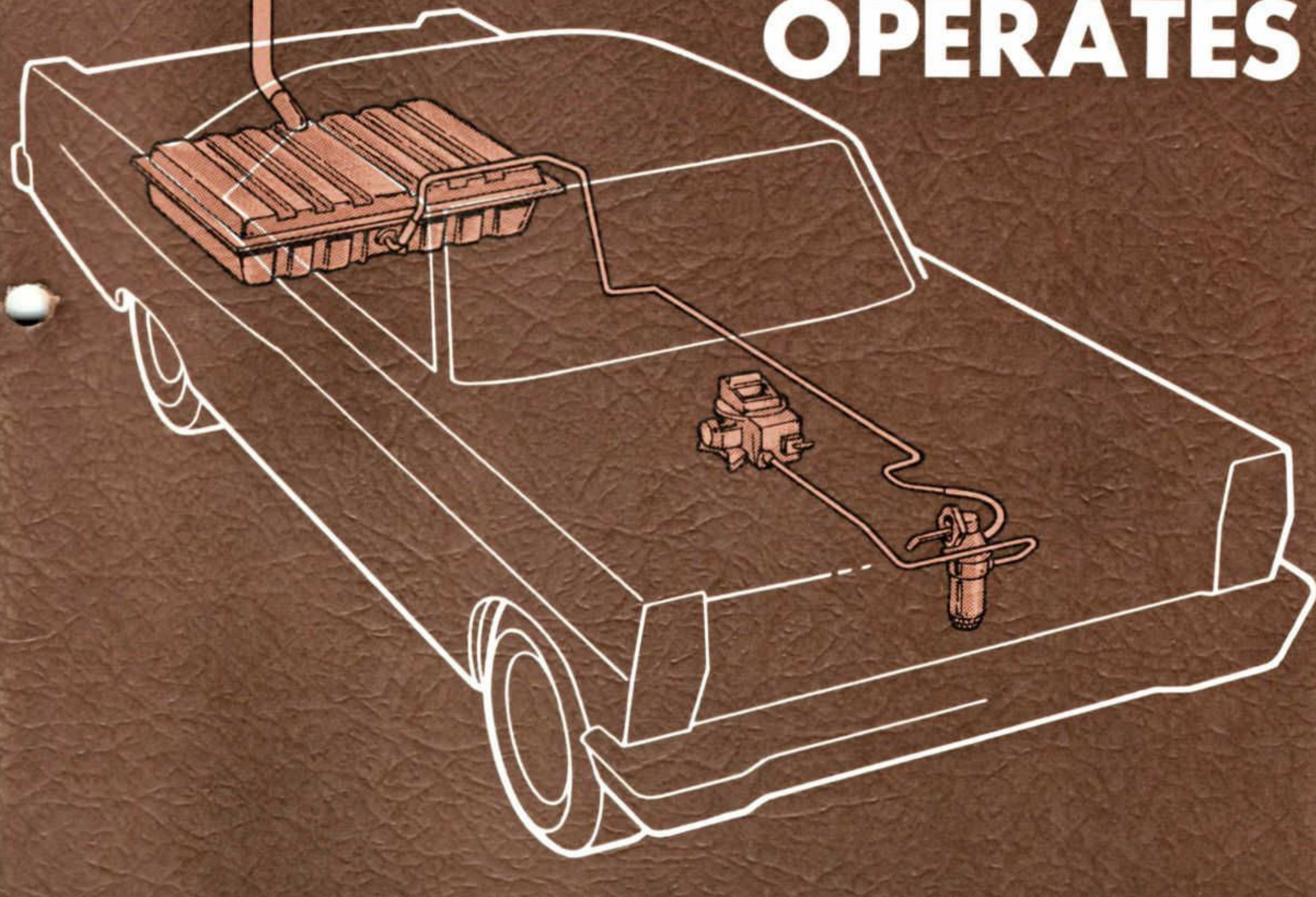
TRAINING HANDBOOK

COURSE 9500.1

HOW THE FUEL SYSTEM OPERATES



SERVICE FORD MOTOR COMPANY TRAINING

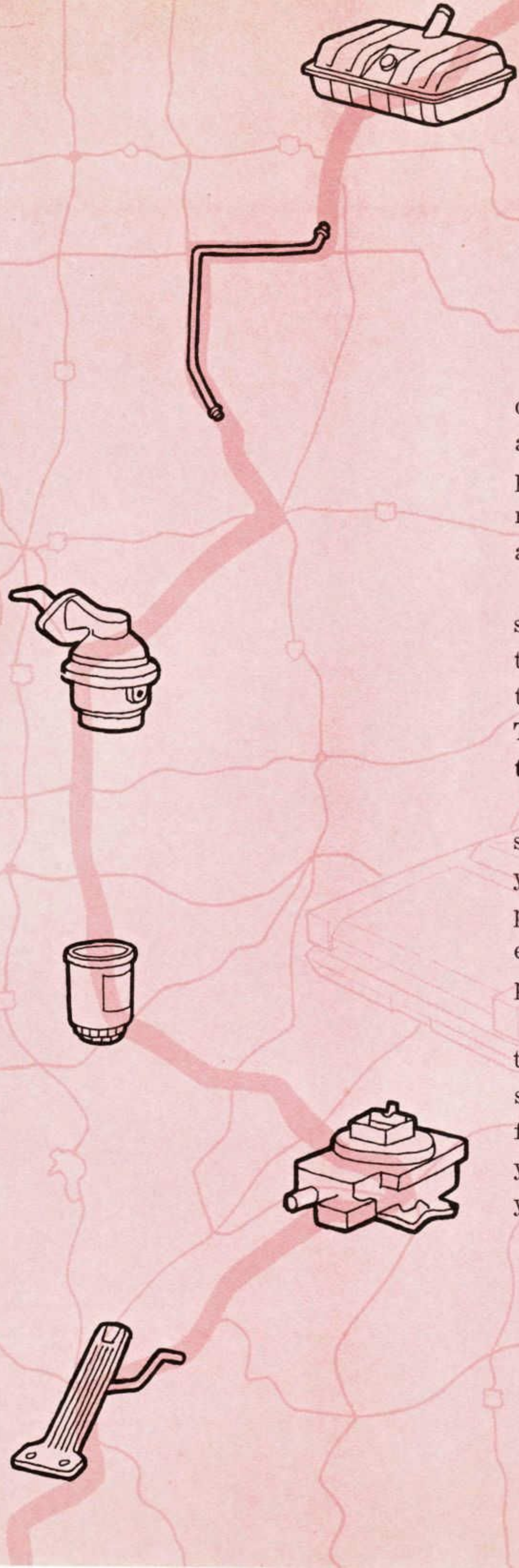
FORD DIVISION

VOL. 66 S9 L2

TABLE OF CONTENTS

SERVICE DEPARTMENT
FORD DIVISION
Ford MOTOR COMPANY

FIRST PRINTING—JANUARY 1966



A TOUR OF THE FUEL SYSTEM

When you think of the word tour, you immediately have visions of vacation visits to faraway places; of strange cities; of mountains, parks and natural wonders; of museums and night spots, and other places of interest and amusement.

Certainly the everyday job of servicing fuel systems is about as far removed from a vacation tour as you can get. Yet there's one thing that both a vacation and a job have in common: **To make the best use of your time, you have to know your way.**

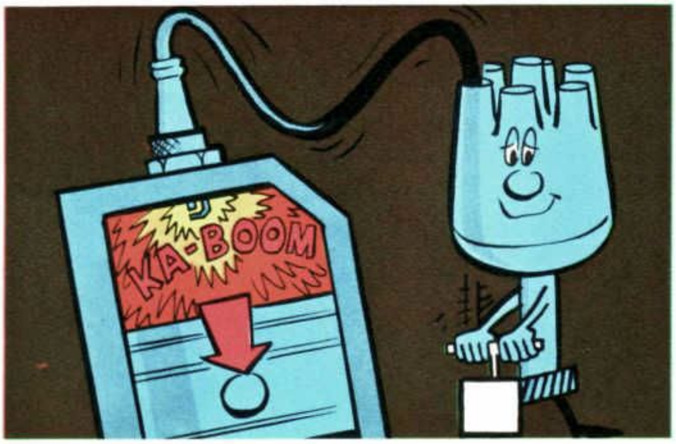
On a tour in a strange place, you'd probably seek a guide to help you find your way. When you're on the firing line in a busy service department, the best guide is your own knowledge of service procedures and of the operating principles of the equipment you're working on.

So use this training handbook as your guide to refresh and add to your storehouse of fuel system knowledge—so that when you have a fuel system problem to diagnose and repair; you can approach it confident that **you** know your way.

INTRODUCTION

The fuel systems and components we shall discuss in this handbook are those used on automotive vehicles with gasoline engines.

For purposes of definition, a gasoline engine is a heat engine in which power is developed by burning a mixture of gasoline and air in the combustion chambers of one or more cylinders, with ignition accomplished by a timed electrical spark.



When we talk of the fuel system, we refer to the parts of the car used to control the **delivery** of fuel to the engine and the **mixture** of fuel and air for greatest power and efficiency. These are your primary interests in this handbook. You need to know how these components are constructed and operate to aid you in diagnosing and repairing problems that may arise.

Yet, the development of fuel systems has gone hand-in-hand with the development of gasoline engines and of gasoline itself. So many fuel system design factors depend on the properties of the fuel that we also must discuss this important subject.

And so in this handbook we shall study not only the fuel system components, but also the makeup of gasoline–how it is refined, and how its chemical properties affect its behavior in the fuel system and combustion chamber of the gasoline engine. Part of the gasoline story will be interwoven with the story of the carburetor, fuel pump, etc.; part of it will appear in a separate section at the end of the handbook. Definitions of the technical terms used in this handbook appear immediately following this "Fuel Characteristics Section".

CONVENTIONAL FUEL SYSTEM

The conventional fuel system (Fig. 1), used on most gasoline engines, consists essentially of the fuel storage tank, a fuel pump, a fuel filter, a carburetor, and an intake manifold.

The **fuel tank** serves basically as a storehouse for

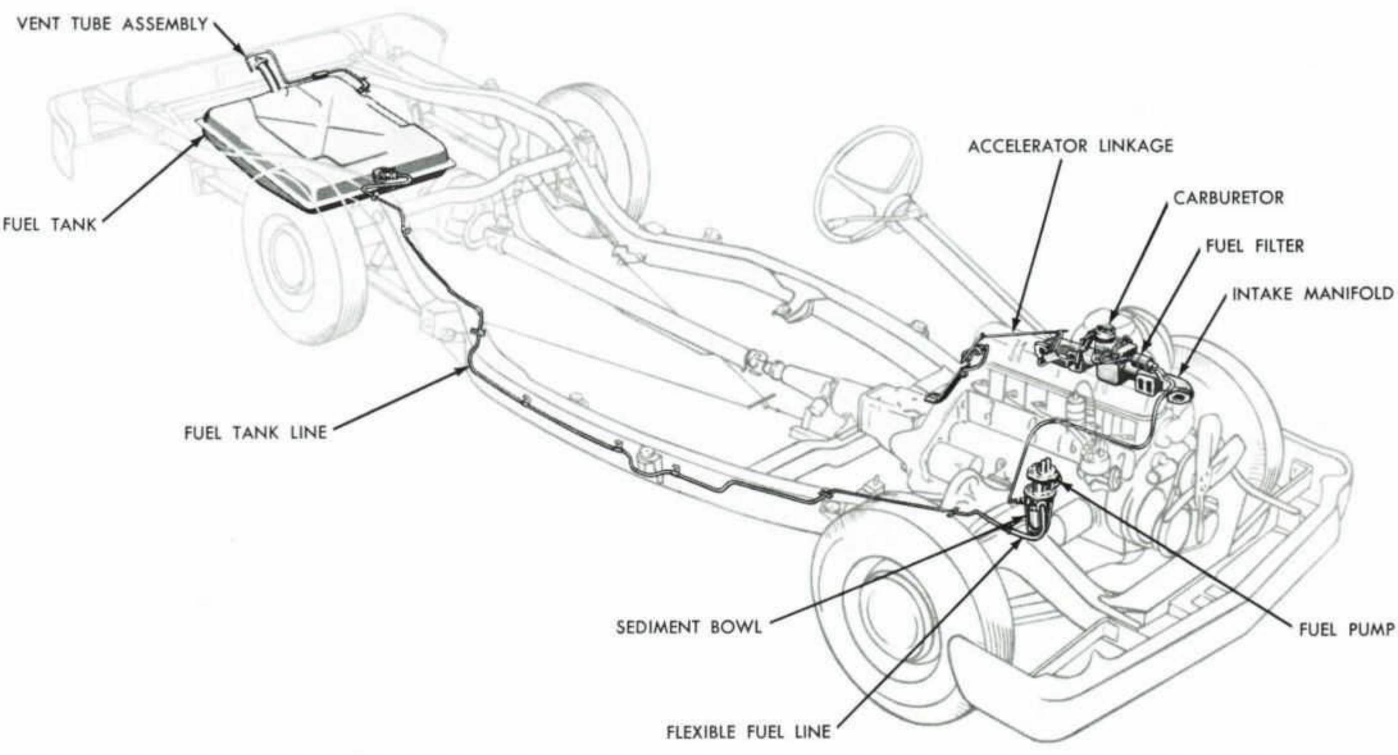


Fig. 1–Conventional Fuel System

the fuel. The **fuel pump** provides a constant supply of fuel from the tank to the carburetor, and the **filter** separates foreign material out of the fuel supply.

The **carburetor,** in response to signals from the accelerator or throttle, the choke, and engine intake manifold vacuum, mixes the fuel and air in correct proportions before it goes to the cylinders. The **intake manifold** directs the fuel-air mixture to the intake valves, which open at the right times to admit the mixture to the cylinders.

There are, of course, many variations of this conventional system. Besides these basic parts, we find **governors** on many vehicles to automatically limit the maximum speed of the engine for economy and long life.

In some engines, we still find the fuel fed to the carburetor by gravity, eliminating the need for a fuel pump. Too, there are engines with **fuel injection** systems, which eliminate the carburetor. Fuel injection is rare on automotive gasoline engines, though all diesel engines use fuel injection.

DEVELOPMENT OF FUEL SYSTEMS

The fuel systems you work on today are the result of many years of evolution in motor car design. Unless you're very young, you've had some experience with the gravity-feed, updraft-carburetor, fuel system (Fig. 2) used in the Model-A Fords, vintage around 1930.

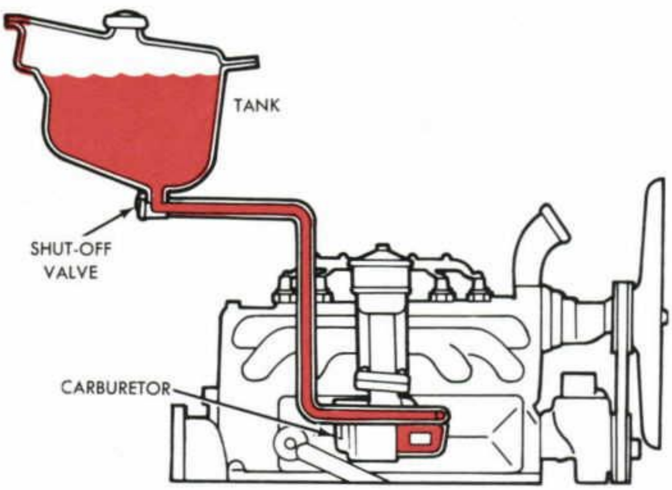


Fig. 2–Gravity-Feed Fuel System

In this system, the fuel tank is mounted under the cowl, very close to the carburetor, and gasoline is fed by its own weight (gravity) to the carburetor. A shut-off valve is placed in the line to prevent the fuel from draining out overnight if the carburetor float valve sticks open. (Remember not being able to start a Model-A because you didn't turn on the gas?) The updraft carburetor (Fig. 3) is so named because the air flows upward in the carburetor to get to the intake manifold.

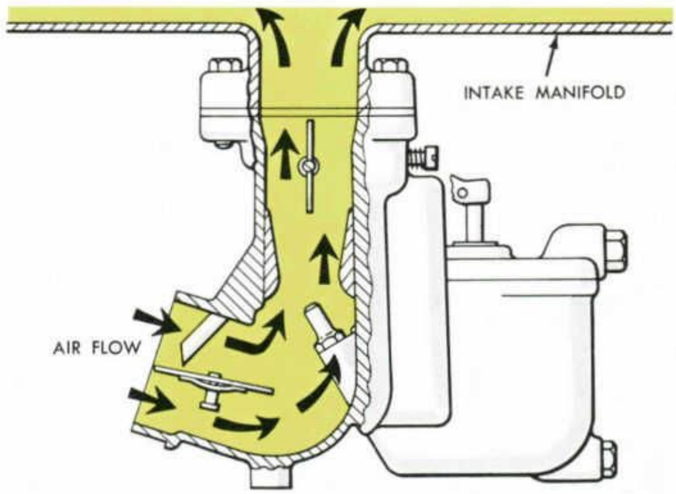


Fig. 3–Updraft Carburetor

Of course, it doesn't really matter in a gravity-feed system whether the tank is close to the carburetor as long as the bottom of the tank is higher than the carburetor inlet.

But it soon became inconvenient for designers to keep the fuel tank above the carburetors. Lower hood lines, increased sound-deadening material, more engine accessories and high under-hood temperatures contributed to the relocation of the tank. Safety, too, was a consideration, since as power and efficiency were increased, more volatile fuels were put to use. Therefore, other methods were devised to get the fuel from the tank to the carburetor.

VACUUM TANK

The vacuum tank feed system was used on some cars in the 1920's. In this system, a small fuel tank or vacuum tank was mounted higher than the carburetor. By means of a system of valves, engine intake manifold vacuum was used to pump fuel from the main tank to the vacuum tank by a difference in pressure. From the vacuum tank, the fuel was gravity-fed to the carburetor.

Another early system used a pressurized fuel tank. An engine-operated air pump maintained pressure in the tank and the pressure difference forced the fuel to the carburetor.

FUEL PUMP

Of course, if you're going to run a pump off the engine, you might as well have it pump the gasoline itself instead of air. The **fuel pump** is used almost universally today. It permits remote location of the fuel tank, without complicated valving or critical sealing problems as in the vacuum tank or pressurized feed systems.

Today we take fuel pumps pretty much for granted, though during their early years, starting in the 1930's, fuel pumps weren't known for long service life. Now, metallurgical and chemical (synthetic) material development has added several years to the operating life of a fuel pump. In fact, new materials have added considerably to reliability and manufacturing ease throughout the fuel system.

The fuel pump has run a full cycle in design. The first pumps were used only to move fuel from the tank to the carburetor; then vacuum boosters were added to help the windshield wiper motor out when engine load was heavy and vacuum was low. Now, electric wipers are used extensively, eliminating the need for a vacuum booster. Also, several kinds of electric fuel pumps are available as original equipment or for replacement use on most vehicles.

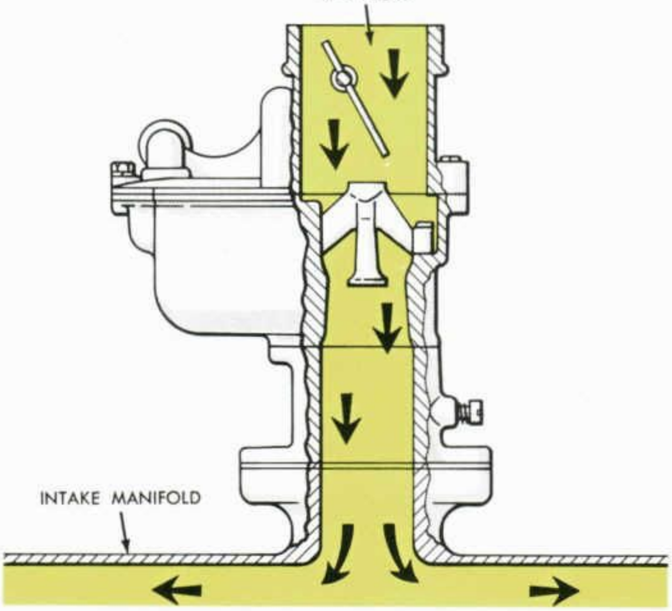


Fig. 4–Downdraft Carburetor

DOWNDRAFT CARBURETORS

The updraft carburetor of the Model-A car has pretty much gone the way of the 25 cent haircut in U.S.-built cars. Downdraft carburetors are mounted above the engine, so that the fuel-air mixture can "fall" in by gravity (Fig. 4). This lessens the energy used to supply the mixture to the cylinders. Other considerations prompting the change to the downdraft design were easier starting, more efficient operation, greater power and more compactness.

AUTOMATIC CHOKE

The automatic choke also is something we take for granted today, but you probably can remember when automatic chokes were less than reliable. Corrosion resistant materials and predictable expansion coefficients have added to the reliability of this component.

FUEL QUALITY

The quality of motor fuels also has undergone many changes for the better. Refining, handling and storage methods left a lot to be desired right up into the 1950's.

The earliest fuels contained acids and other corrosive chemicals, as well as dirt and water. Many car owners strained their fuel to keep foreign material out. Even so, sediment collected, and fuel tanks, lines, pumps, carburetors and engine parts were attacked and damaged.

Sediment bulbs were common in earlier fuel systems. Today we find simple, inline type, throwaway filters in the fuel lines. These filters have paper, fiber or ceramic elements. Modern gasolines are considerably purer and these new filters operate efficiently enough to protect the engine from most impurities.

FUEL TANKS AND LINES

A fuel tank (Fig. 5) serves primarily as a storehouse for the gasoline until it is needed at the carburetor. Additional fuel tank equipment may include a gauge sending unit in most tanks, a fuel shut-off valve on some truck tanks, and a fuel return line on vehicles with a partial recirculating fuel pump (see page 8).

All fuel tanks must be vented in some way–by vent tube or vented filler cap–to allow expansion and contraction of the fuel as the temperature changes, and to allow air in, to replace the fuel as it is used.

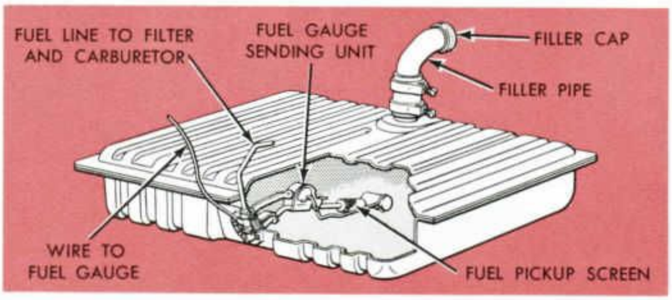


Fig. 5–Fuel Tank

TANK CONSTRUCTION

Most passenger car fuel tanks are made of stamped sheet-steel sections. The sections are welded at formed flanges (Fig. 6) by a method known as **seam welding.** In this process, the formed and mated flanges are passed between closely spaced rollers which have a voltage applied to them. The tank completes the circuit and the sections are fused together.

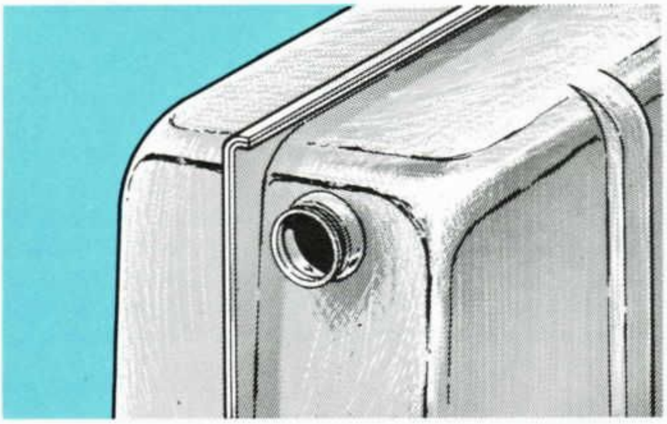


Fig. 6–Tank Seam Construction

Baffles are used in some fuel tanks to prevent the fuel from sloshing around and causing noise and weight shifting. By keeping agitation to a minimum, the baffles also improve separation of condensed moisture.

Most tanks are equipped with drains at the lowest point in the bottom. A fuel return connection is provided on top of the tank if a recirculating-type fuel pump is used (see Fuel Pumps).

PICKUP

The fuel pickup has a mesh screen to block any large particles in the tank from the fuel lines. In some vehicles, the pickup is a float and fuel is always taken from just below the fuel level rather than the bottom. This reduces the possibility of taking in water, unless the fuel level is very low. Of course, a high fuel level is always desirable to reduce condensation of water out of the air on the inside of the tank. The less surface area exposed, the less condensation can take place.

GAUGE SENDING UNIT

The fuel gauge sending unit (Fig. 7) is nothing more than a rheostat that is adjusted by a float. The float moves up-and-down in the tank as the fuel level changes. The rheostat sends an electrical signal to the fuel gauge, and the gauge needle is deflected from zero in proportion to the signal.

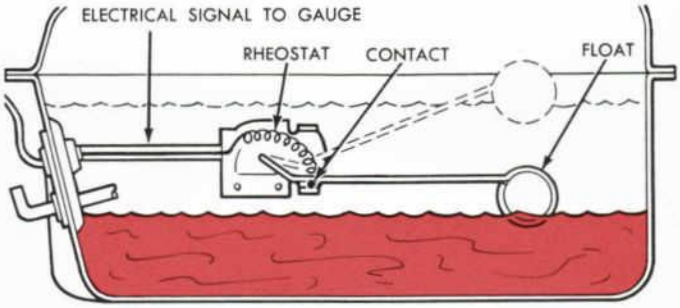


Fig. 7–Gauge Sending Unit

FILLER PIPES

The filler pipe may be welded to the tank, but more often is a friction fit in a welded flange or is clamped to the flange by a rubber sleeve (Fig. 8). When the tube is installed directly in the flange, an O-ring seal prevents fuel from leaking out at the flange.

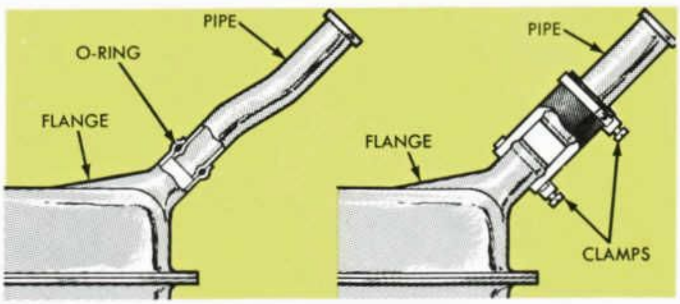


Fig. 8–Filler Pipe Connection

VENTING

Venting is accomplished in several ways. If there's no danger of dirt getting in the tank or fumes getting in the passenger compartment, a vent tube is used and the filler cap seals the pipe. A simple vented filler cap may be used if the filler pipe is long enough that fuel spilling is not likely.

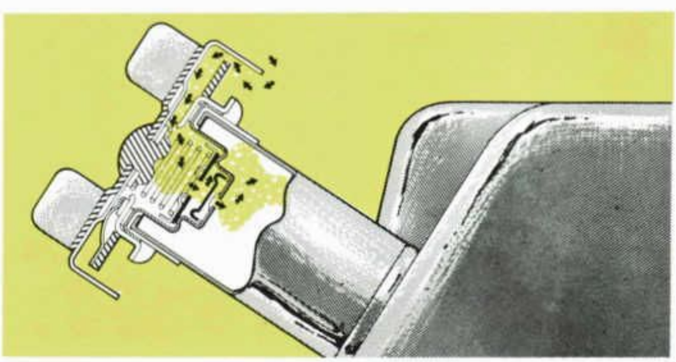
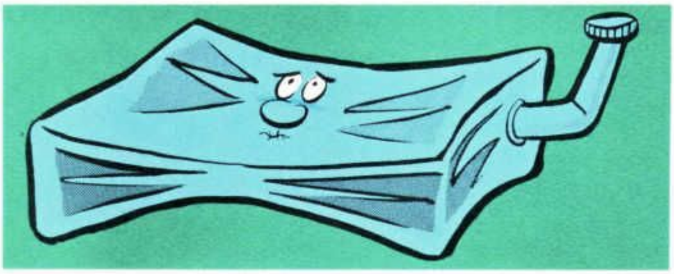


Fig. 9–Anti-Surge Vented Cap

Another method of venting is to incorporate two air valves in the filler cap (Fig. 9), a pressure valve which seats on a baffle cup and a vacuum valve which seats on the pressure valve. The pressure valve is spring loaded against its seat and the vacuum valve floats in the cup. A slight pressure in the tank or sloshing fuel, will force the vacuum valve against the pressure valve and seal off the vent. But if the pressure gets above about one psi, the pressure valve is forced open to relieve pressure. A vacuum condition in the tank pulls the vacuum valve away from the pressure valve and vents the tank through the center of the pressure valve.



Obviously, it's important not to get the wrong kind of filler cap on a tank. A plain vented cap can let fuel spill out on some systems. A nonvented cap used in place of a vented cap will cause the tank to collapse from fuel pump vacuum, or the pressure rise would be gradual and cause fuel to be forced through the pump flooding the carburetor.

TRUCK FUEL TANKS

Truck fuel tanks (Fig. 10) are similar to passenger cars except that on heavier trucks the larger tanks are constructed of thicker metal and are arc welded instead of seam welded. The heavier metal is necessary because increased fuel loads impose greater flexing forces on the tank that would soon crack a light-duty tank.

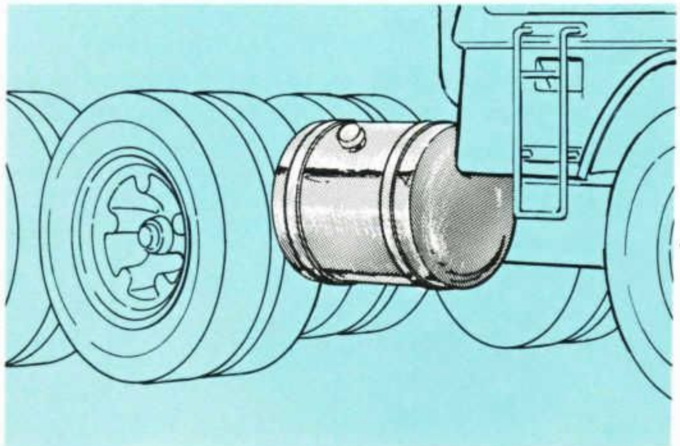


Fig. 10–Truck Fuel Tank

FUEL LINES

Fuel lines or tubes are constructed mainly of steel tubing except where movement of the line is necessary; then flexible hoses are used. Flexible hoses are usually of synthetic rubber construction. In some types of service where the line may be exposed to a gravel road or solid object interference, high strength flexible hose is used. This hose is composed of fabric, rubber and steel wire.

Copper tubing should never be used on a vehicle because of its poor fatigue strength characteristics. (It will break sooner than steel when subjected to vibration and movement.)

FUEL PUMPS

The basic job of the fuel pump is to keep a constant supply of gasoline available at the carburetor. Some pumps have auxiliary devices, such as filter-sediment bulbs, vacuum boosters to assist the windshield wipers, and recirculating valves to combat percolation in the carburetor. These devices will be described after we look at the basic pumps.

It is quite common to refer to the fuel pump as a "lift" pump; and this designation differentiates it from a pressurizing pump, such as a fuel injection pump. For while it is desirable to operate an engine-mounted pump at a moderate pressure to prevent vapor lock, the pump primarily lifts the fuel from the tank to the higher carburetor. If the tank were above the carburetor, the fuel would feed by gravity and no pump would be needed.

RECIPROCATING PUMP

We find two basic fuel pumping mechanisms—reciprocating and centrifugal. The reciprocating principle is used in all mechanical fuel pumps and in all electric types except one. Since we'll encounter this principle throughout this section and in the carburetor accelerating pump, let's see how it works.

A pumping element—either a piston or a diaphragm—moves in and out of a pumping chamber (Fig. 11). Moving out of the chamber, the piston creates a partial vacuum. Since the fuel in the tank is at atmospheric pressure, the pressure difference forces fuel into the pumping chamber. The inlet check

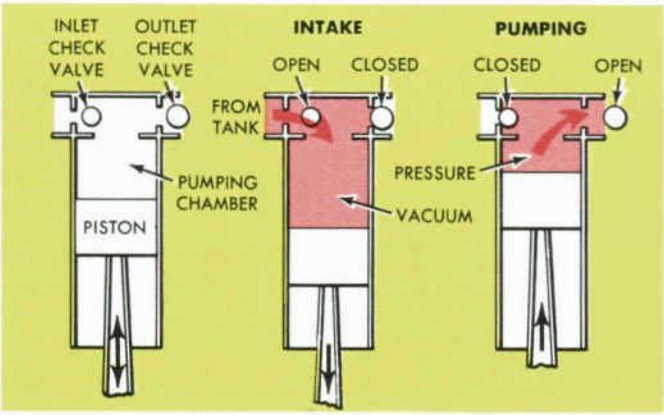


Fig. 11–Reciprocating Pump

valve opens to permit the fuel to flow into the chamber and the outlet check valve prevents backflow.

Then, when the piston moves back in, enough pressure builds up to force the inlet check valve closed and the outlet valve open; and the charge of fuel is forced through the outlet port.

Now let's see how this principle is applied in the mechanical fuel pump.

MECHANICAL FUEL PUMPS

The mechanical fuel pump (Fig. 12) is mounted on the engine block and operated by an **eccentric** on the engine camshaft. The eccentric moves the pump **rocker arm** up and down. The **rocker arm spring** holds the arm against the cam eccentric at all times.

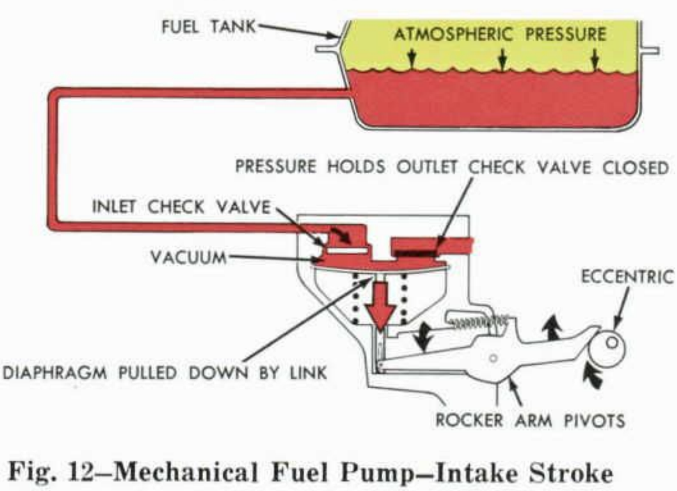


Fig. 12–Mechanical Fuel Pump–Intake Stroke

The pumping element is a diaphragm that is actuated by a spring and by mechanical linkage to the rocker arm. The pumping chamber in the pump illustrated is above the diaphragm. The inlet and outlet ports and the check valves are identical except that they're reversed.

Intake of fuel occurs when the cam eccentric pushes up on the pump rocker arm, causing it to pivot. A link at the opposite end of the arm pulls the diaphragm down so that vacuum is created in the pumping chamber. Atmospheric pressure in the fuel tank forces fuel in past the inlet check valve. The outlet valve is held closed by the pressure in the outlet line.

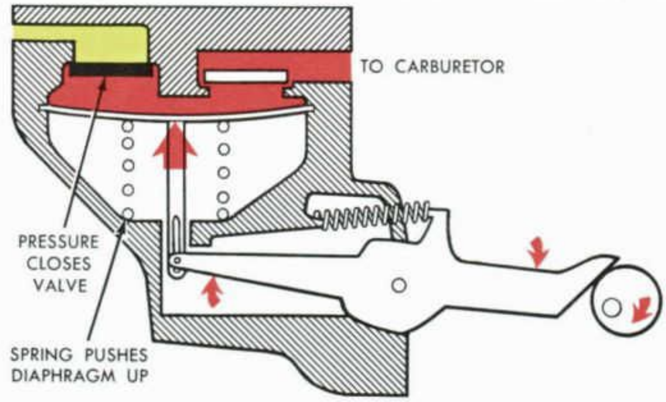


Fig. 13–Mechanical Fuel Pump–Discharge Stroke

Pumping action takes place when the rocker arm moves back (Fig. 13). The spring, which was compressed during intake, now is free to push up on the diaphragm. This push causes pressure to build up in the pumping chamber. The pressure closes the inlet check valve and opens the outlet check valve. The fuel then flows to the carburetor.

IDLE OPERATION

The fuel pump is designed to furnish more fuel than the carburetor needs running wide open, therefore full pump capacity of a normally operating pump is never required. The pump is designed to idle whenever the float valve in the carburetor isn't passing full volume to the bowl.

With the carburetor float valve closed, pressure backs up in the pumping chamber. The pressure is too high for the spring to overcome, so the diaphragm stays down. The mechanical linkage between the rocker arm and diaphragm link is positive in only the down direction, so the rocker arm just moves back-and-forth in the diaphragm push rod slot without moving the diaphragm.

VACUUM BOOSTER

The combination fuel pump and vacuum booster (Fig. 14) has a separate vacuum pump used to operate the windshield wiper motor when engine vacuum is low. The booster pump operates from the rocker arm just like the fuel pump, but this time the diaphragm spring is on the pumping or vacuum chamber side.

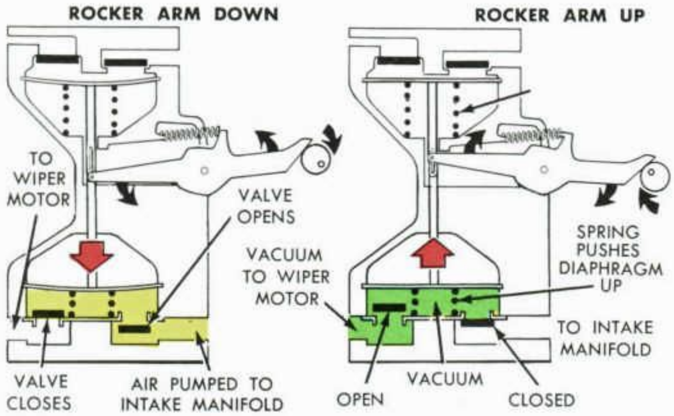


Fig. 14–Vacuum Booster

The intake of the booster pump is connected to the wiper motor. The outlet is connected to the intake manifold.

When the pump starts, the rocker arm pushes the diaphragm down. The outlet check valve opens and air in the chamber is pushed into the intake manifold. Then, when the rocker arm moves up, the spring pushes the diaphragm after it and creates a vacuum below the diaphragm. The inlet valve opens; the outlet valve closes; and the vacuum is used to operate the wiper motor.

If the manifold vacuum is high, it pulls the outlet valve open and manifold vacuum is sensed in the pumping chamber. This vacuum holds the diaphragm down against spring force and the pump "idles." Both valves are held open and manifold vacuum operates the wipers.

ELECTRIC FUEL PUMPS

RECIPROCATING ELECTRIC PUMPS

Reciprocating electric fuel pumps operate on the same principle as the mechanical lift pump. There are three principal kinds of reciprocating electric pumps – PLUNGER; BELLOWS; DIAPHRAGM. They get their names from the type of pumping element.

The pumping element is operated something like an electric vibrator. To move it in one direction, a coil is energized and moves an armature. At a predetermined point in armature travel, the circuit is broken and a spring returns the armature to the starting point. Here the circuit is closed again and the cycle is repeated.

The bellows-type pump (Fig. 15) is probably the simplest of the three, and will serve to illustrate the principle.

When the coil is energized by turning the ignition on, the armature is pulled down magnetically. The spring under the armature is compressed.

The bellows, connected to the armature, expands. A vacuum is created inside the bellows, so that the outlet check valve closes and the inlet check valve opens. Atmospheric pressure in the tank forces the fuel in through the inlet valve.

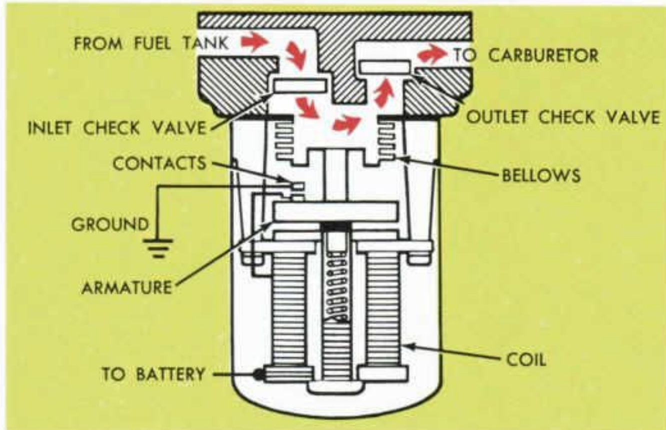


Fig. 15–Bellows Type Electric Fuel Pump

As the armature moves down, the electrical circuit is broken and the coil is de-energized. The spring pushes the bellows up, creating pressure on the fuel charge. The inlet check valve is pushed shut by the pressure. The outlet check valve opens and the fuel flows to the carburetor.

Idling is accomplished just as in the mechanical diaphragm pump. Back pressure from the carburetor float valve holds the bellows expanded and the spring compressed. The circuit is broken in this position so no electrical energy is wasted.

ROTARY IMPELLER ELECTRIC PUMP

The impeller-type electric fuel pump (Fig. 16) is a rotary centrifugal pump. A bladed or vaned impeller

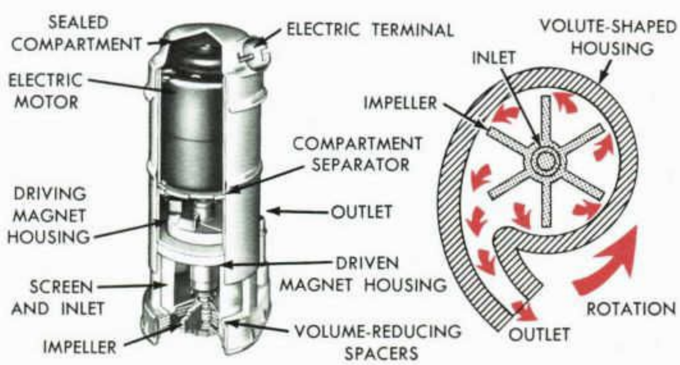


Fig. 16–Impeller-Type Electric Fuel Pump

is driven by an electric motor. Fuel from the inlet is supplied near the center of the rotating impeller. Centrifugal force causes the fluid to move to the outer edge of the impeller blades. The fuel follows the spiral shaped impeller case to the outlet.

This pump is often referred to as a **pusher type** because it is located in the tank and pushes the fuel to the carburetor.

PERCOLATION

Percolation, also called **fuel boiling** or **fuel push-over** is a condition where high under-hood temperatures cause fuel in the line from the fuel pump to the carburetor to vaporize. The vaporized fuel expands greatly so that pressure builds up and pushes the carburetor float open, flooding the engine. You can often see the fuel bubbling or percolating in the carburetor barrel with the air cleaner off.

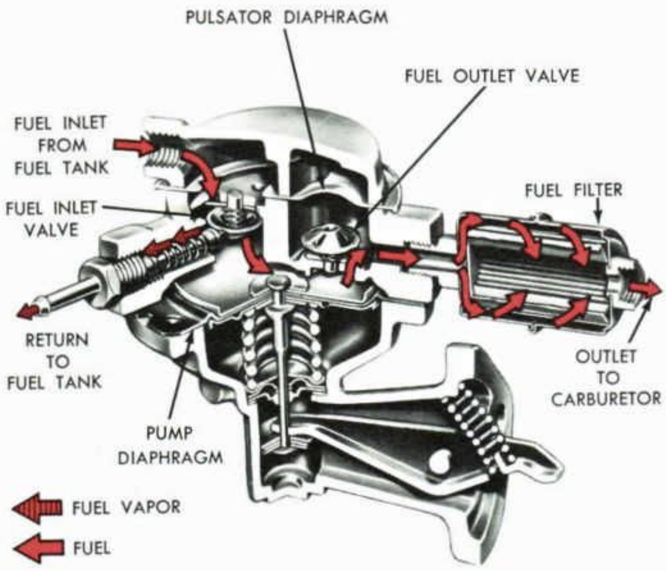


Fig. 17–Partial Recirculating Fuel Pump

Some fuel pumps have a recirculating arrangement to combat percolation (Fig. 17). This arrangement returns part of the fuel flow to the tank to keep a supply of cool fuel in the critical area of the system at all times.

In other pumps, a small bypass hole is drilled through or around the outlet valve. The excess pressure from vaporization is relieved back to the low-pressure side through this bypass, so that the carburetor float can't be pushed open.

VAPOR LOCK

Vapor lock is caused by volatile fuel vaporizing in the fuel pump. On a hot day, the fuel is warm to start with and is heated more in the engine compartment. When the hot fuel enters the inlet of the pump, the decreased pressure permits it to vaporize. Since the vapor occupies a much higher volume than liquid, and of course the pump delivers volume, not weight, the carburetor is starved and the engine just won't operate.

Anything that increases the temperature in the engine compartment can aggravate the tendency toward percolation or vapor lock. The big advantage of electric fuel pumps is that they can be mounted in cooler locations and vapor lock ceases to be a problem.

OPERATING PRESSURES

Depending on flow conditions, the pressure between the fuel tank and fuel pump inlet may be as low as 10 psia–pounds per square inch absolute (Fig. 18).

In other words, the fuel pump operates up to 10 inches of vacuum. (Normal atmospheric pressure is about 15 psi, and one psi is the equivalent of two inches vacuum.) Of course, if the pump is closer to the fuel tank, and the height the fuel must be lifted is less, the vacuum is less.

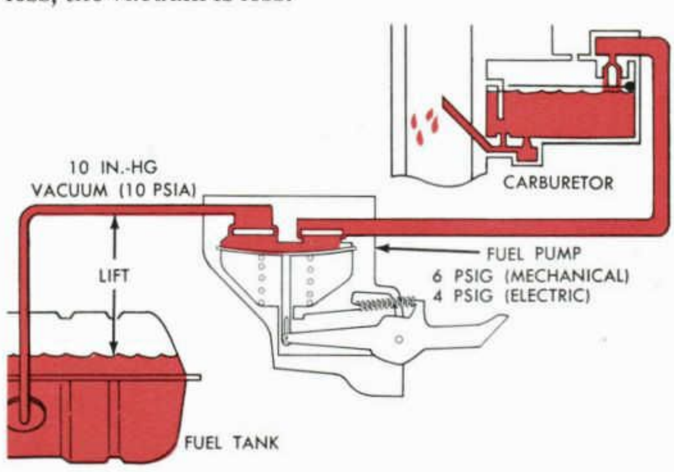


Fig. 18–Fuel Pump Operating Pressures

The **outlet** pressure that can be reached before the pump begins to idle depends on the diaphragm size and the force of the spring compression. Pumps are designed to supply as high a pressure as possible, compatible with the carburetor float and needle valve calibration. With a mechanical pump, the pressure may be as high as six psig (pounds per square inch gauge), or 21 psia (pounds per square inch absolute). Electric pumps usually operate at four psig or less. A high pressure is desirable with engine-mounted pumps to prevent vaporization of the fuel before it gets to the carburetor. However, too high pressure can force fuel past the carburetor float chamber needle valve and cause flooding. Therefore, it is important that fuel pumps operate at their designed discharge pressure.

FILTERS

Keeping the gasoline clean on the way to the carburetor is very important to prevent clogging of the carburetor jets. Also, the less water that gets to the carburetor, the better, to prevent freeze-up in the carburetor throat. Most fuel systems have at least one filter to remove impurities from the gasoline.

TANK FILTERS

Filters incorporated in the gas tank were mentioned briefly earlier, and these are still used on some vehicles. These filters are usually made of porous bronze material that separates dirt and water from the gasoline before it flows to the fuel pump inlet line. As the fuel sloshes in the tank, it washes these impurities back into the tank where they settle to the bottom.

SEDIMENT BOWLS

A sediment bowl (Fig. 19) usually is integral with the fuel pump, though it can be installed anywhere before the carburetor float valve. This type filter has a strainer screen and a bowl to collect impurities.

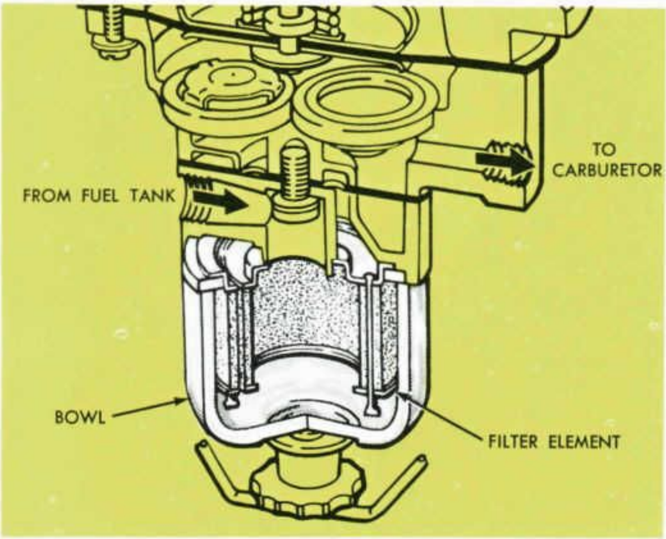


Fig. 19—Sediment Bowl Filter

Gasoline passes through the strainer and into the bowl. Particles of dirt settle at the bottom of the bowl and water also settles at the bottom. Gasoline, of course, floats on water, so the filter outlet is above the bowl.

Though some maufacturers still use sediment bowls, they have been largely replaced by inline-type filters which are completely adequate with present-day improvements in gasoline quality.

INLINE FILTERS

Inline filters are located between the fuel pump and carburetor. Two types of inline filters are used on Ford-built vehicles. Most use the simple throwaway unit (Fig. 20). In this unit, the gasoline enters one end, and flows around the outside of the element, through the element to its center and then to the outlet. This filter is inexpensive and for this reason the element is not replaceable.

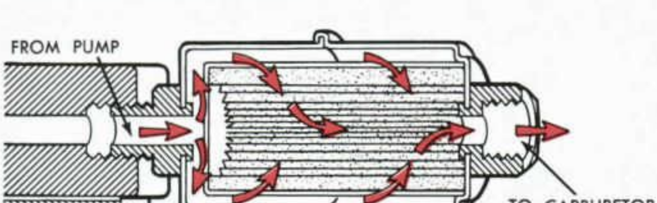


Fig. 20—Throwaway Inline Filter

Another type of inline filter used with high-performance engines has a replaceable element inside a filter can (Fig. 21). These are usually of a higher capacity than the throwaway filter.

Fig. 21—Inline Filter for High-Performance Engine

CARBURETORS

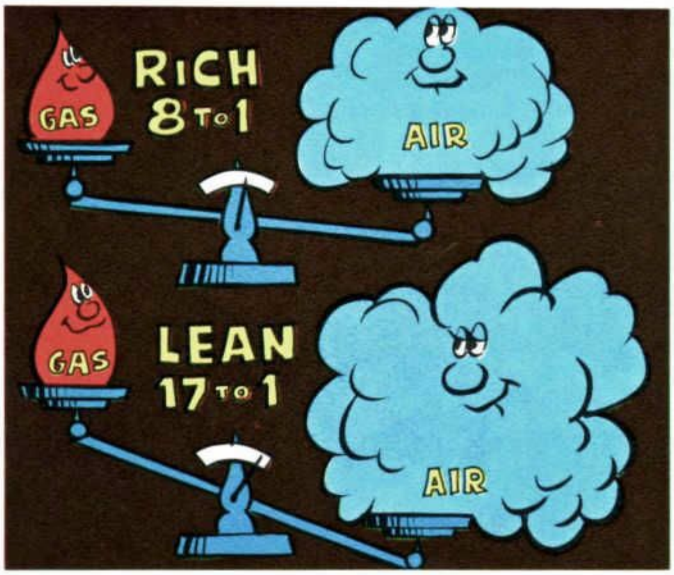
In a gasoline engine, as we mentioned earlier, power is generated by burning a mixture of fuel and air. For best performance and economy, the proportions of air and fuel must be controlled exactly under all operating conditions. The **carburetor** must mix the fuel and air in proper proportions; must help the fuel to vaporize (or else it won't burn) by atomizing it; and must adjust the volume and richness of the mixture in response to the driver's signals for more or less speed or power.

AIR-FUEL RATIO

If we chemically analyzed the proportions of hydrogen and carbon in typical gasoline, and of oxygen in the air, we'd find that it takes just about 15 pounds of air to completely burn **one** pound of gasoline. If we mix the air and gasoline in this proportion, we can say we have a **15-to-1 mixture** or **air-fuel ratio.**

With proportionately **more fuel,** we would have a **rich mixture.**

With proportionately **less fuel,** we would have a **lean mixture.**



Most engines will operate within a range of 8-to-1 (very rich) to 17-to-1 (slightly lean). Actually, we seldom use a mixture richer than about 11-to-1, regardless of conditions. Here are some approximations of air-fuel ratios for different conditions. We'll see why richer mixtures are needed at times as we go over the various systems in a modern carburetor.

TYPE OF OPERATION	AIR-FUEL RATIO
IDLE	11-1 to 12-1
LIGHT LOAD (CRUISING)	14-1 to 17-1
HEAVY LOAD	12-1 to 13-1

THE AIRSTREAM

To build a carburetor, we can begin with a tube or barrel (Fig. 22) positioned to permit an airstream to enter at the top and pass through to the intake manifold and cylinders. The fuel will be vaporized and mixed into this airstream in the barrel.

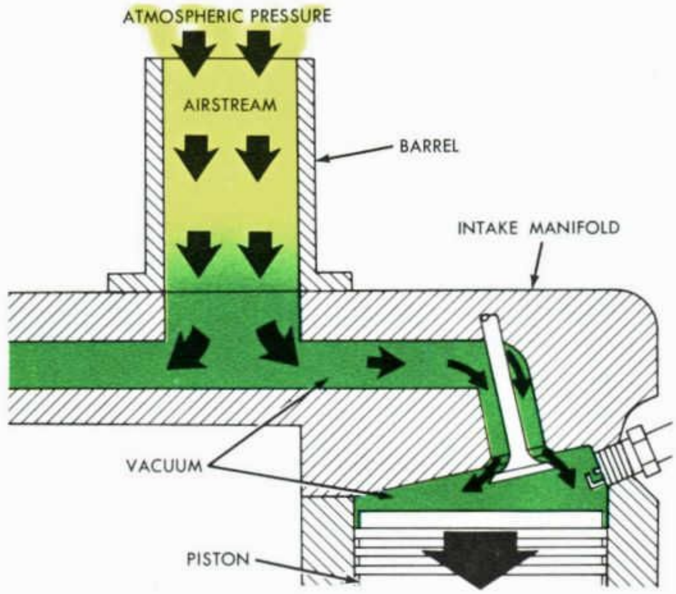


Fig. 22—Carburetor Barrel and Air Intake

Manifold vacuum is what causes the airstream. As far as the carburetor is concerned, the engine is nothing but an air suction pump. The pistons alternately move down on their intake strokes, creating a vacuum in the combustion chamber. Since the intake valves are open at this time, the vacuum is also felt in the intake manifold. But the air above the carburetor tube is at atmospheric pressure. The pressure difference, then, forces the air down the barrel to fill the vacuum. With the engine operating, we have a continuous stream of air through the barrel, with more air flowing at high speed and less air at low speed.

Now if the engine operated at the same speed with the same load all the time, we could just spray a good volatile fuel into this airstream at a constant rate and we'd be all set (Fig. 23). The fuel would vaporize and mix with the air and no other controls would be necessary. But since the **amount** of mixture must be varied to change speed, and/or power output and the **air-fuel ratio** must be varied to suit operating conditions, we must have other systems in the carburetor.

THROTTLE VALVE

The throttle valve (Fig. 24) is a butterfly-type valve placed in the barrel near the bottom to control

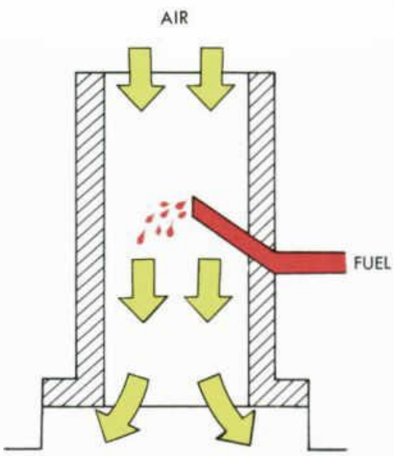


Fig. 23–Mixing Fuel with Airstream

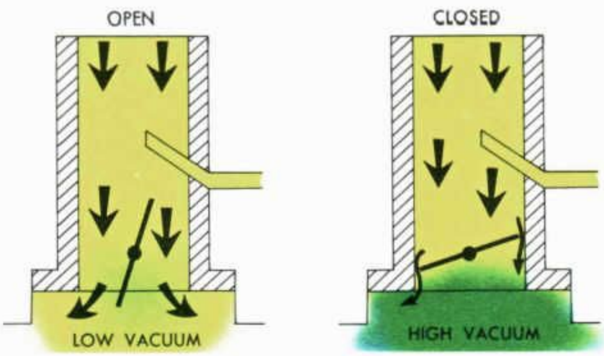
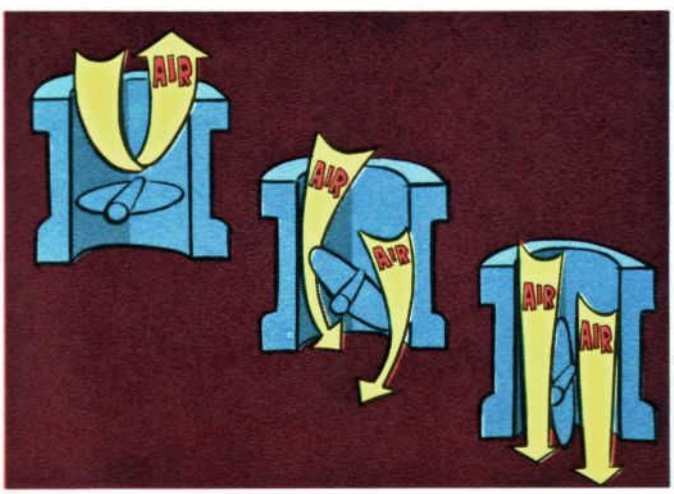


Fig. 24–Throttle Valve

the volume of air flowing through the barrel. The throttle valve is opened and closed by a mechanical linkage to the accelerator pedal.

Opening the throttle valve lets the air flow through unrestricted. Closing it restricts or blocks the air flow, so less air is taken in.



The throttle valve position also has an important effect on **manifold vacuum.** You've noticed that vacuum-operated windshield wipers, operating normally at closed or light throttle, slow down when you step on the gas. With the throttle valve closed and less air getting in to fill the void, manifold vacuum stays high. Open the throttle valve and the airstream rushes in to fill the void, so that vacuum drops.

Now that we have air flowing and a control for the volume of air, we need a way to get the fuel into the airstream in the right proportion. This is accomplished by three different systems for the different operating conditions–the main fuel system, the idle fuel supply system and the power fuel supply system.

MAIN FUEL SUPPLY SYSTEM

The main fuel supply system or main metering system furnishes all the gasoline for cruising speeds where the mixture is the leanest. It also furnishes part of the gasoline for other driving conditions. The essential parts of the main fuel supply system are the **fuel bowl and float valve;** the **main discharge nozzle,** the **venturi** and the **main metering jet.** Let's add them to our basic carburetor in that order.

FLOAT SYSTEM AND MAIN DISCHARGE NOZZLE

A supply of fuel is stored in the carburetor **bowl** or **float chamber** (Fig. 25). This chamber is connected through passages in the carburetor to the **main discharge nozzle** in the carburetor throat; so that the fuel can be sprayed into the airstream.

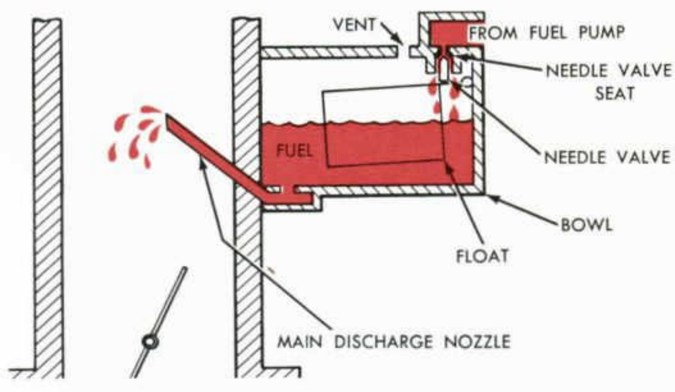
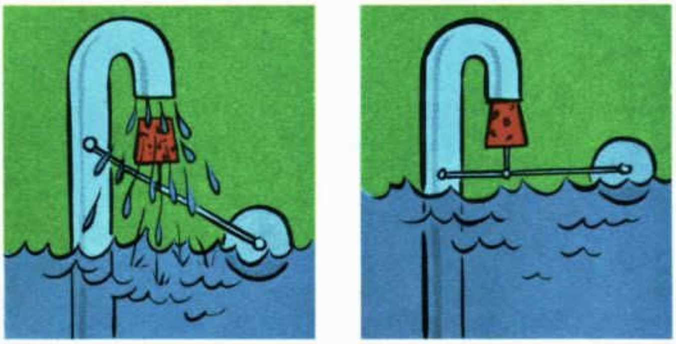


Fig. 25–Carburetor Bowl and Main Discharge Nozzle

The float and needle valve control the fuel level in the float chamber. The float is buoyant so that it moves up and down with the fuel level. As the fuel is used, the float drops and lets the needle valve open to admit fuel from the fuel pump. Then, when the level



rises to the correct point, the float closes the needle valve and blocks flow from the pump. A vent in the top of the bowl prevents the pressure from changing during the slight changes in fuel level. This pressure and the fuel level in the bowl are critical to control of the main fuel supply system, as we'll see later.

Now, with the float valve maintaining a level of fuel in the bowl and main discharge nozzle, and something close to atmospheric pressure in the bowl, we can force fuel out of the nozzle into the airstream if we lower the pressure at the end of the nozzle. Reducing the pressure in the barrel is accomplished by a **venturi.**

THE VENTURI

The venturi principle (Fig. 26), simply stated, is this:

> Fluid flowing through a restriction increases in velocity and decreases in pressure.

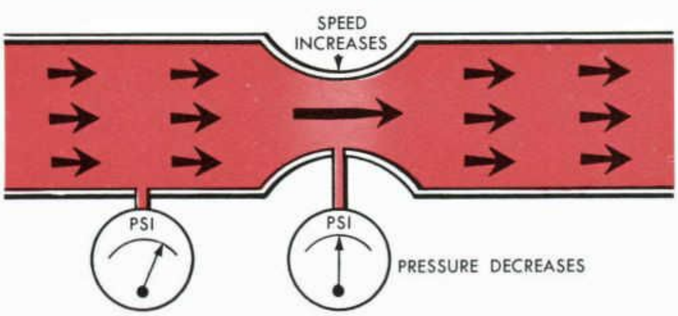


Fig. 26—Venturi Principle

This principle was explained by Daniel Bernoulli, a Swiss scientist, some 200 years ago. Bernoulli, in applying the law of conservation of energy to fluid flow, noted that when a fluid reaches a bottleneck, it must speed up to maintain the same volume of flow. However, speeding up increases the fluid's **kinetic energy** or energy of motion. Since energy cannot be created from nothing, the fluid must lose another form of energy to gain kinetic energy. The gain in kinetic energy is offset by a decrease in pressure. Total energy remains the same.

It is easy to see from this illustration how the venturi will help us get fuel into the airstream in the carburetor throat.

By placing the venturi around the main discharge nozzle (Fig. 27), we can make the nozzle work as an atomizer. As the stream of air flows past the nozzle, its pressure falls. The reduced pressure in the barrel (venturi) permits atmospheric pressure in the carburetor fuel bowl to force the fuel through the nozzle and into the airstream. The fuel atomizes or mists in the airstream and vaporization is aided by the reduced pressure.

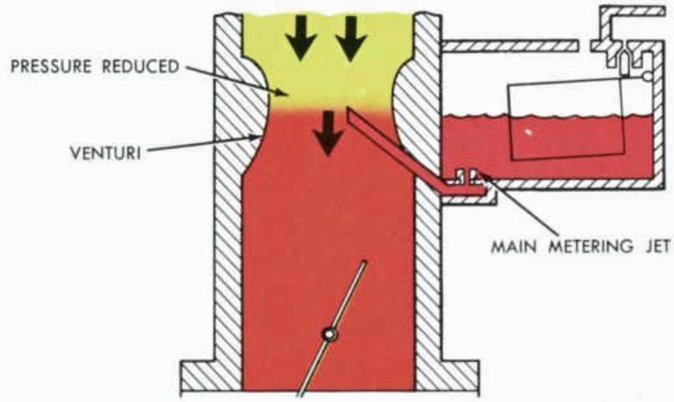


Fig. 27—Carburetor Venturi and Main Metering Jet

Auxiliary Venturi

The size of the venturi is a compromise between low- and high-speed operation requirements. At low speeds, when air flow is minimum, a small venturi is desirable. At high speeds, though, a large venturi is better so that air flow isn't restricted. Thus, we often find two or more venturis working in series (Fig. 28).

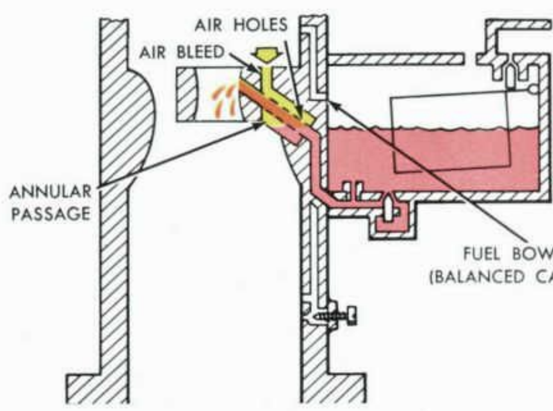


Fig. 28—Balanced Carburetor with Auxiliary Venturi and Air Bleed

Balanced Carburetor

If we use the difference in pressure between the carburetor fuel bowl and the nozzle tip to control fuel discharge into the airstream, we must make certain this pressure difference depends **only** on air flow. However, the carburetor air cleaner offers resistance to air flow which is variable depending on how clean the air cleaner is. Thus, in the carburetor **air horn,** the upper body part of the barrel where air enters, the pressure will be less than atmospheric pressure. How much less it is depends on the pressure drop through the air cleaner.

In a **balanced carburetor,** the fuel bowl is vented into the air horn instead of to the atmosphere and therefore is always at air horn pressure. Thus, only air flow affects the pressure difference.

MAIN METERING JET

Our main fuel supply system now consists of the fuel supply bowl and float system; the discharge nozzle and venturi forming a fuel atomizer; and a throttle valve to control the airstream. Next, we need an orifice to control flow from the bowl to the discharge nozzle. This flow control orifice is called the **main metering jet** (Fig. 27). The main metering jet, in effect, controls the air-fuel mixture of the main fuel system by passing a restricted flow of fuel to the main discharge nozzle.

Of course, the same thing could be accomplished by closely controlling the inside diameter of the nozzle. However, the main metering jet is removable so that we can substitute another size to change the air-fuel ratio. For example, at high altitude, the air is less dense and we use a smaller main jet to prevent too rich a mixture.

AIR BLEEDS

With the main metering jet installed, we now have precise control of the air-fuel ratio at moderate speed. But at very high speed, with a large volume of air, the air is less dense and the fuel mixture tends to richen. This is usually offset by air bleeds (Fig. 28).

In the air bleed system, increased air flow tends to force the fuel down in an annular passage around the nozzle. As the fuel in this passage is forced down, it uncovers holes in the nozzle and lets air into the nozzle. The pressure difference between the nozzle and fuel bowl thus is decreased and less fuel is discharged into the less dense air.

Introducing air into the nozzle at this point also helps the fuel to vaporize and improves its response to changes in air flow.

THE IMPORTANCE OF FLOAT LEVEL

We can easily understand now why the float level is so critical to the operation of the main metering system. If we change the float level, we affect the calibration of the system by changing the distance our pressure difference must lift the fuel in the main discharge nozzle.

If the level is too low, too much lift is required and we get less fuel or too lean a mixture. Conversely, if the level is too high, we get a rich mixture, or even flooding.

PRECISE CONTROL OF MIXTURE

In summary, the job of our main fuel supply system is to provide a constant air-fuel ratio, usually just a little on the lean side, for cruising and other throttle settings. The **quantity** of the mixture that goes to the cylinders and therefore the engine speed, is determined by the position of the throttle valve. When this mixture supplied by the main fuel supply system isn't rich enough to develop the needed power, or when the system is inoperative because of low air flow, other systems provide the necessary enrichment.

IDLE FUEL SUPPLY SYSTEM

Now let's look at what happens to the main fuel supply system at low speeds and at idle. The throttle valve is nearly closed (Fig. 29), and air flow in the

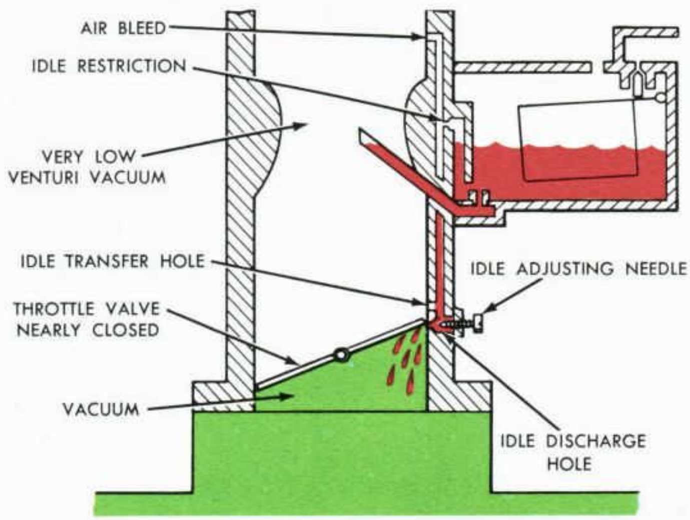


Fig. 29–Idle Fuel Supply System

barrel is minimal. With very low air flow through the venturi, there isn't enough vacuum at the discharge nozzle to pull much of the fuel, if any, out. So we have a separate fuel supply system for idle and low-speed operation.

IDLE DISCHARGE HOLE

In the idle system, a separate passage from the fuel bowl terminates at the **idle discharge hole below** the closed throttle valve (Fig. 29). Remember that with the throttle valve closed, manifold vacuum is very high. High manifold vacuum permits atmospheric pressure in the bowl to force fuel through this passage and out into the barrel during closed-throttle operation.

IDLE TRANSFER HOLE

As the throttle opens slightly, air speed increases and would lean the mixture out immediately except for the **idle transfer hole.** The idle transfer hole, a second opening slightly higher in the barrel, provides a second discharge for fuel when the throttle begins to open, thus preventing a flat spot between idle and main metering system operation. The idle transfer hole also permits air to bleed into the idle system at closed throttle. Another air bleed is located above the fuel passage to help the fuel vaporize when it's discharged. And an idle restriction is provided to control flow to the idle system. In some carburetors, this restriction is in the form of a removable orifice or idle jet.

IDLE MIXTURE

The **idle adjusting needle** controls the fuel flow from the idle discharge hole only. This permits setting the mixture at idle to suit the individual engine.

Idle mixtures are slightly richer than at cruising because of less efficient fuel distribution in the manifold when the air is in short supply. At cruising speed, more air flow improves distribution or "breathing."

TRANSITION TO MAIN METERING SYSTEM

In summary, here are the actions that take place in transition from idle to open-throttle operation.

1 With the throttle closed at idle, manifold vacuum is high. The difference in pressure forces fuel into the carburetor barrel through the idle discharge hole.

2 As the throttle opens and air flow increases, additional fuel is discharged from the idle transfer hole to prevent the mixture from going too lean.

3 Further throttle opening decreases manifold vacuum so that the discharge from the idle system **decreases** as the main metering system discharge **increases.**

Thus, the main metering system takes over smoothly from the idle system as the throttle is opened.

POWER FUEL SUPPLY SYSTEM

During acceleration, or anytime there's a heavy load on the engine, a richer mixture is required for more power. To satisfy this need, we have another system for increasing fuel delivery. This is called the **power fuel supply system.**

POWER VALVE SYSTEM

The power valve type power fuel supply system is operated by manifold vacuum on top of a small piston or diaphragm (Fig. 30). This piston has a long stem that opens the **power valve** when vacuum drops off.

At idle or cruising speeds, the vacuum is high and holds the piston up against spring force. The power valve remains closed.

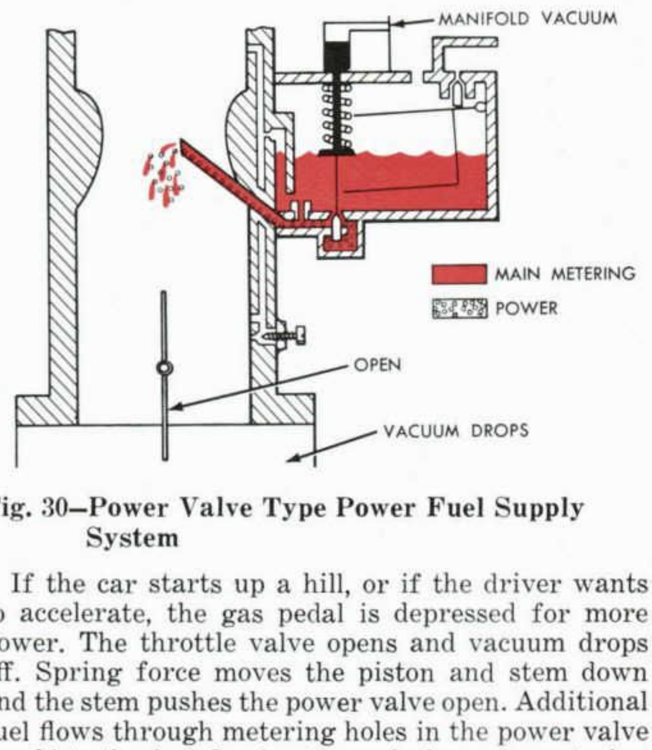


Fig. 30—Power Valve Type Power Fuel Supply System

If the car starts up a hill, or if the driver wants to accelerate, the gas pedal is depressed for more power. The throttle valve opens and vacuum drops off. Spring force moves the piston and stem down and the stem pushes the power valve open. Additional fuel flows through metering holes in the power valve to add to the fuel flowing through the main metering jet. This extra fuel is discharged from the main discharge nozzle and richens the mixture there.

METERING ROD SYSTEM

In another type of power fuel supply system, a metering rod (Fig. 31) is used to change the effective size of the main metering jet. This system also is controlled by vacuum against a spring-loaded piston.

At cruising throttle settings, the piston is held down by manifold vacuum and the tapered stem of

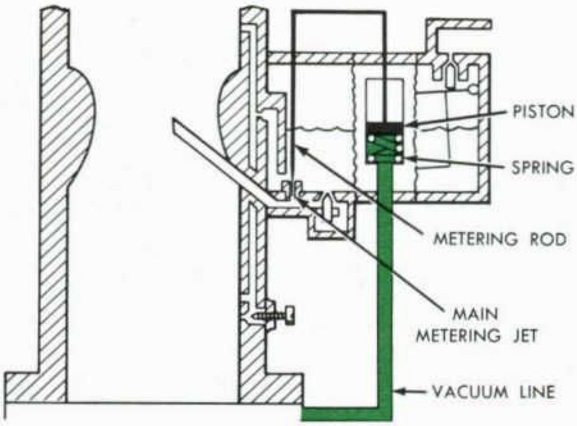


Fig. 31—Metering Rod Power Fuel Supply System

the metering rod falls into the main jet, decreasing its effective size. When higher power is called for, the spring overcomes vacuum and forces the metering rod up. The main jet orifice becomes larger, so more fuel flows to the nozzle.

This type of system can also be operated by a direct mechanical linkage to the throttle valve. In some carburetors, the metering rod is not tapered, but is completely pulled out of the jet for power operation.

ACCELERATING PUMP SYSTEM

We have one other system that is important for power operation and that is the *accelerating pump system*. This system furnishes a single spurt of gasoline to richen the mixture momentarily when the driver calls for a sudden burst of power.

Without an accelerating pump system, opening the throttle suddenly increases the flow of air, but the heavier fuel takes longer to get into motion and the mixture is temporarily lean when we need it rich. The accelerating pump system covers this gap until the power fuel supply system catches up with the needs of the engine.

RECIPROCATING PUMP

The accelerating pump (Fig. 32) is a simple reciprocating piston or diaphragm pump operated by linkage from the throttle and a spring. It has an inlet and outlet check valve and a jet opening into the airstream in the carburetor barrel.

With the throttle released, the piston returns to the retracted position. Moving this way, the piston creates a partial vacuum in the pumping chamber which closes the outlet check valve. The intake check valve opens and fuel from the fuel bowl flows into the pumping chamber.

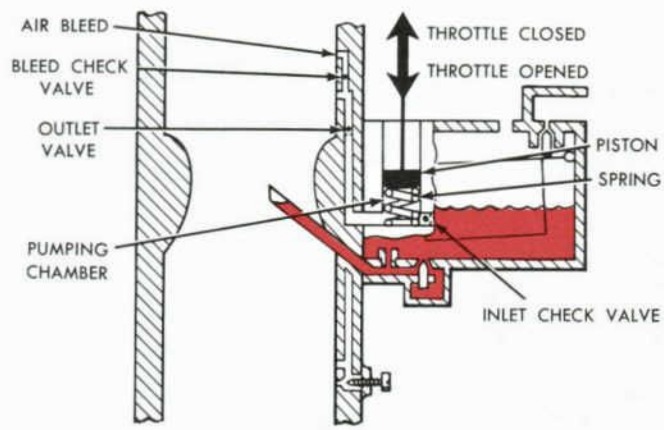


Fig. 32—Accelerating Pump System

When the throttle is opened, the piston is forced into the pumping chamber and pressure builds up. The inlet valve is forced closed and the outlet valve opens to permit the charge of fuel to be injected into the carburetor barrel.

The accelerating pump discharge jet is vented to the air horn through the air bleed during normal carburetor operation. This prevents the venturi vacuum from using the jet as another discharge nozzle. The bleed check valve seals off the bleed passage when the charge of fuel is being delivered from the accelerating pump.

THE CHOKE

There is one more important system to add to our simple carburetor, and that is the choke system. The **choke valve** (Fig. 33) is another butterfly valve lo-

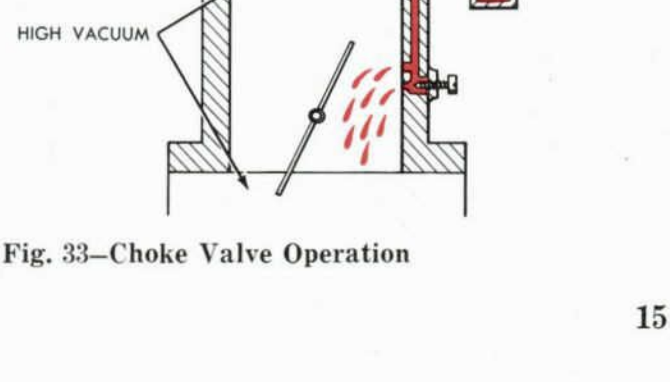


Fig. 33—Choke Valve Operation

cated in the air horn. The purpose of the choke system is to provide a very rich mixture for cold starting and warm-up.

When you start a cold engine, the less volatile gasoline components that vaporized in the carburetor condense to liquid again in the cold manifold. Unless the mixture is richened with more fuel, the slow burning of these liquids causes power loss and stalling. But with a rich enough mixture, enough vapor gets to the cylinders for the engine to operate smoothly.

Closing the choke valve closes off the air flow and causes high vacuum in the whole carburetor barrel below the valve. This vacuum pulls fuel out of the main metering system and the idle system. With the very low air flow, of course, the mixture is very rich.

MANUAL CHOKE

In a typical **manual** choke linkage (Fig. 34), the choke **cam lever** is actuated by the **choke cable.** A **pulldown rod** connects the cam lever to the choke shaft through a spring and adjusting nut. When the driver pulls **out** on the choke cable, the cam lever compresses the spring, causing the pulldown rod to close the choke valve.

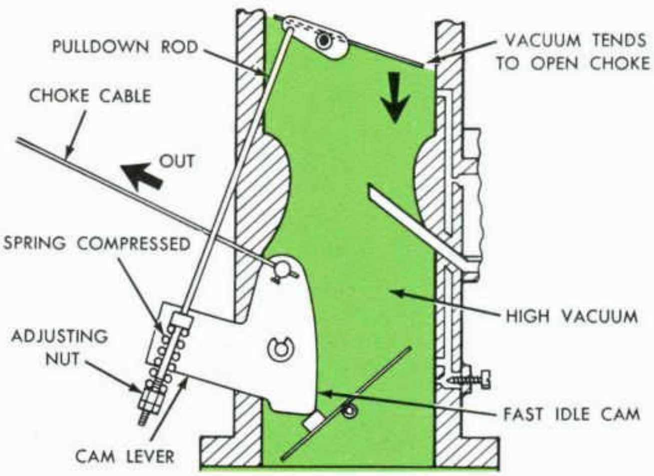


Fig. 34—Manual Choke

The spring is used in this choke system instead of a positive connection to prevent flooding and stalling after the engine starts. As soon as the engine starts, vacuum increases, tending to pull too much fuel from the main and idle discharge openings. Since the choke shaft is off center, engine vacuum tends to open the choke. The spring becomes compressed, permitting the choke to open part way and make the mixture leaner compared to full choke. In some manual choke systems, there is a slot in the cam lever or choke shaft lever to permit the choke to open part way. In other systems, the driver must open the choke manually when the engine starts.

The choke cam lever or a sperarate **fast-idle cam** also actuates the throttle valve to open the throttle slightly at idle. A faster idle speed helps warm the engine quicker and minimizes dilution of the crankcase oil with unburned fuel. It also prevents stalling from overrichness.

AUTOMATIC CHOKE

Automatic chokes are used on most passenger cars today to eliminate the need for the driver to choke a cold engine and push the choke in as the engine becomes warm. The automatic choke (Fig. 35) is controlled by a bi-metal thermostatic spring and a vacuum-actuated piston or diaphragm.

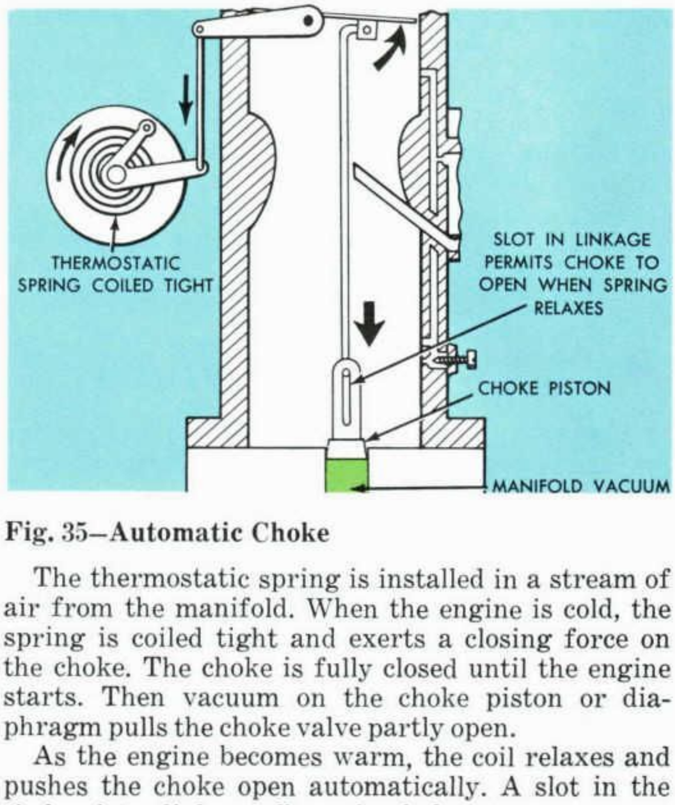


Fig. 35—Automatic Choke

The thermostatic spring is installed in a stream of air from the manifold. When the engine is cold, the spring is coiled tight and exerts a closing force on the choke. The choke is fully closed until the engine starts. Then vacuum on the choke piston or diaphragm pulls the choke valve partly open.

As the engine becomes warm, the coil relaxes and pushes the choke open automatically. A slot in the choke piston linkage allows the choke to open.

MULTIPLE-BARREL CARBURETORS

Multiple-barrel carburetors are used to improve distribution of the mixture to the cylinders. For instance, when a two-barrel carburetor is used on an 8-cylinder engine, each barrel supplies fuel to four cylinders.

A **two-barrel** carburetor (Fig. 36) is two complete carburetors with only the float system in common.

A four-barrel carburetor (Fig. 37) is made up of two two-barrel sections. The primary section is iden-

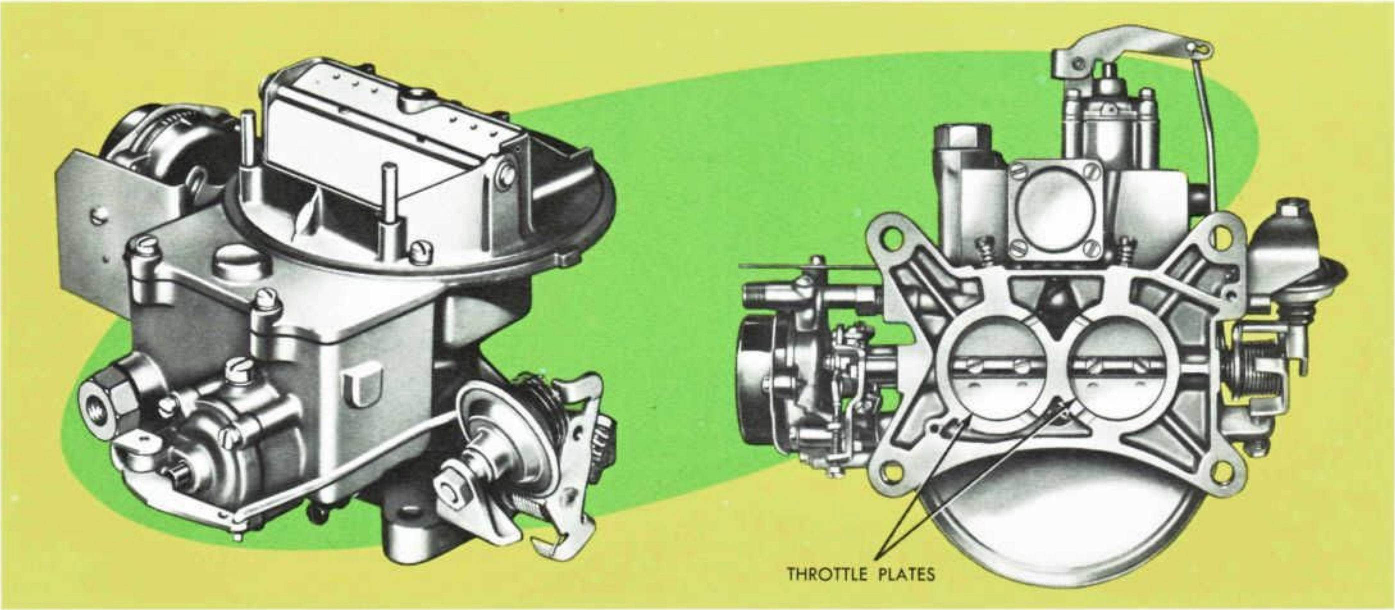


Fig. 36—Two-Barrel Carburetor

tical in operation to a two-barrel carburetor. The secondary section though, operates only when full power is called for; that is, when the primary throttles are wide open. The secondary throttles usually are opened by delayed action linkage from the primary throttles. They can also be activated by air flow from the primary venturis.

The four-barrel carburetor provides more power through better breathing at high speeds. But there's no sacrifice of economy at low speeds.

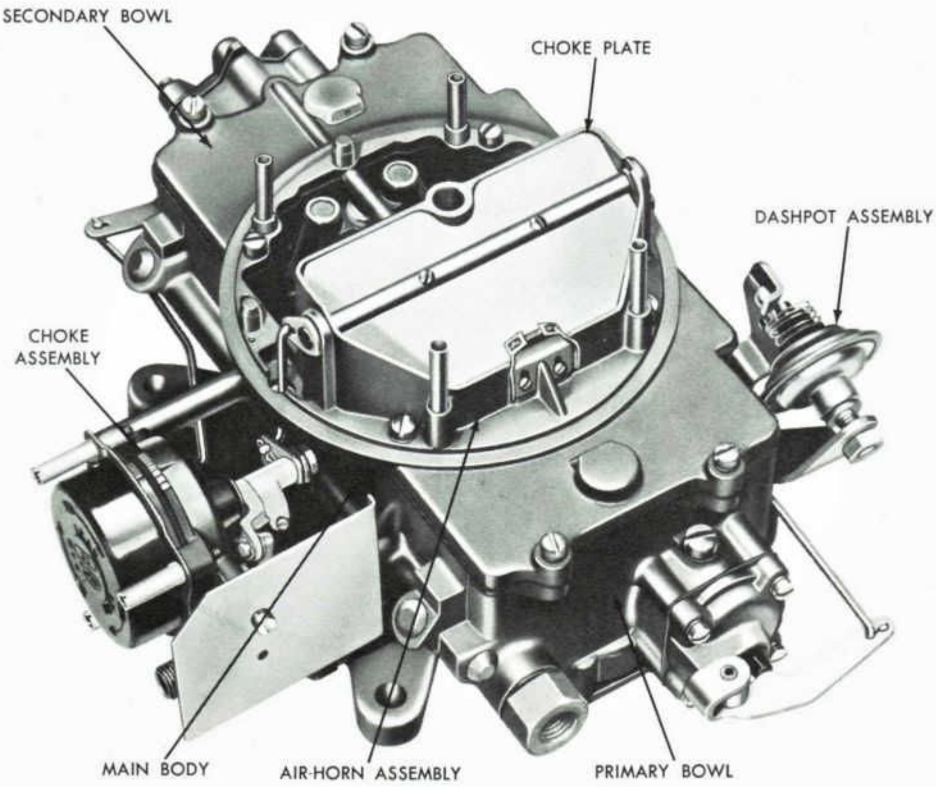
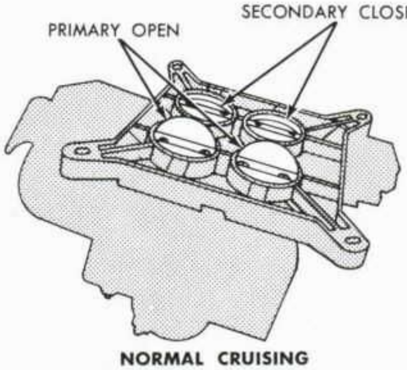
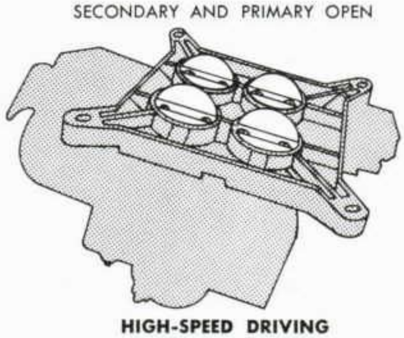


Fig. 37—Four-Barrel Carburetor



NORMAL CRUISING



HIGH-SPEED DRIVING

CARBURETOR ACCESSORIES

Besides its function of supplying the correct air-fuel mixture for various operating conditions, the carburetor has some auxiliary equipment to control other parts of the vehicle operation. These include a dashpot (Fig. 36) to prevent stalling by slowing the throttle closing on automatic-transmission-equipped cars, and a vacuum connection for the automatic low-speed spark advance. Provisions also are made for vacuum control of engine governors and enrichment on deceleration to prevent backfire on truck engines.

AIR CLEANERS

Some type of air cleaner or filter is used on all automotive carburetors to keep dirt and dust out of the cylinders. Both dry-type paper filter elements (Fig. 38) and oil bath air cleaners (Fig. 39) are used.

Air is taken into the cleaner, passes through the filtering medium and is discharged into the air horn.

The air cleaners affect engine operation to the extent that they restrict the flow of air. The effect is the same as choking. A clogged filter can cause very poor economy because of operating with a rich mixture, or even prevent the engine from operating by blocking air flow. A balanced carburetor (page 13), of course, minimizes the effects of a partially clogged air cleaner.

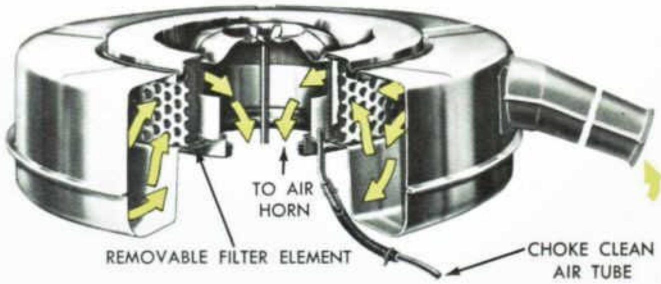


Fig. 38—Typical Dry-Type Air Cleaner

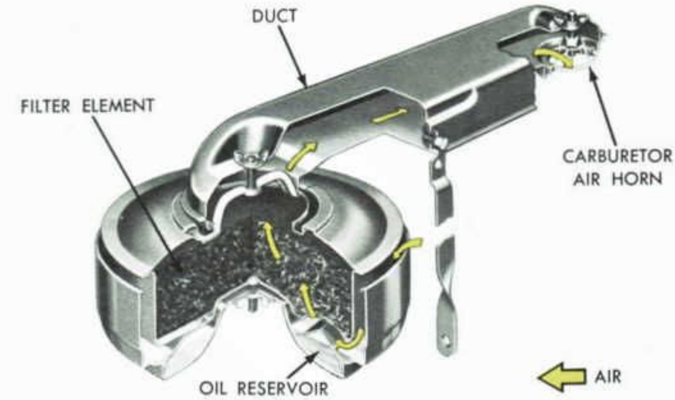


Fig. 39—Typical Oil Bath Air Cleaner

GOVERNORS

A governor, as used on a gasoline engine, is a device that limits the top speed of the engine. Limiting the engine's top speed prevents operating the vehicle at gas-guzzling gear-speed combinations and extends the life of the engine. It also has the salutary effect, on some high-performance and truck engines of preventing the damage that could result from operating at too high an rpm.

There are three types of governors used on Ford vehicles—velocity, mechanical and vacuum. The velocity governor is the least accurate and is used where maintaining the governed speed setting exactly isn't critical. For more precise control, we have the mechanical and vacuum governors which operate by centrifugal force and are highly sensitive to changes in rpm.

VELOCITY GOVERNOR

The velocity governor (Fig. 40) is sensitive to the velocity of the air-fuel mixture rather than to engine speed. This governor is installed between the carburetor and the intake manifold, and has a spring-

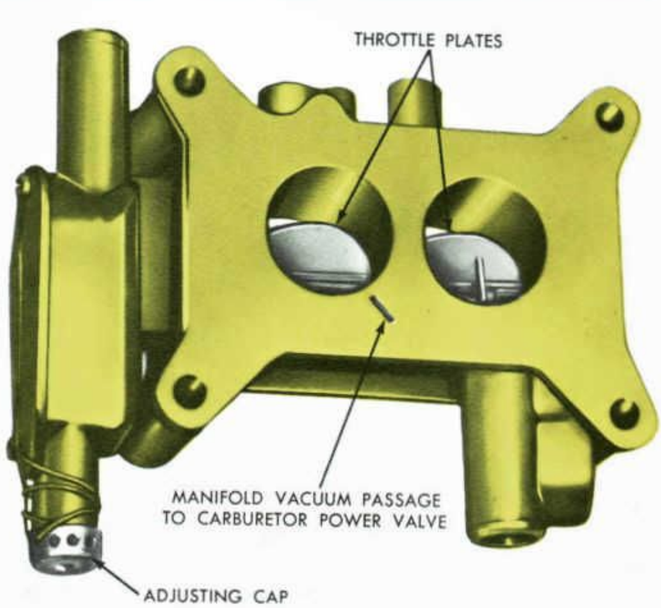


Fig. 40—Velocity Governor for Two-Barrel Carburetor

loaded throttle valve (or valves in multi-barreled units) that governs engine speed by restricting the flow of mixture to the manifold.

SPRING OPPOSES CLOSING

The governor throttle valve is constructed with the throttle shaft off center (Fig. 41). About three-fourths of the valve area is exposed to the force of the air-fuel mixture. Striking the governor valve, the mixture tries to close it and cut off flow. The closing action is opposed by the governor spring which is

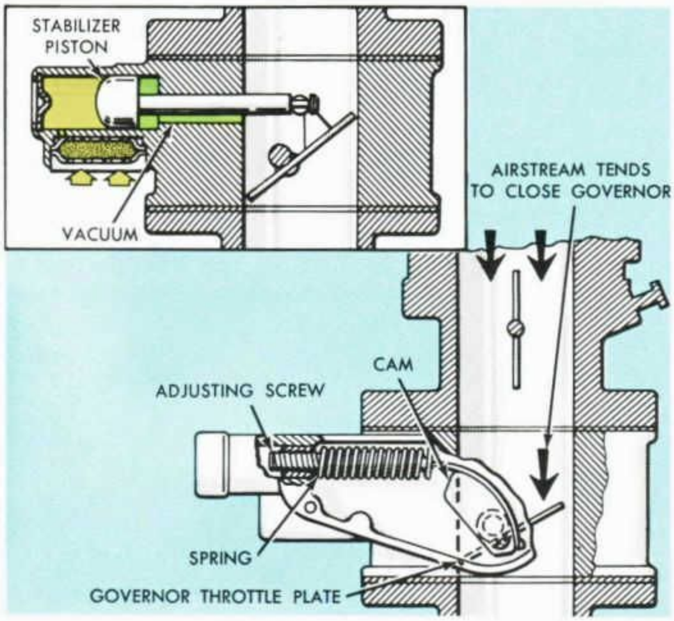


Fig. 41–Velocity Governor Operation

adjustable. The spring tension thereby determines the point at which the valve plate closes–in other words, the mixture velocity at which the governor regulates.

CAM MAINTAINS BALANCE

As the valve closes, more valve area is exposed to the mixture, resulting in an increased closing force. A cam on the governor throttle shaft turns with the throttle valve and increases spring tension as the valve closes. The increased spring tension maintains the balance between closing force and opening force. This way, as engine speed and air flow increase to the governed limit, the throttle maintains a partly closed position to restrict the flow of mixture without cutting it off entirely.

STABILIZER (ANTI-CHEAT) PISTON

A vacuum - operated stabilizer or "anti - cheat" piston (Fig. 41) connected to the throttle plate, prevents the operator from getting around the governor by throttle manipulation. Without the stabilizer, it would be possible to manipulate the carburetor throttle to create a high vacuum above the governor throttle valve and pull it open. Any vacuum above the governor throttle acts on the stabilizer piston to push the governor partly closed.

Idle Operation

At idle, of course, vacuum will be high in the governor barrel and will cause the stabilizer piston to close the governor partly. But the carburetor throttle is closed too, and the governor doesn't unduly restrict flow in this condition.

POWER FUEL SUPPLY VACUUM BYPASS

A drilled passage through the governor body (Fig. 40) supplies manifold vacuum to operate the carburetor power fuel supply when the governor is regulating. A closed governor would otherwise block off vacuum under the carburetor throttle which normally operates the power fuel supply valve or metering rod.

DISTRIBUTOR VACUUM SUPPLY

When the vehicle has a vacuum advance distributor, the velocity governor will have a vacuum transfer valve (Fig. 42) with provision for supplying distributor advance vacuum either from the carburetor or the governor, depending on the operating condition.

With the carburetor throttle controlling engine

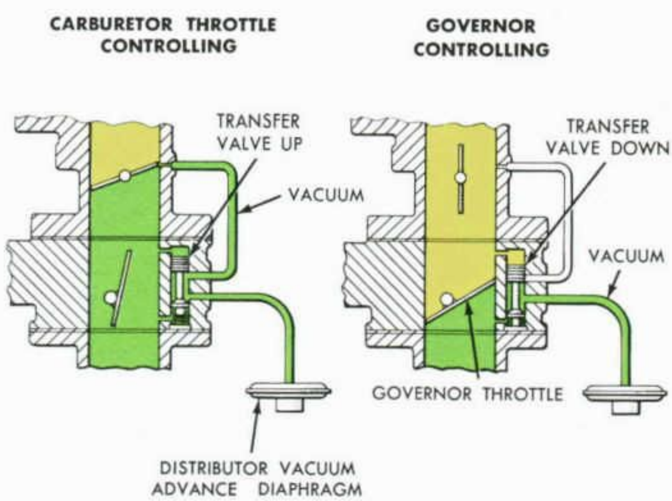


Fig. 42–Vacuum Transfer Valve

speed (left view Fig. 42), vacuum is balanced on both ends of the transfer valve. So the transfer valve **spring** holds the valve up and the carburetor supplies distributor vacuum–just as though the governor wasn't there. But when the governor begins to control (right view Fig. 42), we have a high vacuum under the governor throttle with near atmospheric pressure on top of the transfer valve. This pressure difference moves the transfer valve down so that it cuts off the passage from the carburetor and opens a vacuum passage from the governor to supply the distributor.

MECHANICAL GOVERNOR

A mechanical governor (Fig. 43) senses engine speed through centrifugal force on two weights. It is mounted remotely from the carburetor, and has a mechanical connection to the carburetor throttle which overrides the accelerator when the governed speed is reached.

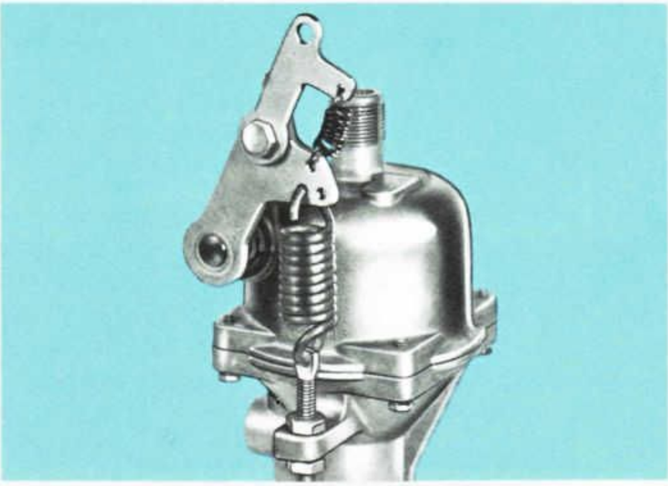


Fig. 43–Mechanical Governor

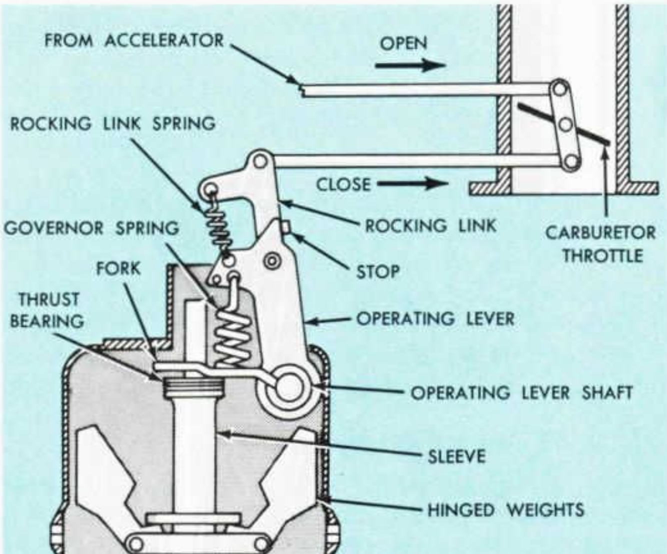


Fig. 44–Mechanical Governor Operation

In the mechanical governor used on Ford trucks (Fig. 44), two revolving **weights** are hinged on the **governor shaft,** which is driven off the engine camshaft. As centrifugal force on the weights pulls them outward, they bear against a sliding **sleeve** and cause the sleeve to move upward.

GOVERNOR FORK MOVES OPERATING LEVER

As the sleeve moves upward, it actuates the **governor fork** through a thrust bearing. Movement of the fork in turn actuates the **governor operating lever** in opposition to the **governor spring.** The balance of forces between the governor spring and the centrifugal force on the weights determines the position of the governor operating lever.

CLOSES THROTTLE

The operating lever is linked to the carburetor throttle shaft and closes the throttle partly as the governed speed is reached. Then if the engine tends to speed up, centrifugal force on the weights moves the operating lever to close the throttle more and decrease speed. Or, if the engine tries to slow down (while the driver still has a heavy foot on the accelerator), decreased centrifugal force permits the throttle to open farther.

The tension of the governor spring is adjustable so that the governor can be set to operate at a different speed.

ONE-WAY CLUTCH

A one-way clutch (Fig. 45) is built into the linkage from the accelerator to the throttle shaft. This clutch permits the driver to select any accelerator position without resistance from the governor, regardless of engine speed. The governor simply overrides the accelerator control when the governed speed is reached. Thus, the driver can hold the accelerator on the floor, and the governor will automatically maintain the governed speed. If the engine load changes as the

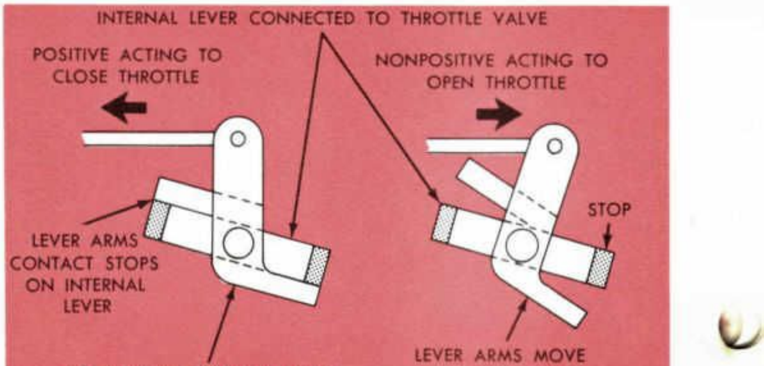


Fig. 45–Accelerator Linkage One-Way Clutch

vehicle goes up and down hill, the governor automatically adjusts the throttle opening. Of course, the governor will **not** prevent the vehicle from running away on a steep downgrade, any more than closing the throttle would normally.

ROCKING LINK AND SPRING

With the one-way clutch in the throttle linkage, the accelerator has positive control of the throttle in closing it only. When the accelerator is depressed, it can only **permit** the throttle to open. The actual opening up to governed speed is caused by the tension of the **rocking link spring** (Fig. 46) on the governor operating lever. This spring maintains a constant **opening** tension on the throttle anytime the governor **isn't** regulating. The spring, then, opens the throttle when the accelerator pedal is depressed. When the pedal is released, the spring is overcome by the throttle return spring. The rocking link "breaks" to permit the throttle to close.

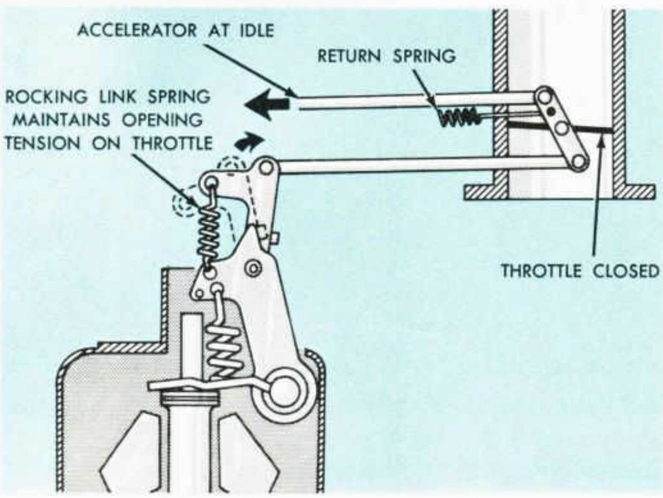


Fig. 46–Rocking Link Breaks at Closed Throttle

VACUUM GOVERNOR

The vacuum governor (Fig. 47) also senses engine speed by centrifugal force on a spring-loaded weight. A vacuum diaphragm is actuated when the governed speed is reached, and the diaphragm overrides the accelerator, through a one-way clutch, to close the throttle.

AIR-BLEED VALVE

Movement of the diaphragm is controlled by the centrifugal air-bleed valve, which consists of a weight, an adjustable spring and an air entrance port (Fig. 48). The valve is housed in a rotor driven by the distributor shaft.

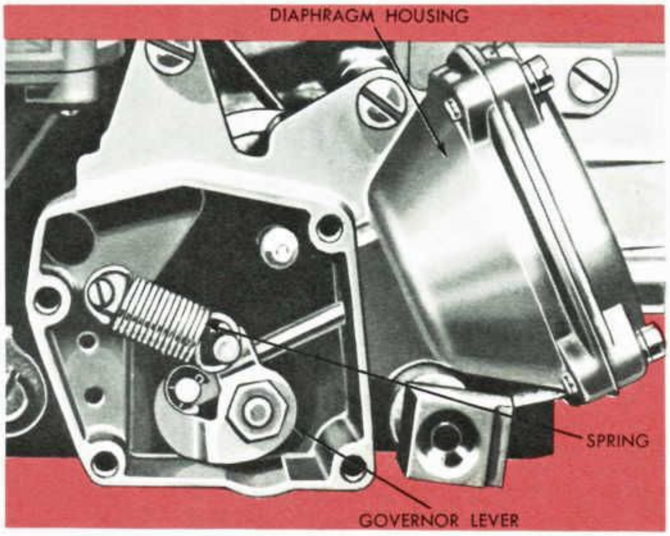


Fig. 47–Vacuum Governor

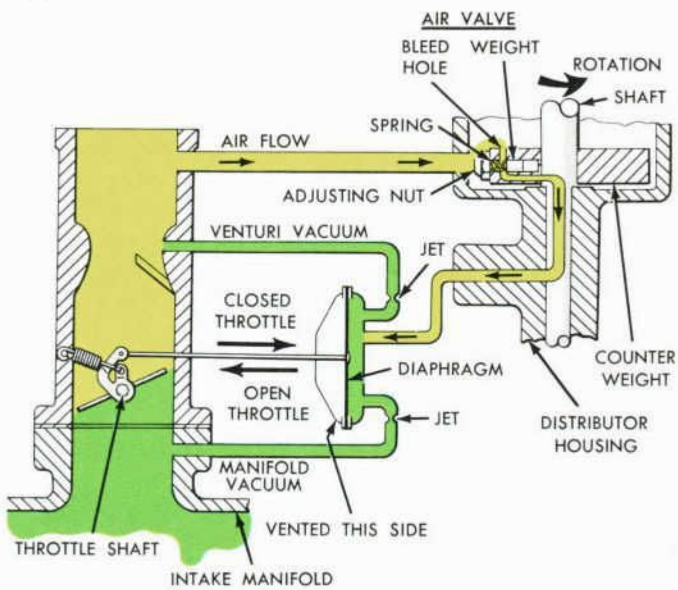


Fig. 48–Vacuum Governor Operation

Below governed speed, the spring holds the governor weight in and leaves the air entrance port uncovered. Filtered air from the carburetor flows through the valve to the diaphragm. The diaphragm is actuated only by vacuum, so it remains stationary and the accelerator controls the throttle position. The governor spring pulls the throttle open when the accelerator is depressed and is overcome by the throttle return spring when the accelerator is released.

WEIGHT COVERS PORT

When the governed speed is reached, centrifugal force on the weight overcomes the force of the valve spring and the weight begins to cover the air entrance port. As the port is covered, vacuum from the carburetor venturi and the intake manifold is sensed at the diaphragm. The diaphragm then pulls the throttle closed against the governor spring.

The throttle position now depends on the balance between governor spring force and diaphragm force. If the engine tends to speed up, the air valve closes off more, so that vacuum builds up higher and the diaphragm exerts more closing force. If the engine slows, the air valve decreases vacuum and the diaphragm exerts less closing force.

VACUUM JETS

Vacuum is supplied to the diaphragm through two calibrated restrictions or jets to compensate for changes in engine manifold and venturi vacuum. The governor will regulate at different throttle openings, depending on engine load. With more throttle opening, manifold vacuum is lower and venturi vacuum is higher. With less throttle opening, the reverse is true. The jets are calibrated, then, to maintain a balanced vacuum so the governor balance isn't changed as the throttle position changes.

FUEL CHARACTERISTICS

To understand exactly what goes on, and why, in the fuel system, it helps to understand the fuel itself. So in this section, we'll explain what the composition of gasoline is, how it's produced and behaves, and what the factors are that affect efficiency and power output in the combustion chamber. We'll mention other fuels in passing, but confine the story principally to gasoline.

WHAT IS GASOLINE?

It isn't possible to write down a specific chemical formula and say, "this is gasoline." Gasoline is not a single compound, but it is a mixture of many compounds known as hydrocarbons. A hydrocarbon is a chemical compound of the elements hydrogen and carbon. There are many thousands of hydrocarbons, and every batch of gasoline has different ones depending on the crude oil it came from and the refining processes it went through.

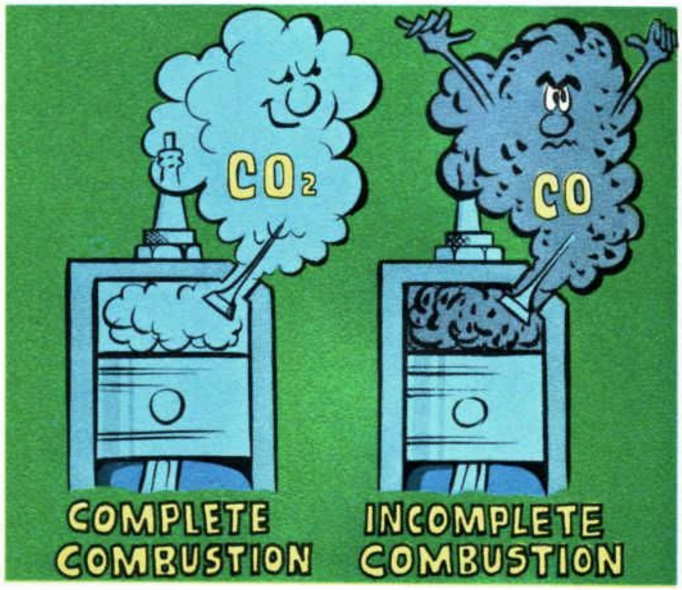
We could most easily define gasoline as a mixture of the lightest or most volatile **liquid** hydrocarbons found in crude petroleum oil. This is not a comprehensive definition, but will do to start us into the chemistry of combustion and refining of gasoline.

ALL ABOUT COMBUSTION

CHEMISTRY OF COMBUSTION

Combustion is a rapid chemical reaction that releases large quantities of heat and is accompanied by flame. In an internal combustion engine, a petroleum fuel composed of hydrocarbons is mixed with air and ignited. The burning is the chemical reaction between the oxygen in the air and the hydrogen and carbon in the fuel.

Carbon and oxygen combine to form carbon dioxide (CO_2) if the fuel burns completely or carbon monoxide (CO) if combustion is incomplete. Hydrogen and oxygen combine to form water (H_2O). Nitrogen, the other principal component of air doesn't enter into the reaction.



The heat created by combustion causes these gases in the combustion chamber to expand, creating a very high pressure. The pressure becomes a downward force on the piston, and the force is converted to rotating power at the crankshaft (Fig. 49).

How much power we get to the crankshaft depends on the initial heat content of the fuel and the thermal efficiency of the engine.

THERMAL EFFICIENCY

The **thermal efficiency** of an engine is equal to the heat energy output divided by the heat energy input.

Suppose that a pound of fuel contains 20,000 Btu's of heat energy. If the fuel burned completely and all the available heat energy was converted to work, we would say that the engine's thermal efficiency was 100 percent. Actually the thermal efficiency of a gasoline engine averages more in the nature of 25 percent. In

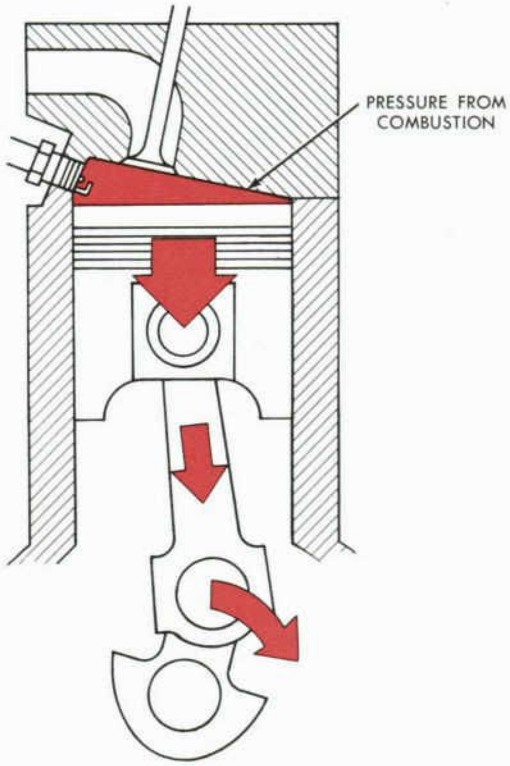


Fig. 49—Combustion Pressure Becomes Rotating Power

this example, 25 percent or 5,000 Btu's would be converted to work; the other 15,000 Btu's going out the exhaust or cooling system.

$$\textbf{Efficiency} = \frac{\textbf{Energy Output}}{\textbf{Energy Input}} = \frac{\textbf{5000 Btu}}{\textbf{20,000 Btu}} = \tfrac{1}{4} = 25\%$$

With a rich mixture—not enough oxygen to burn the fuel completely—less of the available heat is released, so thermal efficiency is lower than with a mixture lean enough to burn all the fuel.

COMPRESSION RATIO AND EFFICIENCY

When gasoline engines began to be used extensively, it didn't take long to discover that increasing the compression ratio resulted in better efficiency. Engineers found that when a pressurized fuel-air charge is burned, the compression pressure approximately quadruples after ignition.

For instance, if we start with a compression pressure of 100 psi, as in a low-compression gasoline engine, the pressure after combustion is about 400 psi. In a high-compression gasoline engine (10:1 ratio), the initial compression is over 200 psi and the combustion pressure is over 800 psi. In each example, the engine has to do some work to compress the mixture. But in the high-compression engine, the net gain is much greater.

	LOW COMPRESSION ENGINE		HIGH COMPRESSION ENGINE	
	Pressure	Force on 3″ Piston	Pressure	Force on 3″ Piston
Combustion Pressure	400 psi	2800#	800 psi	5600#
Compression Pressure	100 psi	700#	200 psi	1400#
Net Gain	300 psi	2100#	600 psi	4200#

Of course, these are not exact figures. But they do illustrate the point that the high-compression engine gets a lot more kick out of the fuel charge. Less of the heat energy is wasted then, so the high-compression engine is more efficient.

Engine compression ratios, accordingly, have been creeping upward since this discovery was made; limited only by the tendency of the fuel to **detonate** as compression is increased.

DETONATION

Detonation or "knock" or "ping" is a condition where a portion of the mixture explodes during combustion. It is caused by a rapidly burning flame-front compressing the unburned part of the mixture to the

point of self-ignition.

Normally, combustion begins at the spark plug and the flame spreads out rapidly through the combustion

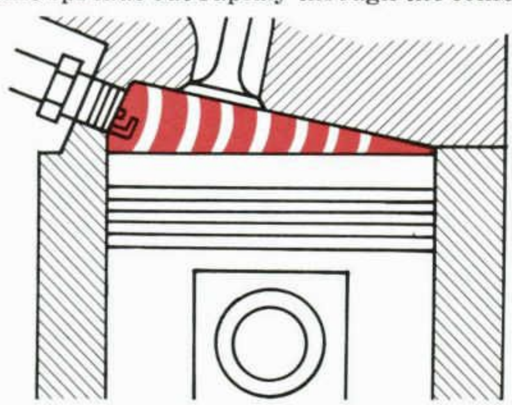


Fig. 50—Normal Combustion

chamber, burning the fuel evenly and smoothly (Fig. 50). Of course, the unburned part of the mixture is being heated and compressed by the burning part. If the heat and pressure become too great, the unburned

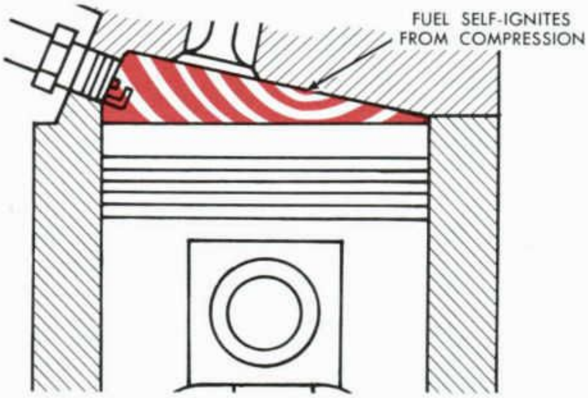


Fig. 51—Detonation

mixture "self-ignites" at another point (Fig. 51).

Being under greater compression, this part of the mixture has a real kick when it burns. In fact, it explodes rather than burning evenly. The effect is a severe impact on the piston instead of the smoothly increasing pressure of normal combustion.

Several factors can contribute to detonation or knock, besides high compression. Carbon deposits, of course, increase compression and induce knock from hot spots. Cooling system defects, lean mixtures and too much spark advance also contribute to knock. It's easy to see, therefore, why detonation has also been referred to as "spark knock" and "carbon knock."

In the 1920's, two important facts about detonation were discovered.

1. The kind of hydrocarbons in the gasoline has a definite effect on detonation tendencies. In other words, some kinds of hydrocarbons are prone to self-ignition; others are much less liable to cause knock.
2. Certain additives, such as tetraethyl lead, will reduce detonation, or increase the gasoline **anti-knock qualities.**

Methods were devised soon afterward to rate the anti-knock qualities of a fuel. The standard for rating fuels today is known as **octane number,** which is based on the anti-knock quality of a hydrocarbon called **iso-octane.**

OCTANE RATING

Nearly everyone knows that the premium gasolines required for high-compression engines are referred to as high-octane fuels, while regular gasoline is considered to be low octane.

The **octane number** of a fuel is determined by comparing it with a mixture of **iso-octane** and **heptane.** Pure iso-octane, which has a high resistance to knock, is assigned an octane number of 100. Pure heptane detonates severely in all but the lowest-compression engines, and is assigned an octane number of zero.

Unknown fuels are tested in engines in laboratories and the knock intensity is measured on a **knockmeter.** This intensity is compared with the knock intensity of various proportions of iso-octane and heptane. If, for example, the fuel registers the same knock intensity as a reference mixture of 90 percent iso-octane and 10 percent heptane, that fuel has an octane rating of 90, regardless of its actual composition.

PERFORMANCE NUMBERS

The performance number system was devised to express anti-knock qualities higher than 100 octane and also to relate fuel quality to engine output. Performance numbers are in direct proportion to engine output, assuming corresponding increases in compression ratio.

Performance Number	Octane Number
40	58
50	72
60	81
70	88
80	93
90	97
100	100
110	–
120 etc.	–

CRUDE OIL

The crude oil we take from the ground contains thousands of hydrocarbons mixed together. The mixture can contain substances like methane or propane which are vapors at normal temperature; octane which is a liquid component of some gasolines; and substances like asphalt and paraffin which are very thick liquids. In fact, we often find some solid hydrocarbons dissolved in the liquid oil.

The first step in refining petroleum, then, consists of separating these many hydrocarbons into groups by weight, or volatility. This step is called **fractioning.**

FRACTIONING

In the fractioning process, the crude oil is heated, under pressure, to temperatures around 800 degrees, and is discharged into the **bubble tower** or **fractionator** (Fig. 52). Here the pressure is released, and all but the heaviest components or **fractions** immediately vaporize and rise in the tower.

The tower consists of a number of "trays", one above the other. As the vapor rises in the tower, the

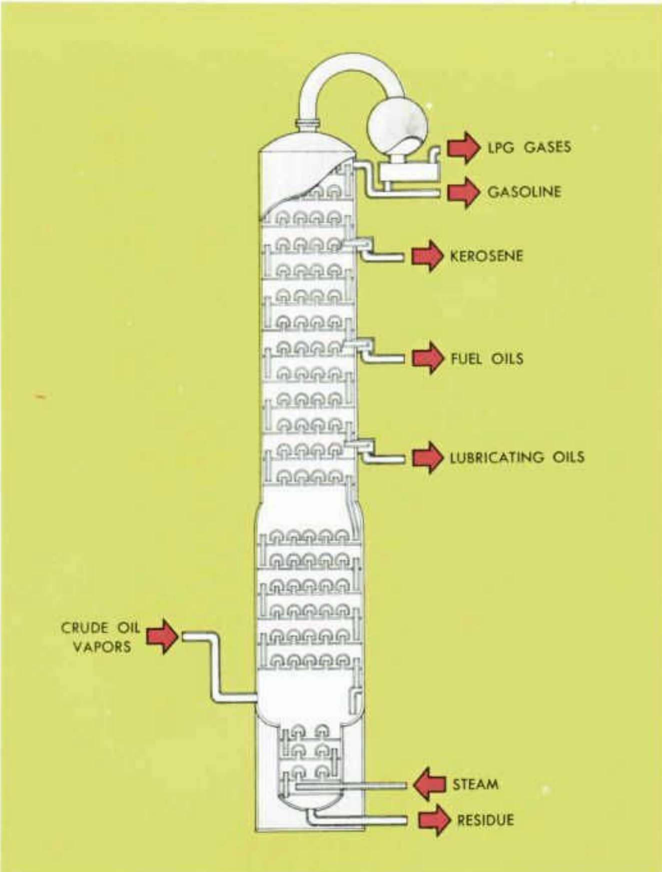


Fig. 52—Fractioning in a Bubble Tower

fractions one-by-one reach a level where it's cool enough for them to condense. As the fractions condense, they are collected in the trays. The more volatile the hydrocarbon, the higher it rises in the tower before condensing.

Lubricating oils and other heavy petroleum products collect in the lowest trays. Then come heavy fuel oils and light fuel oils, followed by kerosene. The gasoline components collect near the top of the tower. Some very light components, such as methane and propane are collected, still in a gaseous form, at the top. A condenser at the top of the tower liquifies any gasoline components remaining in the vapor, so as to separate them from the petroleum gases.

STRAIGHT-RUN GASOLINE

The gasoline which is removed from the bubble tower is referred to as **straight-run** gasoline. Early in the history of the gasoline engine, straight-run fuel was produced in large enough quantities to satisfy the demand. However, this situation changed shortly before World War I. About the same time, it became evident that many straight-run fuels weren't high enough in anti-knock quality as compression ratios began to climb. So other refining processes were developed to increase the gasoline yield and to improve octane rating. These basic processes are:

- **Cracking**—making gasoline out of heavier components.
- **Polymerization**—making gasoline out of lighter components.
- **Reforming**—making gasoline out of gasoline

The first two processes are concerned with increasing the gasoline yield from a quantity of crude oil, though better octane rating is also a benefit of these processes. Reforming is principally a process to improve anti-knock quality.

CRACKING

Cracking can be described simply as making little ones out of big ones. The molecules of the heavy hydrocarbons with high boiling points are broken into the smaller molecules of more volatile hydrocarbons.

Cracking is accomplished by subjecting the petroleum to temperatures approaching 1000 degrees Fahrenheit and pressures around 1000 psi. Of course, the molecules don't break right in the middle as in Fig. 53, but they are broken into lighter components. After cracking, the petroleum is again put through the fractioning process.

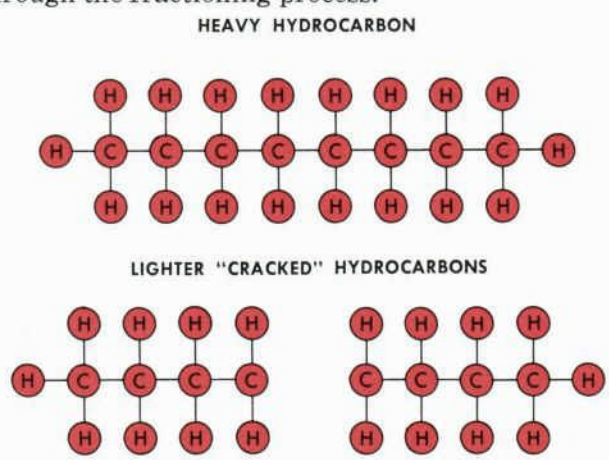


Fig. 53—Cracking

POLYMERIZATION

Polymerization is the reverse of cracking. It consists of combining two or more gaseous hydrocarbons to form a liquid in the gasoline range.

Polymerization was developed more to prevent wasting the light gases produced in the refining process. Today, liquefied petroleum gases (LPG) are so widely used that this is no longer a problem. Propane and butane, for instance, are widely used in internal combustion engines, for many industrial applications, and as the base for many commercial chemicals.

REFORMING

Reforming is converting straight-run gasolines to synthetic hydrocarbons with higher octane quality by rearranging the hydrocarbon molecules. Straight-run fuels contain large proportions of low-octane hydrocarbons. Heat and high pressure alter their makeup, producing higher quality gasoline.

Cracking and polymerization also tend to produce high-octane hydrocarbons from straight-run components.

TYPICAL GASOLINE OCTANE NUMBERS (WITHOUT TETRAETHYL LEAD ADDED)

TYPE	OCTANE
STRAIGHT RUN	55
CRACKED	75-80
POLYMERIZED	80-85
REFORMED	75-80

BENZENE

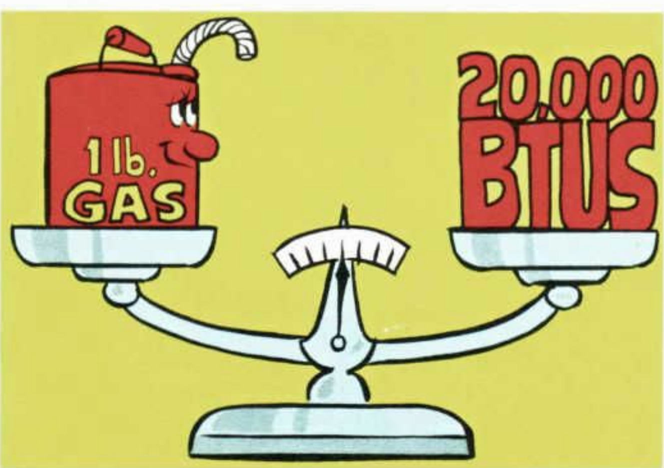
Undoubtedly at some time you've seen fuel pumps marked "Benzene" or "Benzol." Benzene is actually a by-product of coke production, and is sold separately as an engine fuel, or is added to gasoline to increase volatility and octane rating.

We often refer to Benzene as "white gas." Gasolines with tetraethyl lead added are dyed various colors to indicate that they're leaded. Benzene is sold unleaded, therefore has a natural clear color.

GASOLINE QUALITIES

Now, having seen something of the makeup of gasoline and how it behaves in the combustion chamber, we're in a position to discuss the properties or characteristics that make quality motor fuel.

HEAT CONTENT



Most gasolines contain about 20,000 Btu's per pound or 120,000 Btu's per gallon. Of course, if a fuel has a higher heat content, it develops more pressure in the combustion chamber when it burns. The result is better performance and more miles-per-gallon.

GRAVITY

The specific gravity (or A.P.I. gravity) of gasoline is to a degree an indicator of heat content, since low-gravity fuels generally contain more heat-per-pound. However, gravity is seldom mentioned in gasoline specifications today. Btu's per gallon is a more convenient measure of heat content.

OCTANE RATING

Octane ratings of the gasoline you buy have crept up little-by-little to keep pace with increases in engine compression. Today in the midwestern U.S., for instance, regular gasolines are around 94-95 octane with premium gasolines running to 100 octane or higher. This spread of five octane numbers accounts for the price difference of about five cents per gallon between regular and premium fuels. An increase of one octane number seems to be worth about one cent per gallon.

Regular gasolines can be produced easily by present refining methods with anti-knock additives added. Premium fuels require larger amounts of these additives. One major oil company sells gasoline in several different octane ratings by mixing high and low-octane fuel in the gas pump. The low-octane fuel is about 93 octane and the high octane is about 104. The in-between blends are varying mixtures of the two.

Octane requirement varies even in supposedly-identical engines, but it is predictable within limits, taking into consideration the compression ratio and other design and operating factors, such as spark timing and advance, intake manifold temperature and fuel-air mixture.

ECONOMY AND PERFORMANCE

Usually, the most economical fuel for an engine is the lowest grade that runs without detonation or "ping" when the engine is properly tuned. Increased economy and performance can be had with high-octane fuel **only if the engine is designed and tuned to take advantage of it.**

It's a common fallacy that low-compression engines get better performance and economy from premium fuels. The truth is, that if an engine operates properly with regular fuel, it won't get any more kick from high octane without increasing the compression ratio. If the compression ratio remains constant, another fuel can increase power **only** if it has a higher heat content.

VOLATILITY

A good gasoline must be a mixture of components with various boiling points. Some of the components must evaporate readily at low temperature so that the engine can be started easily when it's cold. Then, as the engine begins to warm up, other less volatile components vaporize. Too many highly volatile components can cause vapor lock in the fuel pump or percolation of the fuel. Also, fuel can be lost in storage from evaporation. This lowers the octane, since the more volatile components usually are higher octane.

On the other hand, too many components with high-boiling temperatures will prevent complete vaporization in the carburetor. Fuel is wasted and the crank-case oil becomes diluted.

SULFUR CONTENT

Sulfur is found in most crude oil in varying quantities. It is undesirable in refined gasoline for several reasons. Sulfur combines with combustion products to form corrosive sulfurous acid. It also can cause wear and deposits in the engine. Some other effects are unpleasant odors, decreased chemical stability of the fuel and reduced octane of the fuel because of interference with the anti-knock additives. Where sulfur content runs more than three percent, additional processing is often needed to desulfurize the gasoline. This usually involves special chemical treatment, but in some cases is a fringe benefit of other refining processes.

STABILITY

It's an unfortunate fact that most gasolines contain some hydrocarbons that are chemically unstable. These unstable components tend to **polymerize** or combine to form heavier, gummy hydrocarbons in the fuel system. The result is sticky valves and gumming up of carburetor jets and other parts if the gum isn't removed. Various chemical processes are used to remove the unstable hydrocarbons.

Stability has greatly increased in recent years by chemical treatment, by more care in selecting the crudes gasoline is refined from, and by gum-inhibiting additives.

WATER

Because water vapor is always found in the air, and we must have air in fuel tanks for breathing, it's impossible to keep water out of gasoline. At night when it's cool, moisture condenses out of the air on the inner surface of the tank. Since the water doesn't mix with gasoline, and is heavier, it settles at the bottom of the tank.

Of course, some of this water can get into the carburetor and fuel pump, and combine with sulfur in the fuel to form corrosive acids. Fuel filters and sediment bowls prevent this. Also, keeping the tank full reduces condensation and the possibility of moisture getting beyond the tank.

DE-ICERS

Anti-icing additives are incorporated by most major oil companies in their gasoline to prevent fuel line freeze-up and carburetor icing.

Fuel line freeze-up is usually the result of not servicing the fuel filter or sediment bowl often enough. The accumulated moisture from tank condensation freezes in cold weather and blocks fuel flow to the carburetor.

Carburetor icing is caused by moisture condensing in the carburetor and then freezing. The temperature gets low enough to condense and freeze the moisture because the gasoline vaporizing in the carburetor throat absorbs heat from the metal parts. The ice interferes with the flow of air and the movement of the throttle valve.

The de-icer additives are either anti-freeze solvents, or surface-active agents which coat the ice particles and prevent them from sticking to metal surfaces.

Accelerating Pump—A device to supply a single burst of fuel to the engine when the throttle is opened quickly.

Air-Fuel Ratio—The proportions of air and fuel in the mixture. If the mixture contains 15 parts air and one part fuel by weight, we say the ratio is 15-to-1.

Air Horn—Upper body of a downdraft carburetor through which air enters the barrel (venturi).

Atmospheric Pressure—The pressure on all objects in the atmosphere due to the weight of the air which makes up the atmosphere. Atmospheric pressure at sea level is about 15 psi and decreases as altitude increases.

British Thermal Unit (Btu)—The amount of heat necessary to raise the temperature of one pound of liquid water one degree Fahrenheit. The measure of heat quantity.

1 Btu = 778 pound-feet or 252 calories

Carbon Knock—Detonation caused by carbon deposits increasing the cylinder compression ratio.

Carburetor—The device that mixes fuel and air before the mixture goes to the combustion chambers. A carburetor must measure the fuel accurately, vaporize the fuel, mix the fuel and air in the right proportions, and control the amount of mixture the cylinders receive.

Centrifugal Force—The force on a body revolving about a center that tends to move the body away from the center.

Check Valve—A valve that permits flow in one direction and blocks flow in the other direction (Fig. 54). A one-way valve.

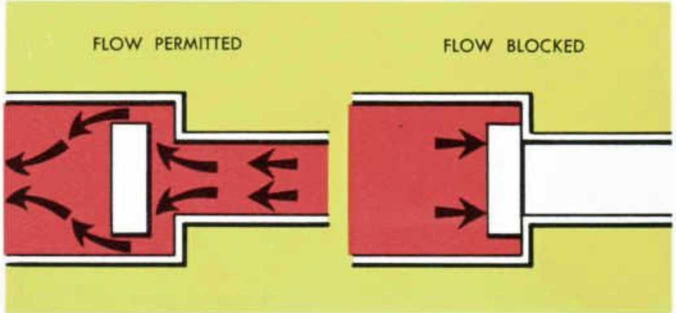


Fig. 54—Check Valve

Choke—A device used with a carburetor to enrich the fuel mixture when the engine is cold. Usually accomplished by reducing or choking off the air supply.

Compression Ratio—The total volume of the cylinder with the piston at bottom-dead-center compared to the volume with the piston at top-dead-center.

Condensation—Changing from a vapor or gas to liquid. Water condensation occurs inside fuel tanks when it gets cool, as at night.

Cracking—Making light gasoline hydrocarbons from heavier hydrocarbons.

Downdraft Carburetor—A carburetor in which the air flows downward to get to the intake manifold.

Eccentric—A disc or wheel set off center so as to change circular motion to back-and-forth motion.

Energy—The ability or capacity to do work. Usually measured in work units (pound-feet), but also expressed in terms of heat energy (Btu's).

Fast Idle Cam—A cam that opens the throttle in the carburetor to increase idle speed when the carburetor is being choked.

Float Valve—A valve that maintains the fuel in the carburetor bowl at the proper level. Controlled by the float.

Fractionator—The "bubble tower" in which crude oil components are condensed in the fractioning process.

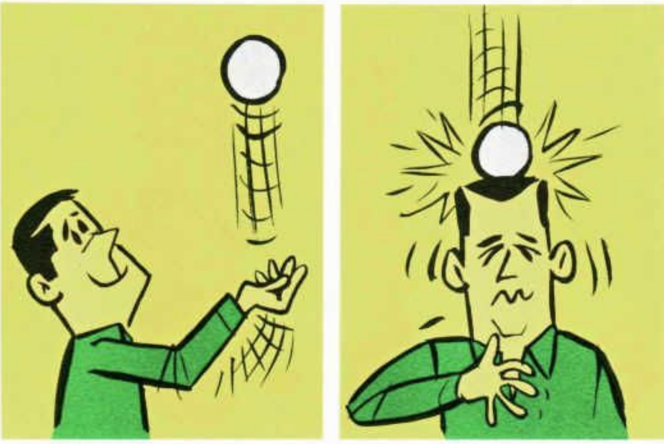
Fractioning—A distillation process for separating crude oil into different weight components.

Fuel Injection—A system in which fuel is sprayed into the cylinder or into the manifold instead of mixing fuel and air in the carburetor.

Gasoline—An engine fuel composed of the more volatile liquid hydrocarbons found in crude oil.

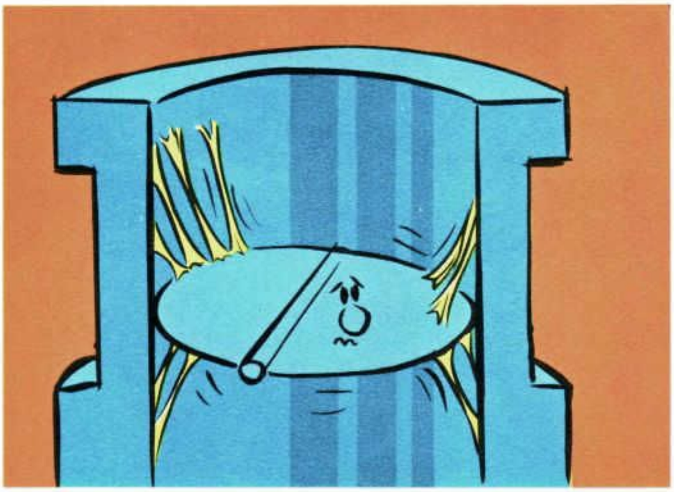
Governor—A device used to limit the amount of mixture an engine receives so as to limit top speed.

Gravity—Weight. The downward force exerted on all objects on or near the earth.



Gravity Feed—A fuel system where the fuel tank is higher than the carburetor so that a fuel pump is unnecessary.

Gum—Sticky substance in the fuel system caused by chemical union of unstable gasoline hydrocarbons.



Hydrocarbon—A chemical compound of the elements hydrogen and carbon.

Jet—A restriction used to control the flow of gasoline. An orifice.

Knock—See Detonation.

Lean Mixture—A mixture with a larger proportion or air than normal, or with more air than is necessary to completely burn the fuel.

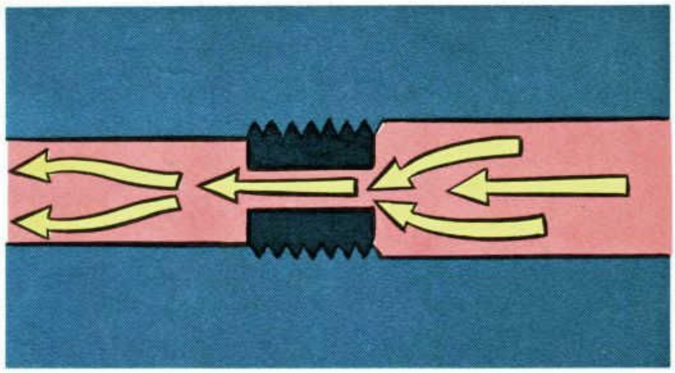
Lift Pump—An automotive low-pressure fuel pump.

Liquefied Petroleum Gas (LPG)—Highly volatile gases, such as Methane and Propane, condensed to a liquid and stored under pressure for use as motor fuels and for industrial and chemical applications.

Metering—Measuring the amount of a fluid; very accurate control of fluid quantity.

Octane Number—A measure of gasoline anti-knock quality based on the detonation properties of iso-octane.

Orifice—A restricted passage in a line carrying a liquid or gas.



Percolation—Liquid bubbles flooding the carburetor venturi throat—caused by vaporization beyond the fuel pump outlet.

Performance Number—A measure of gasoline anti-knock quality based on increased power output as compression increases.

Ping—Detonation.

Power—The rate of doing work, expressed in pound-feet per unit of time. To understand power as opposed to work, think of climbing up a flight of stairs. The work you do is equivalent to the pound-feet necessary to lift your weight the height of the stairs. But it's a lot easier to walk up the stairs than to run up. Running up, you do the work at a faster rate, so you use more power.

Pre-ignition—A condition where the fuel ignites ahead of time from overheating.

Pump—A device used to cause a liquid to flow.

Pressure—Force per unit area or force divided by area. **Pascal's Law** tells us that when a fluid (liquid or gas) is confined, pressure is equal throughout. Pressure is built up in an engine combustion chamber on the compression stroke. The compression pressure is approximately quadrupled (multiplied by 4) when the fuel burns. The pressure increases because the heated gases try to expand. Pressure is measured on several scales (Fig. 55). Any pressure less than **atmospheric** pressure is called a **vacuum.**

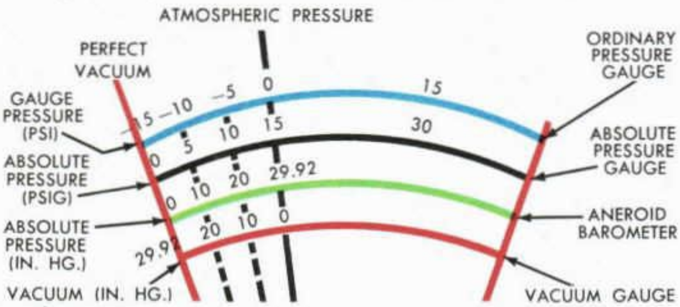


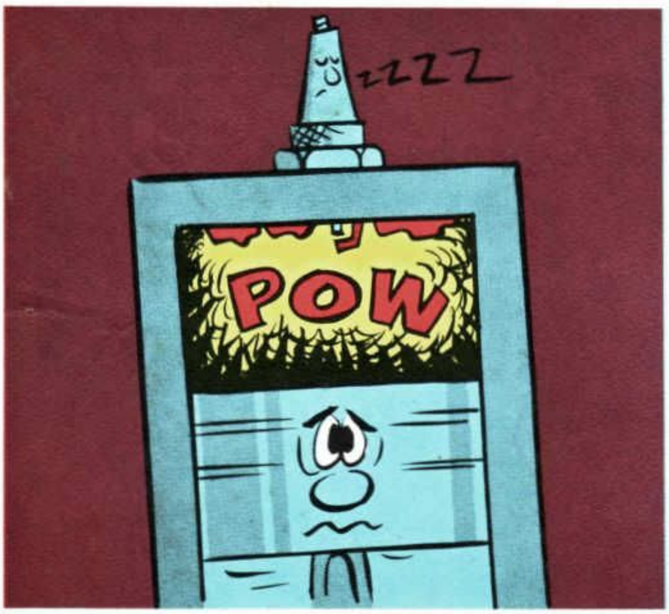
Fig. 55—Pressure and Vacuum Scales

Reciprocate—Move back-and-forth in a straight line.

Reforming—Changing the structure of a gasoline hydrocarbon to improve octane rating.

Rich Mixture—A mixture with a larger proportion of fuel then normal; or with less air than is needed to completely burn the fuel.

Self-ignition—A condition where the fuel ignites from heat concentration rather than from the electrical spark. Detonation and pre-ignition are two kinds of self-ignition.



Spark Knock—Detonation. The term spark knock came from the fact that retarding the spark tends to reduce detonation.

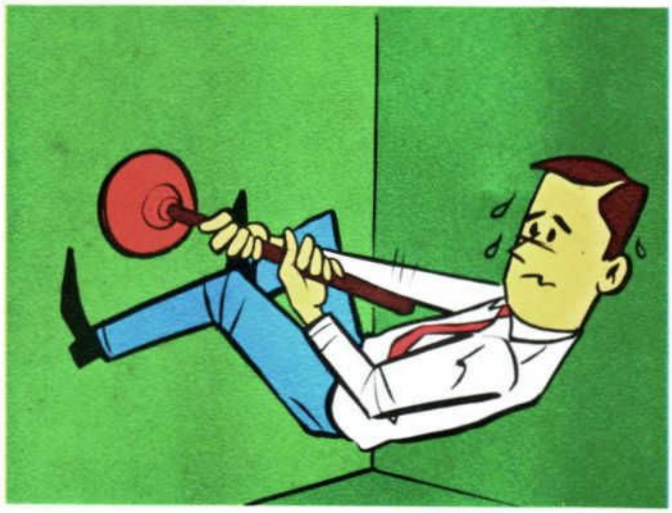
Specific Gravity—The weight of a volume of a substance compared to the weight of an equal volume of water at a specific temperature.

Tetraethyl Lead (TEL)—A chemical compound of lead, carbon and hydrogen used as an additive to increase the anti-knock quality of gasoline. TEL reduces the tendency of the gasoline to self-ignite or detonate.

Thermal Efficiency (of an engine)—The ratio of the number of heat units converted to useful work divided by the total number of heat units released by combustion.

Updraft Carburetor—A carburetor in which the air flows upward to get to the intake manifold.

Vacuum—A condition of pressure less then atmospheric pressure (Fig. 55). Vacuum can be measured in psi, but is more commonly measured in inches of mercury (Hg.). In a perfect vacuum, it is 29.92 inches of mercury at sea level.



Vacuum Booster—An auxiliary pumping unit on a fuel pump used to supply vacuum to operate the windshield wipers when engine manifold vacuum is low.

Vacuum Tank System—A system in which an auxiliary fuel tank is located above the carburetor and fuel is fed to the carburetor by gravity. The fuel is transferred from the main tank to the vacuum tank by manifold vacuum.

Vapor Lock—Condition where the carburetor gets only fuel vapors from the fuel pump. Caused by vaporization in the pump.

Vent—An air opening used to maintain atmospheric pressure in a closed chamber.

Venturi—A restriction placed in a line where a fluid is flowing to reduce pressure.

Volatile—Having a low boiling point.

QUALITY CAR CARE

FORD DIVISION Ford MOTOR COMPANY

FORM FD-7902-1

LITHO IN U.S.A.