minimum Check regulator mounting position <ul style="list-style-type: none"> • must be below top of radiator Check coolant hoses <ul style="list-style-type: none"> • watch for kinks and/or pinched hoses • verify one pressure hose and one return hose |
| | Incorrect idle air/fuel mixture | Check air/fuel mixture <ul style="list-style-type: none"> • see section 16.1 |
| | Incorrect idle speed | Check idle speed <ul style="list-style-type: none"> • adjust idle speed to OEM specs |

| Problem | Probable Cause | Probable Solution |
|-------------------------|---|--|
| Won't Accelerate | Fuel container almost empty | LPG vapor from liquid outlet <ul style="list-style-type: none"> • Fill fuel container • Do not exceed 80% of liquid capacity |
| | Excess flow valve closed | Reset excess flow valve <ul style="list-style-type: none"> • close liquid valve • wait for click sound • open valve slowly |
| | Clogged fuel filter | Repair/replace as required <ul style="list-style-type: none"> • close liquid fuel valve • run engine out of fuel • remove/replace filter • open liquid fuel valve • leak test |
| | Plugged fuel line | Remove obstruction from fuel line <ul style="list-style-type: none"> • close liquid fuel valve • using caution, disconnect fuel line • clear obstruction with compressed air • re-connect fuel line • leak test |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> • no holes in hose • clamps must be tight • watch for kinked and/or pinched and/or collapsed hose |
| | Balance line too small | Check balance line <ul style="list-style-type: none"> • remove balance line, see if problem goes away • replace balance line with larger hose size and fittings |
| | Throttle butterfly not opening | Verify wide open throttle |
| | Incorrect full load air/fuel mixture | Check full load air/fuel mixture <ul style="list-style-type: none"> • see section 16.3 |
| Engine Stalls | Fuel container almost empty | LPG vapor from liquid outlet <ul style="list-style-type: none"> • Fill fuel container • Do not exceed 80% of liquid capacity. |
| | Excess flow valve closed | Reset excess flow valve <ul style="list-style-type: none"> • close liquid valve • wait for click sound • open valve slowly |
| | Clogged fuel filter | Repair/replace as required <ul style="list-style-type: none"> • close liquid fuel valve • run engine out of fuel • remove/replace filter • open liquid fuel valve • leak test |
| | Plugged fuel line | Remove obstruction from fuel line <ul style="list-style-type: none"> • close liquid fuel valve • using caution, disconnect fuel line • clear obstruction with compressed air • re-connect fuel line • leak test |

| Problem | Probable Cause | Probable Solution |
|----------------------|---|---|
| Engine Stalls | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> • no holes in hose • clamps must be tight • watch for kinked and/or pinched and/or collapsed hose |
| | Vacuum leak | Check for vacuum leaks <ul style="list-style-type: none"> • between LPG mixer and gasoline carburetor/injector(s) (bi-fuel only) • between carburetor and intake manifold • between intake manifold and cylinder head |
| | Fuel lock malfunction | Vacuum fuel lock <ul style="list-style-type: none"> • check vacuum hose and fittings • see IMPCO LPG Quick Test • check diaphragm for damage Electric fuel lock <ul style="list-style-type: none"> • check circuit wiring • check safety switch • see IMPCO LPG Quick Test |
| | Pressure regulator malfunction | Test pressure regulator operation <ul style="list-style-type: none"> • use IMPCO ITK-1 test kit • install primary pressure gauge • install secondary pressure gauge • crank engine and observe readings on pressure gauges (note secondary spring color) • compare readings to IMPCO specifications • if readings are out of spec repair/replace pressure regulator |
| | Pressure regulator freezes | Check level in cooling system <ul style="list-style-type: none"> • must be full Check coolant strength <ul style="list-style-type: none"> • -35F minimum Check regulator mounting position <ul style="list-style-type: none"> • must be below top of radiator Check coolant hoses <ul style="list-style-type: none"> • watch for kinks and/or pinched hoses • verify one pressure hose and one return hose |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> • no holes in hose • clamps must be tight • watch for kinked and/or pinched and/or collapsed hose |

| Problem | Probable Cause | Probable Solution |
|------------------------------------|---|--|
| Engine Stalls | Carburetor malfunction | Check carburetor <ul style="list-style-type: none"> remove air/gas valve assembly clean air/gas valve and carb throat check diaphragm for holes/damage check air/gas valve for wear/damage repair/replace as required |
| | | |
| Rough Idle | Incorrect idle speed setting | Check idle speed <ul style="list-style-type: none"> adjust idle speed to OEM specs |
| | Incorrect idle air/fuel mixture | Check air/fuel mixture <ul style="list-style-type: none"> see section 16.1 |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> no holes in hose clamps must be tight watch for kinked and/or pinched and/or collapsed hose |
| | Vacuum leaks | Check for vacuum leaks <ul style="list-style-type: none"> between LPG mixer and gasoline carburetor/injector(s) (bi-fuel only) between carburetor and intake manifold between intake manifold and cylinder head |
| | Engine mechanical | See preliminary checks part #1 and #2 |
| High Idle Speed | Incorrect idle speed setting | Check idle speed <ul style="list-style-type: none"> adjust idle speed to OEM specs |
| | Sticking throttle | Check throttle <ul style="list-style-type: none"> repair replace as required |
| Carburetor Backfire | Incorrect full load air/fuel mixture | Check full load air/fuel mixture <ul style="list-style-type: none"> see section 16.3 |
| | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> no holes in hose clamps must be tight watch for kinked and/or pinched and/or collapsed hose |
| | Ignition malfunction | Check ignition system, repair/replace |
| | Incorrect ignition timing setting | Check ignition timing <ul style="list-style-type: none"> measure initial timing measure centrifugal timing advance measure vacuum timing advance |
| | Engine mechanical | See preliminary checks part #1 and #2 |
| Poor High Speed Performance | Clogged fuel filter | Repair/replace as required <ul style="list-style-type: none"> close liquid fuel valve run engine out of fuel remove/replace filter open liquid fuel valve leak test |
| | Plugged fuel line | Remove obstruction from fuel line <ul style="list-style-type: none"> close liquid fuel valve using caution, disconnect fuel line clear obstruction with compressed air re-connect fuel line leak test |

| Problem | Probable Cause | Probable Solution |
|------------------------------------|---|---|
| Poor High Speed Performance | Faulty vapor connection between pressure regulator and carburetor | Check connection <ul style="list-style-type: none"> no holes in hose clamps must be tight watch for kinked and/or pinched and/or collapsed hose |
| | Throttle butterfly not opening | Verify wide open throttle |
| | Incorrect full load air/fuel mixture | Check full load air/fuel mixture <ul style="list-style-type: none"> see section 16.3 |
| | Carburetor malfunction | Check carburetor <ul style="list-style-type: none"> remove air/gas valve assembly clean air/gas valve and carb throat check diaphragm for holes/damage check air/gas valve for wear/damage repair/replace as required |
| | Pressure regulator malfunction | Test pressure regulator operation <ul style="list-style-type: none"> use IMPCO ITK-1 test kit install primary pressure gauge install secondary pressure gauge crank engine and observe readings on pressure gauges (note secondary spring color) compare readings to IMPCO specifications if readings are out of spec repair/replace pressure regulator |
| | Incorrect ignition timing setting | Check ignition timing <ul style="list-style-type: none"> measure initial timing measure centrifugal timing advance measure vacuum timing advance |
| | Air filter clogged | Check air filter <ul style="list-style-type: none"> clean/replace as required |
| | Restricted exhaust system | Check exhaust system <ul style="list-style-type: none"> measure exhaust back-pressure compare to OEM specs |
| Excessive Fuel Consumption | Engine mechanical | See preliminary checks part #1 and #2 |
| | Carburetor malfunction | Check carburetor <ul style="list-style-type: none"> remove air/gas valve assembly clean air/gas valve and carb throat check diaphragm for holes/damage check air/gas valve for wear/damage repair/replace as required |
| | Incorrect ignition timing setting | Check ignition timing <ul style="list-style-type: none"> measure initial timing measure centrifugal timing advance measure vacuum timing advance |
| | Incorrect full load air/fuel mixture | Check full load air/fuel mixture <ul style="list-style-type: none"> see section 16.3 |
| | Engine mechanical | See preliminary checks part #1 and #2 |

| Problem | Probable Cause | Probable Solution |
|-----------------------------------|--------------------------------|--|
| Excessive Fuel Consumption | Pressure regulator malfunction | Test pressure regulator <ul style="list-style-type: none"> • use IMPCO ITK-1 test kit • install primary pressure gauge • install secondary pressure gauge • crank engine and note readings on pressure gauges • compare readings to IMPCO specifications • if readings are out of spec repair/replace pressure regulator |
| | Air filter clogged | Check air filter <ul style="list-style-type: none"> • clean/replace as required |

16.5 SERVICE PROCEDURES

Maintenance Suggestions

Gaseous fuel powered vehicles should have their maintenance schedules developed to suit the needs specific to their service conditions:

- A. Local climate
- B. Fuel purity
- C. Operating conditions (stop-and-go or steady)
- D. Frequent use or extended periods of non-operation

IMPCO carries a one-year warranty against defects in material and workmanship. It is reasonable to expect 2,000 hours of service without a need to replace any parts in the system, assuming adequate maintenance of the vehicle in general, and a normal operating environment.

- A. In extreme cold conditions, after starting the engine, it should be run at a fast idle for a period of time sufficient to raise engine coolant temperature to a slight warmth of 50-60 F. A slow cold idle may damage the engine due to insufficient oil circulation. Starting the engine in extreme cold to move the vehicle a short distance and stopping the engine without warming the coolant can result in trapping liquid propane in the heat exchanger. As this liquid vaporizes with the engine stopped, pressure in the heat exchanger will rise until excessive force is applied to closing the primary regulator valve against its seat. If this occurs frequently, the primary valve in the vaporizer regulator may be damaged.
- B. Carburetion equipment **in use** deteriorates very slowly, with Viton rubber seats and diaphragms frequently lasting 4,000 hours. However, equipment removed from a vehicle and stored for any length of time must have repair kits installed, as diaphragms and gaskets tend to dry, shrink and harden as the light petroleum ends evaporate and the coolant dries out of the gaskets.

Maintenance Checks

At scheduled preventative maintenance increments:

1. Check coolant hoses for deterioration. Hardened hoses may crack or be subject to rupture, particularly if thermostats hotter than 160-170 F are used, or if hoses are located adjacent to an exhaust manifold. Also check all vacuum hoses.
2. If a fuel vapor hose is used between the vaporizer/regulator and the carburetor, remove the hose and check for undue deterioration. Particularly check the vapor outlet fitting from the regulator for tightness.
3. If starting and idling have been consistently satisfactory, it should be unnecessary to disassemble the carburetor air valve from the bowl. If inconsistent, remove the air valve cover, spring and air valve with the diaphragm. Check the gas-metering valve and gas jet for accumulation of foreign deposits or greasy substance, and clean both with a brush and kerosene or equivalent solvent as needed.

Check the air valve diaphragm for integrity and flexibility. Hold the diaphragm up against a strong light to check for small tears or pinholes. Normal life of the diaphragm and seat is 2,000 hours, barring excessive backfiring or similar abnormalities. When reinstalling the air-gas valve assembly in the bowl, mixer models CA100, CA125 and CA225 require reinstallation of the gas-metering valve in position with two gas valve slots opposing the gas inlet flow. This is for ideal air-fuel distribution. See the section entitled "Idle Mixture Spacers" for more details.

4. With the carburetor air-gas valve and cover removed, it is a simple matter to check the converter and fuelock for leaks. The following checks should indicate each component is operating properly.
 - A. Turn fuel on at the tank and check carburetor open gas jet for leakage. If the fuelock and the converter are operating properly, no fuel will leak through.
 - B. Press the primer button on the front of the converter to open the gas regulator valve. A small amount of gas should pass through the jet as the system is emptied back to the fuelock. If the fuelock is operating properly, the gas flow will soon cease as soon as the fuel downstream of the fuelock is exhausted.
 - C. Next remove the vacuum hose to the VFF30 fuelock from the fitting at the source of vacuum. With the primer button depressed, apply vacuum to the fuelock vacuum hose. Fuel should flow immediately and stop flowing when suction is relieved.
5. With consistent starting and idling, the vaporizer/regulator need not be disassembled. If inconsistent, remove the regulator front cover and diaphragm assembly to check for oil and dirt deposits. If granules of foreign matter are embedded in the Viton rubber of the secondary valve, the valve and seat may be washed clean, however it may be wise to replace the Viton valve for a perfect seal. These granules almost invariably enter the vaporizer in solution in the liquid propane and drop out as the fuel is vaporized, similar to salt water through a filter with deposits of salt left after evaporation of the water. It is seldom a sign of insufficient filtration.

Foreign matter and scale from the tank generally deposit in the filter when a new tank is installed. Welding scale and rust are frequently present in new tanks, and occasionally residual water from the hydrostatic pressure testing is still in the tank.

For specific repair kit installation instructions, please refer to our "How To" instructions in the Service Manual.

16.6 INSTALLATION TIPS

Starting Problems

Starting has never been a serious problem when dealing with single fuel alternate-fuel engines. However, with dual fuel applications, especially those under 250 cid, there are many factors than can contribute to hard starting. These are:

1. Vacuum and air leaks.
2. Incorrect carburetor sizing.
3. Improper idle mixture adjustment.
4. Over-richening by start valve.
5. Incorrect location of carburetor, regulator and/or fuelock.
6. Improper location of electric fuelock head.
7. Poor engine condition.
8. Incorrect spark plug gap.
9. Cold ambient air temperatures.
10. Incorrect starting technique.

Vacuum and Air Leaks

In dual fuel applications on small displacement engines, an air leak, which would not bother a larger engine, becomes critical, especially at cranking speed. Any leak downstream of the air-gas valve will reduce the amount it will rise off its seat during cranking.

In extreme conditions, air enters through the leak during the entire intake stroke, while the gas valve is lifted only during part of the stroke. This creates a mixture too lean to burn. A primer may furnish the added fuel around the metering valve to allow the engine to start, and with more numerous intake cycles the leak may be overcome.

Vacuum leaks may be detected by spraying gasket sealed surfaces with a soapy solution. If a leak is located, the engine will speed up due to the richer mixture. This technique is quite effective around the gasoline carburetor area.

Air leaks may also be found in the engine, through intake valve seals or past rings, which are not seated. The orifice in the PCV valve, which is open during cranking and closed under vacuum, can add a sizeable amount of air. Be sure the PCV valve does close properly after the engine starts.

Carburetor Sizing

It is important to correctly size the airflow capacity of the mixer to the engine requirement. Use of a mixer that is too large for the engine displacement makes idle adjustment extremely sensitive. When the larger mixers are applied to smaller engines, enrichment for acceleration or power occurs too high in the RPM range to be practical. The small engine cannot lift the large air valve quickly or as high as a larger engine will.

Idle Mixture Adjustment

Correct idle mixture adjustment is critical to ease of starting. This is compounded if the mixer is oversized for the engine. When the idle mixture (air bypass) adjustment is closed, the air valve will open farther at cranking. Thus, the airflow volume remains the same but gas flow is increased.

If the engine starts hard, check the idle mixture adjustment, following this procedure: Tighten the idle mixture screw in. If the engine starts more easily, slow the engine down while adjusting the idle mixture to prevent stalling from an over-rich mixture. Setting the idle mixture to the best idle (high vacuum) cold will give a reasonable lean but satisfactory mixture after the engine warms, however it should be adjusted to specifications in the fuel mixture adjustment section.

If the idle adjustment must be backed out excessively in order to obtain a smooth idle, this may be compensated for by installing an R1-29 spacer ring (for CA125 mixer). Placed between the air valve ring (R1-19) and the air valve shoulder, it raises the R1-19 by .003", thereby decreasing airflow at idle. This allows the idle screw to be adjusted in to richen the mixture, shutting off most of the bypass air and lifting the air valve further off the seat during cranking. Always readjust mixtures to specifications after installing the spacer ring.

Start Valve Enrichment

Use of the SV start assist valve for priming during cranking is helpful. However, on engines two liters and under, a restriction such as the IMPCO J1-20 (1/16" I.D.) should be used. If these are not available, a spark plug nut, approximately 1/16" I.D., pushed into the hose will prevent over-priming.

The sizing of the orifice to the engine can be checked for accuracy by energizing the SV valve separate from the starting circuit. When activated with the engine idling, it may slow the speed or actually kill the engine. However, if by opening the throttle it will start in a turn or two, the orifice is satisfactory.

The SV should always connect to the air valve vacuum, not the intake manifold.

Location of Components

Mounting the converter and fuelock off the engine is desirable when carbureting 4-cylinder engines. The vibration of the engine moves the converter rapidly back and forth while the secondary diaphragm assembly tends to stay still. This causes the gas pressure to pulse, and can cause excess fuel consumption.

The added weight of an LPG mixer and adapter on a gasoline carburetor, if not properly braced, can combine with the vibration of a 4-cylinder engine to cause the gasoline carburetor fasteners to loosen, creating air leaks.

Keep the atmospheric vent of the regulator out of the direct air stream of the fan. This also can cause fluctuation of the secondary diaphragm and result in gas pressure pulsations.

Electric Fuellock Connection

Attaching the electric fuellock vacuum switch power lead to an ignition coil terminal often leads to starting difficulties. The coil terminal is a weak source of current, and having the fuellock's power lead attached to it robs the ignition system of needed amperage.

Engine Condition

As previously mentioned, the engine itself can be a source of air leaks. Leaking intake seals, poorly seated rings and leakage through the PCV valve hose are problem areas to be checked. Beyond these problems, however, the engine must be in good working order. Check the engine for any leaks downstream of the air valve. Compression pressures of 150 psi or better at cranking is desirable to prevent hard starting.

Incorrect Spark Plug Gap

Spark plugs should be in good condition and gapped to factory specs. A protruded nose plug is helpful if it will clear the piston at the top of its stroke.

Ambient Temperature

At very cold ambient temperatures (-30 F/-34 C or below), there may be insufficient vapor pressure in the fuel tank to supply fuel to the convertor/regulator, resulting in no start or hard starting. Another condition, which may prevent starting in cold weather, involves over-priming. If this condition is suspected, attempt to start the engine with the primer disconnected. The primer can be disconnected by removing the electrical connector or by pinching the fuel hose.

Incorrect Starting Technique

Over-cranking the engine, especially in cold weather, causes over-priming and flooding, a common a starting problem.

16.7 INDOOR AIR QUALITY

OSHA 1917.24 Carbon Monoxide

- a) *Exposure limits.* The carbon monoxide content of the atmosphere in a room, building, vehicle, rail car or any other enclosed space shall be maintained at not more than 50 parts per million (0.005%) as a time weighted average, and employees shall be removed from the compartment if the carbon monoxide concentration exceeds 100 parts per million (0.01%).

(The term "time weighted average" means that for any period of time in which the concentration exceeds 50 parts per million, it shall be maintained at a corresponding amount below 50 parts per million for an equal period of time.)

- b) *Testing.* Tests to determine carbon monoxide concentration shall be made when necessary to ensure that employee exposure does not exceed the limits specified in paragraph (a) of this section.
- c) *Instrumentation.* Tests for carbon monoxide concentration shall be made by designated persons using gas detector tube units certified by NIOSH under 30 CFR part 11 or other measuring instruments whose accuracy is as great or greater.
- d) *Records.* A record of the date, time, location and results of carbon monoxide tests shall be available for thirty (30) days.

SECTION 17

USEFUL INFORMATION

17.1 MASTER CONVERSION TABLE

| Multiply | By | To Obtain |
|--|---------------------------|---------------------------------------|
| abamperes | 10. | amperes |
| abamperes | 30. x 10 ⁹ | statamperes |
| abamperes / centimeter ² | 64.52 | amperes / inch ² |
| abampere-turns | 10. | ampere-turns |
| abampere-turns | 12.57 | Gilberts |
| abampere-turns / centimeter | 25.40 | ampere-turns / inch |
| abcoulombs | 10. | Coulombs |
| abcoulombs | 30. x 10 ⁹ | Statcoulombs |
| abcoulombs / centimeter ² | 4.52 | Coulombs / inch ² |
| abfarads | 10 ⁹ | Farads |
| abfarads | 10 ¹⁵ | microfarads |
| abfarads | 900. x 10 ¹⁸ | statfarads |
| abhenries | 10 ⁻⁹ | Henries |
| abhenries | 10 ⁻⁶ | millihenries |
| abhenries | 1.111 x 10 ⁻¹² | stathenries |
| abmhms / centimeter ³ | 166.2 | mhos / mil foot |
| abmhms / centimeter ³ | 10 ³ | megmhms / centimeter ³ |
| abohms | 10 ⁻¹⁵ | megohms |
| abohms | 10 ⁻³ | microhms |
| abohms | 10 ⁻⁹ | ohms |
| abohms | 1.111 x 10 ⁻²¹ | statohms |
| abohms / centimeter ³ | 10 ⁻³ | microhms / centimeter ³ |
| abohms / centimeter ³ | 6.015 x 10 ⁻³ | ohms / mil foot |
| abvolts | 10 ⁻⁸ | volts |
| abvolts | 33.33 x 10 ⁻¹² | statvolts |
| acres | 43,560 | square feet |
| acres | 4047 | square meters |
| acres | 1.562 x 10 ⁻³ | square miles |
| acres | 5645.38 | square varas |
| acres | 4840 | square yards |
| acres-feet | 43,560 | cubic feet |
| acres-feet | 3.259 x 10 ⁵ | gallons |
| amperes | 10 ⁻¹ | abamperes |
| amperes | 3. x 10 ⁹ | statamperes |
| amperes / centimeter ² | 6.453 | amperes / inch ² |
| amperes / inch ² | 15.5 x 10 ⁻³ | abamperes / centimeter ² |
| amperes / inch ² | 155. x 10 ⁻³ | amperes / centimeter ³ |
| amperes / inch ² | 465.0 x 10 ⁶ | statamperes / centimeter ² |
| ampere-turns | 0.1 | abampere-turns |
| ampere-turns | 1.257 | Gilberts |
| ampere-turns / centimeter | 2.540 | ampere-turns / inch |
| ampere-turns / inch | 39.37 x 10 ⁻³ | abampere-turns / centimeter |
| ampere-turns / inch | 0.3937 | ampere-turns / centimeter |
| ampere-turns / inch | 0.4950 | Gilberts / centimeter |
| amp-weber / meter | 1. | Newton |
| atmospheres | 76.0 | centimeters of Mercury |
| atmospheres | 29.92 | inches of Mercury |
| atmospheres | 33.90 | feet of H ₂ O |
| atmospheres | 10.333 | kilograms/meter ² |
| atmospheres | 14.70 | pounds/inch ² |
| atmospheres | 1.058 | tons/foot ² |
| ave. noon sunlight on 1 meter ² | approx.1 | kilowatt-hours |
| bar | 4.5 | pounds/inch ² |

| <u>Multiply</u> | <u>By</u> | <u>To Obtain</u> |
|-------------------------------------|-------------------------|--|
| BTU | 0.2530 | kilogram-calories |
| BTU | 777.5 | pound-feet |
| BTU | 392.7×10^{-6} | horsepower-hours |
| BTU | 1054. | Joules |
| BTU | 107.5 | kilogram-meters |
| BTU | 292.8×10^{-6} | kilowatt-hours |
| BTU/(hour-foot ² -°F) | 4.88 | kilogram-Calories/ (hour-meter ² -°C) |
| BTU/(hour-foot ² -°F/in) | 12.40 | kilogram-Calories/ (hour-meter °C/cm) |
| BTU/foot ² | 2.712 | kilogram-Calories/meter ² |
| BTU/minute | 12.96 | pound-fee/second |
| BTU/minute | 23.56×10^{-3} | horsepower |
| BTU/minute | 17.57×10^{-3} | kilowatts |
| BTU/minute | 17.57 | watts |
| BTU/pound | .05556 | kilogram-Calories/kilogram |
| Calories | 0.239 | Joules |
| Celsius ° + (17.8) | 1.8 | temperature (°F) |
| Celsius ° + (273). | 1. | abs. temperature (K) |
| centimeter-dynes | 1.020×10^{-3} | centimeter-grams |
| centimeter-dynes | 10.20×10^{-9} | meter-kilograms |
| centimeter-dynes | 73.76×10^{-9} | pound-feet |
| centimeter-grams | 980.7 | centimeter-dynes |
| centimeter-grams | 10^{-5} | meter-kilograms |
| centimeter-grams | 72.33×10^{-6} | pound-feet |
| centimeters / second | 1.969 | feet / minute |
| centimeters / second | 32.81×10^3 | kilometers / hour |
| centimeters / second | 0.036 | kilometers / hour |
| centimeters / second | 0.6 | meters / minute |
| centimeters / second | 22.37×10^3 | miles / hour |
| centimeters / second | 372.8×10^6 | miles / minute |
| centimeters / second ² | 32.81×10^3 | feet / sec ² |
| centimeters / second ² | 0.036 | kilometers / hour / second |
| centimeters / second ² | 22.37×10^3 | miles / hour / second |
| centimeters of Mercury | 132.16×10^{-3} | atmospheres |
| centimeters of Mercury | 0.4461 | feet of H ₂ O |
| centimeters of Mercury | 136.0 | hilograms/meter ² |
| centimeters of Mercury | 27.85 | pounds/foot ² |
| centimeters of Mercury | 0.1924 | pounds/inch ² |
| Coulombs | 0.1 | abcoulombs |
| Coulombs | $3. \times 10^9$ | statcoulombs |
| Coulombs / inch ² | 15.50×10^{-3} | abcoulombs / centimeter ² |
| Coulombs / inch ² | 0.1550 | Coulombs / centimeter ² |
| Coulombs / inch ² | 46.50×10^9 | statcoulombs / centimeter ² |
| days | 24. | hours |
| days | 1 440. | minutes |
| days | 86 400. | seconds |
| degrees (angle) | 60. | minutes (angle) |
| degrees (angle) | 17.45×10^3 | radians |
| degrees (angle) | 3 600. | seconds (angle) |
| degrees / second | 17.45×10^3 | radians / second |
| degrees / second | 0.1667 | revolutions / minute |
| degrees / second | 2778×10^3 | revolutions / second |

| <u>Multiply</u> | <u>By</u> | <u>To Obtain</u> |
|--|----------------------------|--|
| Dg-Calories/(hour) (meter ²)(°C/centimeters) | 0.0806 | BTU/ (hour)(foot ²)(°F/inch) |
| dynes | 10 ⁻⁵ | Newtons |
| dynes/centimeter ² | 1. | bars |
| Ergs | 94.80 x 10 ⁻¹² | BTU |
| Ergs | 1. | dyne-centimeters |
| Ergs | 73.76 x 10 ⁻⁹ | pound-feet |
| Ergs | 1.020 x 10 ⁻³ | grams-centimeter |
| Ergs | 10 ⁻⁷ | Joules |
| Ergs | 23.90 x 10 ⁻¹² | kilogram-Calories |
| Ergs | 10.20 x 10 ⁻⁹ | kilogram-meters |
| Ergs/second | 5.692 x 10 ⁻⁹ | BTU/minute |
| Ergs/second | 4.426 x 10 ⁻⁶ | pound-feet/minute |
| Ergs/second | 73.76 x 10 ⁻⁹ | pound-feet/second |
| Ergs/second | 134.10 x 10 ⁻¹² | horsepower |
| Ergs/second | 1.434 x 10 ⁻⁹ | kilogram-Calorie/minute |
| Ergs/second | 10 ⁻¹⁰ | kilowatts |
| Fahrenheit° - (32.) | 0.5555 | temperature (°C) |
| Fahrenheit° + (460) | 1. | abs. temperature (°R) |
| Farads | 10 ⁻⁹ | abfarads |
| Farads | 10 ⁶ | microfarads |
| Farads | 90. x 10 ⁻¹² | statfarads |
| feet / minute | 0.5080 | centimeters / second |
| feet / minute | 16.67 x 10 ³ | feet / second |
| feet / minute | 18.29 x 10 ³ | kilometers / hour |
| feet / minute | 0.3048 | meters / minute |
| feet / minute | 11.36 x 10 ³ | miles / hour |
| feet / second | 30.48 | centimeters / second |
| feet / second | 1.097 | kilometers/ hour |
| feet / second | 18.29 | meters / minute |
| feet / second | 0.6818 | miles / hour |
| feet / second | 11.36 x 10 ³ | miles / minute |
| feet / second ² | 30.48 | centimeters / second ² |
| feet / second ² | 1.097 | kilometers / hour / second |
| feet / second ² | 0.3048 | meters / second ² |
| feet / second ² | 0.6818 | miles / hour / second |
| feet of H ₂ O | 29.50 x 10 ⁻³ | atmospheres |
| feet of H ₂ O | 0.8826 | inches of Mercury |
| feet of H ₂ O | 304.8 | kilograms/meter ² |
| feet of H ₂ O | 62.43 | pounds/foot ² |
| feet of H ₂ O | 0.4335 | pounds/inch ² |
| feet/100 feet | 1. | percent grade |
| gausses | 6.452 | lines / inch ² |
| Gilberts | 79.58 x 10 ⁻³ | abampere-turns |
| Gilberts | 0.7958 | ampere-turns |
| Gilberts / centimeter | 2.021 | ampere-turns / inch |
| grains/US gallon | 17.118 | parts per million |
| gram-calories | 3.968 x 10 ⁻³ | BTU |
| gram-centimeters | 93.02 x 10 ⁻⁹ | BTU |
| gram-centimeters | 980.7 | ergs |
| gram-centimeters | 72.33 x 10 ⁻⁶ | pound-feet |
| gram-centimeters | 98.07 x 10 ⁻⁶ | Joules |
| gram-centimeters | 23.44 x 10 ⁻⁹ | kilograms-Calories |
| gram-centimeters | 10 ⁻⁵ | kilogram-meters |
| grams/centimeter | 5.600 x 10 ⁻³ | pounds/inch |

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Multiply

kilogram-Calories
 kilogram-Calories
 kilogram-Calories/kilogram
 kilogram-Calories/meter²
 kilogram-Calories/meters³
 kilogram-Calories/minute
 kilogram-Calories/minute
 kilogram-Calories/minute
 kilogram-meters
 kilogram-meters
 kilogram-meters
 kilogram-meters
 kilogram-meters
 kilogram-meters
 kilogram-meters/second²
 kilograms/meter
 kilograms/meter²
 kilograms/meter²
 kilograms/meter²
 kilograms/meter²
 kilograms/meter²
 kilograms/meter²
 kilograms/meter²
 kilograms/meter³
 kilograms/meter³
 kilograms/meter³
 kilograms/meter³
 kilograms/meter³
 kilograms/meter³
 kilograms/meter³
 kilograms/millimeter²
 kilograms-centimeters²
 kilograms-meter²
 kilolines
 kilometers / hour
 kilometers / hour
 kilometers / hour
 kilometers / hour
 kilometers / hour
 kilometers / hour
 kilometers / hour / second
 kilometers / hour / second
 kilometers / hour / second
 kilometers / hour / second
 kilometers / minutes
 kilowatt-hours
 kilowatt-hours
 kilowatt-hours
 kilowatt-hours
 kilowatt-hours
 kilowatt-hours
 kilowatts
 kilowatts
 kilowatts
 kilowatts
 kilowatts
 kilowatts
 kilowatts
 kilowatts
 kilowatts
 knots

By

426.6
 1.162 x 10⁻³
 1.80
 0.3688
 0.1124
 51.43
 93.51 x 10⁻³
 69.72 x 10⁻³
 9.302 x 10⁻³
 98.07 x 10⁶
 7.233
 9.807
 2.344 x 10⁻³
 2.724 x 10⁻⁶
 1.
 0.6270
 96.78 x 10⁻⁶
 98.07
 3.281 x 10⁻³
 2.896 x 10⁻³
 0.2048
 1.422 x 10⁻³
 10⁻³
 62.43 x 10⁻³
 36.13 x 10⁻⁶
 340.5 x 10⁻¹²
 10⁶
 2.373 x 10⁻³
 0.3417
 10³
 27.78
 54.68
 0.9113
 0.5396
 16.67
 0.6214
 27.78
 0.9113
 0.2778
 0.6215
 60.
 Approx. 1.
 3415.
 2.655 x 10⁶
 1.341
 3.6 x 10⁶
 860.5
 367. x 10³
 56.92
 44.25 x 10³
 737.6
 1.341
 14.34
 10³
 6 080.

To Obtain

kilogram-meters
 kilogram-hours
 BTU/pound
 BTU/foot²
 BTU/foot³
 pound-feet/second
 horsepower
 kilowatts
 BTU
 ergs
 pound-feet
 Joules
 kilogram-Calories
 kilowatt-hours
 Newton
 pounds/foot
 atmospheres
 bas
 feet of H₂O
 inches of Mercury
 pounds/foot²
 pounds/inch²
 grams/meter³
 pounds/foot³
 pounds/inch³
 pounds/mil-foot
 kilograms/meter²
 pound-foot²
 pound-inches²
 Maxwells
 centimeters / second
 feet / minute
 feet / second
 knots
 meters / minute
 miles / hour
 centimeters / second²
 feet / second²
 meters / second²
 miles / hour / second
 kilometers / hour
 avg. noon sunlight on 1 meter²
 BTU
 pound-feet
 horsepower-hours
 Joules
 kilogram-Calories
 kilogram-meters
 BTU/minute
 pound-feet/minute
 pound-feet/second
 horsepower
 kilogram-Calories/minute
 Watts
 feet / hour

| <u>Multiply</u> | <u>By</u> | <u>To Obtain</u> |
|------------------------------------|--------------------------|------------------------------------|
| knots | 1.853 | kilometers / hour |
| knots | 1.152 | miles / hour |
| knots | 2 027. | yards / hour |
| lines / centimeter ² | 1. | Gauss |
| lines / inch ² | 0.1550 | Gauss |
| log ₁₀ N | 2.303 | ln N (or log _e N) |
| lumens/foot ² | 1. | foot-candles |
| Maxwells | 10 ⁻³ | kilolines |
| megalines | 10 ⁶ | Maxwells |
| megmhos / centimeter ³ | 10 ⁻³ | abmhos / centimeter ³ |
| megmhos / centimeter ³ | 2.540 | megmhos / inch ³ |
| megmhos / centimeter ³ | 0.1662 | mhos / mil foot |
| megmhos / inch ³ | 0.3937 | megmhos / centimeter ³ |
| megohms | 10 ⁶ | ohms |
| meter-kilograms | 98.07 10 ⁶ | centimeter-dynes |
| meter-kilograms | 10 ⁵ | centimeter-grams |
| meter-kilograms | 7.233 | pound-feet |
| meters / minute | 1.667 | centimeters / second |
| meters / minute | 3.281 | feet / minute |
| meters / minute | 54.68 x 10 ³ | feet / second |
| meters / minute | 0.06 | kilometers / hour |
| meters / minute | 37.28 x 10 ³ | miles / hour |
| meters / second | 1 968. | feet / minute |
| meters / second | 3.281 | feet / second |
| meters / second | 6.0 | kilometers / hour |
| meters / second | 0.06 | kilometers / minute |
| meters / second | 2.237 | miles / hour |
| meters / second | 37.28 x 10 ³ | miles / minute |
| meters / second ² | 3.281 | feet / second ² |
| meters / second ² | 3.6 | kilometers / hour / second |
| meters / second ² | 2.237 | miles / hour / second |
| mhos / mil foot | 6.015 x 10 ⁻³ | abmhos / centimeter ³ |
| mhos / mil foot | 6.015 | megmhos / centimeter ³ |
| mhos / mil foot | 15.28 | Megmhos / inch ³ |
| microbar | 987.0 x 10 ⁻⁹ | atmospheres |
| microbar | 1. | dynes/centimeter ² |
| microbar | 10.20 x 10 ⁻³ | kilograms/meter ² |
| microbar | 2.089 x 10 ⁻³ | pounds/foot ² |
| microbar | 14.50 x 10 ⁻⁶ | pounds/inch ² |
| microfarads | 10 ⁻¹⁵ | abfarads |
| microfarads | 10 ⁻⁶ | Farads |
| microfarads | 900. x 10 ³ | statfarads |
| microhms | 10 ³ | abohms |
| microhms | 10 ¹² | megohms |
| microhms | 10 ⁻⁶ | ohms |
| microhms | 11.11 x 10 ¹⁵ | statohms |
| microhms / centimeter ³ | 10 ³ | abohms / centimeter ³ |
| microhms / centimeter ³ | 0.3937 | microhms / inch ³ |
| microhms / centimeter ³ | 6.015 | ohms / mil foot |
| microhms / inch ³ | 2.540 | microhms / centimeter ³ |
| miles / hour | 44.70 | centimeters / second |
| miles / hour | 88. | feet / minute |
| miles / hour | 1.467 | feet / second |
| miles / hour | 1.6093 | kilometers / hour |
| miles / hour | 0.8684 | knots |

Multiply

miles / hour
 miles / hour / second
 miles / hour / second
 miles / hour / second
 miles / hour / second
 miles / minute
 miles / minute
 miles / minute
 miles / minute
 millibar
 millihenries
 millihenries
 millihenries
 minutes (angle)
 minutes (angle)
 months
 months
 months
 months
 months
 myriawatts
 Newton-meters
 Newton-meters / amp
 Newtons
 Newtons
 Newtons
 Newtons
 Newtons
 Ohms
 Ohms
 Ohms
 Ohms
 Ohms
 Ohms
 Ohms / mil foot
 Ohms / mil foot
 Ohms / mil foot
 ounces/inch²
 parts per million
 pennyweight (troy)
 pennyweights (troy)
 poundals
 poundals
 poundals
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet
 pound-feet/minute
 pound-feet/minute
 pound-feet/minute

By

26.82
 44.70
 1.467
 1.6093
 0.4470
 2 682.
 88.
 1.6093
 60.
 14.5×10^{-3}
 10^6
 10^{-3}
 1.111×10^{-15}
 290.9×10^6
 60.
 30.42
 730.
 43 800.
 2.628×10^6
 10.
 1.
 1.
 1.
 1.
 1.355
 10^5
 1.
 10^9
 10^{-6}
 10^6
 1.111×10^{-12}
 166.2
 0.1662
 65.24×10^{-3}
 0.0625
 0.584
 1.555
 0.05
 13.826
 14.10
 31.08×10^{-3}
 1.286×10^{-3}
 13.56×10^6
 505.0×10^{-9}
 1.356
 324.1×10^{-6}
 0.1383
 376.6×10^{-9}
 13.56×10^6
 13.825
 .01383
 0.738
 1.286×10^{-3}
 16.67×10^{-3}
 30.30×10^{-6}

To Obtain

meters / minute
 centimeters / second²
 feet / second²
 kilometers / hour / second
 meters / second²
 centimeters / second
 feet / second
 kilometers / minute
 miles/ hour
 pounds/inch²
 abhenries
 henries
 stathenries
 radian
 seconds (angle)
 days
 hours
 minutes
 seconds
 kilowatts
 Joules
 Webers
 amp-Webers/meter
 kilogram-meters/second²
 pound-feet
 Dynes
 Joules / (amp-second)²
 abohms
 megohms
 microhms
 statohms
 abohms / centimeter³
 microhms / centimeter³
 microhms / inch³
 pounds/inch²
 grains/U.S. gallon
 grams
 ounces (troy)
 dynes
 grams
 pounds
 BTU
 ergs
 horsepower-hours
 Joules
 kilogram-Calories
 kilogram-meters
 kilowatt-hours
 centimeter-dynes
 centimeter-grams
 meter-kilograms
 Newtons
 BTU/minute
 pound-feet/second
 horsepower

Multiply

pound-feet/minute
 pound-feet/minute
 pound-feet/second
 pound-feet/second
 pound-feet/second
 pound-feet/second
 pound-feet²
 pound-feet²
 pound-inches²
 pound-inches²
 pounds
 pounds
 pounds
 pounds
 pounds
 pounds (troy)
 pounds/foot
 pounds/foot²
 pounds/foot²
 pounds/foot²
 pounds/foot²
 pounds/foot²
 pounds/foot²
 pounds/foot²
 pounds/foot²
 pounds/foot³
 pounds/foot³
 pounds/foot³
 pounds/foot³
 pounds/foot³
 pounds/inch
 pounds/inch³
 pounds/inch³
 pounds/inch³
 pounds/inch³
 pounds/mil-foot
 pounds/mil-foot
 quadrants (angle)
 quadrants (angle)
 quadrants (angle)
 quintals
 quires
 radians
 radians
 radians
 radians / second
 radians / second
 radians / second
 radians / second²
 radians / second²
 radians / second²
 reams
 revolutions
 revolutions
 revolutions
 revolutions / minute
 revolutions / minute

By

324.1×10^{-6}
 22.60×10^{-6}
 77.17×10^{-3}
 1.818×10^{-3}
 19.45×10^{-3}
 1.356×10^{-3}
 421.3
 144
 2.926
 6.945×10^{-3}
 444.823
 7000.
 453.6
 16.
 32.17
 0.8229
 1.488
 16.02×10^{-3}
 4.882
 6.944×10^{-3}
 68.04×10^{-3}
 2.307
 2.036
 703.1
 144.
 16.02×10^{-3}
 16.02
 578.7×10^{-6}
 5.456×10^{-9}
 178.6
 27.68
 27.68×10^3
 1.728
 9.425×10^{-6}
 2.306×10^6
 90.
 5 400.
 1.571
 100.
 25.
 57.3
 3 438.
 0.637
 57.30
 0.1592
 9.549
 573.0
 9.549
 0.1592
 500.
 360.
 4.
 6.283
 6.
 0.1047

To Obtain

kilogram-Calories/minute
 kilowatts
 BTU/minute
 horsepower
 kilogram-Calories/minute
 kilowatts
 kilogram- centimeter²
 pound-inches²
 kilogram-centimeters²
 pound-feet²
 dynes
 grains
 grams
 ounces
 poundals
 pounds (av)
 kilograms/meter
 feet of H₂O
 kilograms/meter²
 pounds/inch²
 atmospheres
 feet of H₂O
 inches of Mercury
 kilograms/meter²
 pounds/foot²
 grams/centimeter³
 kilograms/meter³
 pounds/inch³
 pounds/mil-foot
 grams/centimeter
 grams/centimeter³
 kilograms/ meter³
 pounds/foot³
 pounds/ mil-foot
 grams/centimeter³
 degrees
 minutes
 quadrants
 pounds
 sheets
 degrees
 minutes
 quadrants
 degrees / second
 revolutions / second
 revolutions / minute
 revolutions / mintue²
 revolutions / minute/ second
 revolutions / second²
 sheets
 degrees
 quadrants
 radians
 degrees / second
 radians / second

Multiply

revolutions / minute
 revolutions / minute / second
 revolutions / minute²
 revolutions / minute²
 revolutions / second
 revolutions / second
 revolutions / second
 revolutions / second²
 revolutions / second²
 revolutions / second²
 seconds (angle)
 spheres (solid angle)
 spherical right angles
 spherical right angles
 spherical right angles
 statamperes
 statamperes
 statcoulombs
 statcoulombs
 statfarads
 statfarads
 statfarads
 stathenries
 stathenries
 stathenries
 stathenries
 statohms
 statohms
 statohms
 statohms
 statohms
 statvolts
 statvolts
 steradians
 steradians
 steradians
 tons (long)
 tons (long)
 tons (metric)
 tons (short)
 tons (short)
 tons (short)/foot²
 tons (short)/foot²
 tons (short)/inch²
 tons (short)/inch²
 volt-coulomb
 volts
 volts
 volts / inch
 volts / inch
 Watt-hours
 Watt-hours
 Watt-hours
 Watt-hours
 Watt-hours
 Watt-hours
 Watts

By

16.67×10^3
 277.8×10^6
 1.745×10^3
 16.67×10
 360.
 6 283
 60.
 6.283
 6 600.
 60.
 4.484×10^6
 12.57
 0.25
 0.125
 1.571
 33.33×10^{-12}
 0.3333×10^{-9}
 33.33×10^{-12}
 0.3333×10^{-9}
 1.111×10^{-20}
 1.111×10^{-12}
 1.111×10^{-6}
 $900. \times 10^{18}$
 $900. \times 10^9$
 $900. \times 10^{12}$
 $900. \times 10^{18}$
 $900. \times 10^3$
 $900. \times 10^{15}$
 $900. \times 10^9$
 $30. \times 10^9$
 300.
 .0.1592
 79.58×10^3
 0.6366
 1016.
 2240.
 2205
 907.2
 2000.
 9765
 13.89
 1.406×10^6
 2000
 1.
 10^8
 3.333×10^{-3}
 39.37×10^6
 1.312×10^{-3}
 3.415
 2655.
 1.341×10^{-3}
 0.8605
 367.1
 10^{-3}
 56.92×10^{-3}

To Obtain

revolutions / second
 revolutions / second²
 radians / second²
 revolutions / minute / second
 degrees /second
 radians / second
 revolutions / minute
 radians / second²
 revolutions / minute²
 revolutions / minute / seconds
 radians
 steradians
 hemispheres
 spheres
 steradians
 abamperes
 amperes
 abcoulombs
 Coulombs
 abfarads
 Farads
 microfarads
 abhenries
 henries
 millihenries
 abohms
 megohms
 microhms
 ohms
 abvolts
 volts
 hemispheres
 spheres
 spherical right angles
 kilograms
 pounds
 pounds
 kilograms
 pounds
 kilograms/meter²
 pounds/inch²
 kilograms/meter²
 pounds/inch²
 Joules
 abvolts
 statvolts
 abvolts / centimeter
 statvolts / centimeter
 BTU
 pound-feet
 horsepower-hours
 kilogram-Calories
 kilogram-meters
 kilowatt-hours
 BTU/minute

Multiply

Watts
Watts
Watts
Watts
Watts
Watts
Watts
Watt-seconds
Weber
Webers
weeks
weeks
weeks
years
years (common)
years (common)
years (leap)
years (leap)

By

10^7
44.26
0.7376
 1.341×10^{-3}
 14.34×10^{-3}
 10^{-3}
1.
1.
1.
 10^8 .
168.
10 080.
 604.8×10^3
 31.536×10^6
365.
8 760.
366.
8 784.

To Obtain

ergs/second
pound-feet/minute
pound-feet/second
horsepower
kilogram-Calories/minute
kilowatts
Joules/second
Joules
Newton-Meter / amp
Maxwells
hours
minutes
seconds
seconds
days
hours
days
hours

17.2 FRACTION-INCH / DECIMAL-INCH / MILLIMETER CONVERSION TABLE

| Millimeters | Fractions | Inches | Millimeters | Fractions | Inches |
|--------------------|------------------|---------------|--------------------|------------------|---------------|
| 0.397 | 1/64 | 0.015625 | 13.097 | 33/64 | 0.515625 |
| 0.794 | 1/32 | 0.03125 | 13.494 | 17/32 | 0.53125 |
| 1.191 | 3/64 | 0.046875 | 13.891 | 35/64 | 0.546875 |
| 1.588 | 1/16 | 0.0625 | 14.288 | 9/16 | 0.5625 |
| 1.984 | 5/64 | 0.078125 | 14.684 | 37/64 | 0.573125 |
| 2.381 | 3/32 | 0.09375 | 15.081 | 19/32 | 0.59375 |
| 2.778 | 7/64 | 0.109375 | 15.478 | 39/64 | 0.609375 |
| 3.175 | 1/8 | 0.125 | 15.875 | 5/8 | 0.625 |
| 3.572 | 9/64 | 0.140625 | 16.272 | 41/64 | 0.640625 |
| 3.969 | 5/32 | 0.15625 | 16.669 | 21/32 | 0.65625 |
| 4.366 | 11/64 | 0.171875 | 17.066 | 43/64 | 0.671875 |
| 4.762 | 3/16 | 0.1875 | 17.462 | 11/16 | 0.6875 |
| 5.159 | 13/64 | 0.203125 | 17.859 | 45/64 | 0.703125 |
| 5.556 | 7/32 | 0.21875 | 18.256 | 23/32 | 0.71875 |
| 5.953 | 15/64 | 0.234375 | 18.653 | 47/64 | 0.734375 |
| 6.350 | 1/4 | 0.25 | 19.050 | 3/4 | 0.75 |
| 6.747 | 17/64 | 0.265625 | 19.447 | 49/64 | 0.765625 |
| 7.144 | 9/32 | 0.28125 | 19.844 | 25/32 | 0.78125 |
| 7.541 | 19/64 | 0.296875 | 20.241 | 51/64 | 0.796875 |
| 7.938 | 5/16 | 0.3125 | 20.638 | 13/16 | 0.8125 |
| 8.334 | 21/64 | 0.328125 | 21.034 | 53/64 | 0.828125 |
| 8.731 | 11/32 | 0.34375 | 21.431 | 27/32 | 0.84375 |
| 9.128 | 23/64 | 0.359375 | 21.828 | 55/64 | 0.859375 |
| 9.525 | 3/8 | 0.375 | 22.225 | 7/8 | 0.875 |
| 9.922 | 25/64 | 0.390625 | 22.622 | 57/64 | 0.890625 |
| 10.319 | 13/32 | 0.40625 | 23.019 | 29/32 | 0.90625 |
| 10.716 | 27/64 | 0.421875 | 23.416 | 59/64 | 0.921875 |
| 11.112 | 7/16 | 0.4375 | 23.812 | 15/16 | 0.9375 |
| 11.509 | 29/64 | 0.453125 | 24.209 | 61/64 | 0.953125 |
| 11.906 | 15/32 | 0.46875 | 24.606 | 31/32 | 0.96875 |
| 12.303 | 31/64 | 0.484375 | 25.003 | 63/64 | 0.984375 |
| 12.700 | 1/2 | 0.5 | 25.400 | 1 | 1.000 |

17.3 TAP DRILL SIZES (INCH) FOR A 75% THREAD

| Fastener Size | Tap Drill | Clearance Drill | Fastener Size | Tap Drill | Clearance Drill |
|----------------------|------------------|------------------------|----------------------|------------------|------------------------|
| 0-80-NF | 3/64 | 50 | 10-32-NF | 21 | 7 |
| 1-56-NS | 54 | 46 | 12-24-NC | 16 | I |
| 1-64-NC | 53 | 46 | 12-28-NF | 14 | I |
| 1-72-NF | 53 | 46 | 12-32-NS | 13 | I |
| 2-56-NC | 50 | 41 | 1/4-20-NC | 7 | H |
| 2-64-NF | 49 | 41 | 1/4-28-NF | 3 | H |
| 3-48-NC | 47 | 35 | 5/16-18-NC | F | Q |
| 3-56-NF | 45 | 35 | 5/16-24-NF | I | Q |
| 4-32-NS | 45 | 30 | 3/8-16-NC | 5/16 | X |
| 4-36-NS | 44 | 30 | 3/8-24-NF | Q | X |
| 4-40-NC | 43 | 30 | 7/16-14-NC | U | 15/32 |
| 4-48-NF | 42 | 30 | 7/16-20-NF | 25/64 | 15/32 |
| 5-36-NS | 40 | 29 | 1/2-13-NC | 27/64 | 17/32 |
| 5-40-NC | 38 | 29 | 1/2-20-NF | 29/64 | 17/32 |
| 5-44-NF | 37 | 29 | 9/16-12-NC | 31/64 | |
| 6-32-NC | 35 | 25 | 9/16-18-NF | 33/64 | |
| 6-36-NS | 34 | 25 | 5/8-11-NC | 17/32 | |
| 6-40-NF | 33 | 25 | 5/8-18-NF | 37/64 | |
| 8-30-NS | 30 | 16 | 3/4-10-NC | 21/32 | |
| 8-32-NC | 29 | 16 | 3/4-16-NF | 11/16 | |
| 8-36-NF | 29 | 16 | 7/8-9-NC | 49/64 | |
| 8-40-NS | 28 | 16 | 7/8-14-NF | 13/16 | |
| 10-24-NC | 25 | 7 | 7/8-18-NS | 53/64 | |
| 10-28-NS | 23 | 7 | 1-8-NC | 7/8 | |
| 10-30-NS | 22 | 7 | 1-14-NF | 15/16 | |

17.4 TAP DRILL SIZES (INCH) FOR PIPE THREAD (NPT)

| Fastener Size | Tap Drill | Fastener Size | Tap Drill |
|----------------------|------------------|----------------------|------------------|
| 1/8-27 | R | 1 1/2-11 1/2 | 1 47/64 |
| 1/4-18 | 7/16 | 2-11 1/2 | 2 7/32 |
| 3/8-18 | 37/64 | 2 1/2-8 | 2 5/8 |
| 1/2-14 | 23/32 | 3-8 | 3 1/4 |
| 3/4-14 | 59/64 | 3 1/2-8 | 3 3/4 |
| 1-11 1/2 | 1 5/32 | 4-8 | 4 1/4 |
| 1 1/4-11 1/2 | 1 1/2 | - | - |

17.5 LETTER DRILL SIZES

| Letter | Decimal-Inch | Letter | Decimal-Inch |
|---------------|---------------------|---------------|---------------------|
| A | 0.234 | N | 0.302 |
| B | 0.238 | O | 0.316 |
| C | 0.242 | P | 0.323 |
| D | 0.246 | Q | 0.331 |
| E | 0.250 | R | 0.339 |
| F | 0.257 | S | 0.348 |
| G | 0.261 | T | 0.358 |
| H | 0.266 | U | 0.368 |
| I | 0.272 | V | 0.377 |
| J | 0.277 | W | 0.386 |
| K | 0.281 | X | 0.397 |
| L | 0.290 | Y | 0.404 |
| M | 0.295 | Z | 0.413 |

17.6 NUMBER DRILL SIZES

| Number | Decimal-Inch | Number | Decimal-Inch |
|--------|--------------|--------|--------------|
| 1 | 0.2280 | 41 | 0.0960 |
| 2 | 0.2210 | 42 | 0.0935 |
| 3 | 0.2130 | 43 | 0.0890 |
| 4 | 0.2090 | 44 | 0.0860 |
| 5 | 0.2055 | 45 | 0.0820 |
| 6 | 0.2040 | 46 | 0.0810 |
| 7 | 0.2010 | 47 | 0.0785 |
| 8 | 0.1990 | 48 | 0.0760 |
| 9 | 0.1960 | 49 | 0.0730 |
| 10 | 0.1935 | 50 | 0.0700 |
| 11 | 0.1910 | 51 | 0.0670 |
| 12 | 0.1890 | 52 | 0.0635 |
| 13 | 0.1850 | 53 | 0.0595 |
| 14 | 0.1820 | 54 | 0.0550 |
| 15 | 0.1800 | 55 | 0.0520 |
| 16 | 0.1770 | 56 | 0.0465 |
| 17 | 0.1730 | 57 | 0.0430 |
| 18 | 0.1695 | 58 | 0.0420 |
| 19 | 0.1660 | 59 | 0.0410 |
| 20 | 0.1610 | 60 | 0.0400 |
| 21 | 0.1590 | 61 | 0.0390 |
| 22 | 0.1570 | 62 | 0.0380 |
| 23 | 0.1540 | 63 | 0.0370 |
| 24 | 0.1520 | 64 | 0.0360 |
| 25 | 0.1495 | 65 | 0.0350 |
| 26 | 0.1470 | 66 | 0.0330 |
| 27 | 0.1440 | 67 | 0.0320 |
| 28 | 0.1405 | 68 | 0.0310 |
| 29 | 0.1360 | 69 | 0.02925 |
| 30 | 0.1285 | 70 | 0.0280 |
| 31 | 0.1200 | 71 | 0.0260 |
| 32 | 0.1160 | 72 | 0.0250 |
| 33 | 0.1130 | 73 | 0.0240 |
| 34 | 0.1110 | 74 | 0.0225 |
| 35 | 0.1100 | 75 | 0.0210 |
| 36 | 0.1065 | 76 | 0.0200 |
| 37 | 0.1040 | 77 | 0.0180 |
| 38 | 0.1015 | 78 | 0.0160 |
| 39 | 0.0995 | 79 | 0.0145 |
| 40 | 0.0980 | 80 | 0.0135 |

17.7 BOLT TORQUE TABLES (STANDARD FASTENERS)

| Size | Grade 5 (Torque + ft. lbs.) | | Grade 8 (Torque = ft. lbs.) | |
|-----------|--------------------------------|------------|--------------------------------|------------|
| | Dry | Lubricated | Dry | Lubricated |
| 1/4 - 20 | 8 | 6.3 | 12 | 9 |
| 1/4 - 28 | 10 | 7.2 | 14 | 10 |
| 5/16 - 18 | 17 | 13 | 24 | 18 |
| 5/16 - 24 | 19 | 14 | 27 | 20 |
| 3/8 - 16 | 30 | 23 | 45 | 35 |
| 3/8 - 24 | 35 | 25 | 50 | 35 |
| 7/16 - 14 | 50 | 35 | 70 | 50 |
| 7/16 - 20 | 50 | 40 | 80 | 60 |
| 1/2 - 13 | 75 | 55 | 110 | 80 |
| 1/2 - 20 | 85 | 65 | 120 | 90 |
| 9/16 - 12 | 110 | 80 | 150 | 110 |
| 9/16 - 18 | 120 | 90 | 170 | 130 |
| 5/8 - 11 | 150 | 110 | 210 | 160 |
| 5/8 - 18 | 170 | 130 | 240 | 180 |
| 3/4 - 10 | 260 | 200 | 380 | 280 |
| 3/4 - 16 | 300 | 220 | 420 | 310 |
| 7/8 - 9 | 430 | 320 | 600 | 450 |
| 7/8 - 14 | 470 | 350 | 670 | 500 |
| 1 - 8 | 640 | 480 | 910 | 680 |
| 1 - 14 | 720 | 540 | 1020 | 760 |

17.8 BOLT TORQUE TABLES (METRIC FASTENERS)

| Metric (DIN Standard) | Metric Class 8.8 (Torque = ft. lbs.) | Metric Class 10.9 (Torque = ft. lbs.) |
|----------------------------------|---|--|
| M4 x .70 | 1.65 | - |
| M5 x .80 | 4.13 | - |
| M6 x 1.00 | 7.13 | 10.50 |
| M7 x 1.00 | 11.63 | - |
| M8 x 1.25 | 17.25 | 25.50 |
| M8 x 1.00 | 18.38 | - |
| M10x 1.50 | 34.50 | 51.00 |
| M10 x 1.25 | 36.75 | - |
| M10 x 1.00 | 39.00 | - |
| M12 x 1.75 | 59.25 | 87.75 |
| M12 x 1.50 | 62.25 | - |
| M12 x 1.25 | 65.25 | - |
| M14 x 2.00 | 93.75 | 138.75 |
| M14 x 1.50 | 101.25 | - |
| M16 x 2.00 | 146.25 | 210.00 |
| M18 x 2.50 | 210.00 | - |
| M20 x 2.50 | 292.50 | - |
| M22 x 2.50 | 397.50 | - |
| M24 x 3.00 | 502.50 | - |

17.8 SHEET METAL GAUGE TO DECIMAL-INCH CONVERSION TABLE

| Gage Number | Steel | Stainless Steel | Aluminum |
|--------------------|--------------|------------------------|-----------------|
| 7 | .179 | | |
| 8 | .164 | .172 | - |
| 9 | .150 | .156 | - |
| 10 | .135 | .141 | - |
| 11 | .120 | .125 | - |
| 12 | .105 | .109 | |
| 13 | .090 | .094 | .072 |
| 14 | .075 | .078 | .064 |
| 15 | .067 | .070 | .057 |
| 16 | .060 | .063 | .051 |
| 17 | .054 | .056 | .045 |
| 18 | .048 | .050 | .040 |
| 19 | .042 | .044 | .036 |
| 20 | .036 | .038 | .032 |
| 21 | .033 | .034 | .028 |
| 22 | .030 | .031 | .025 |
| 23 | .027 | .028 | .023 |
| 24 | .024 | .025 | .020 |
| 25 | .021 | .022 | .018 |
| 26 | .018 | .019 | .017 |
| 27 | .016 | .017 | .014 |
| 28 | .015 | .016 | - |
| 29 | .014 | .014 | - |
| 30 | .012 | .013 | - |
| 31 | - | .011 | - |