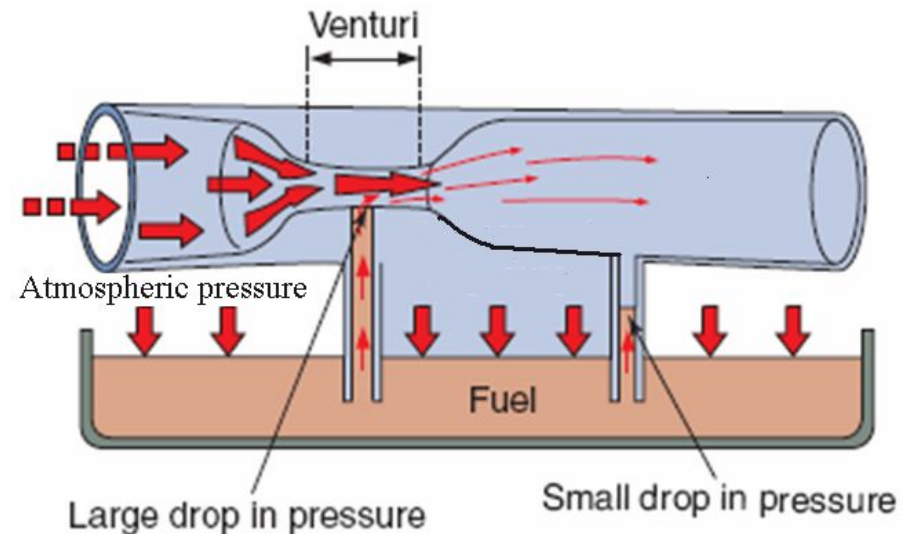


# Internal Combustion Engine

## Fuel Systems

# The carburetors

Aleksey Terentyev



# Aleksey Terentyev

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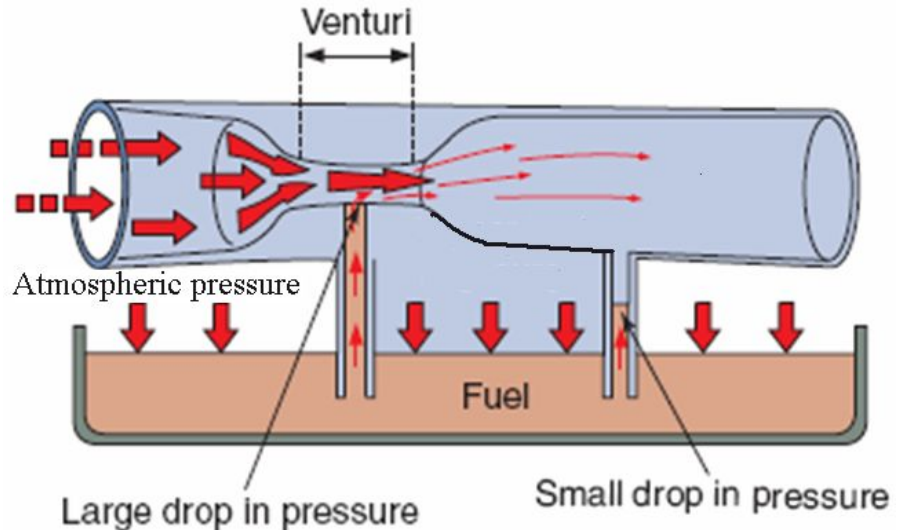
Date of Birth: 30.11.1975

Work experience: from 1999

# The carburetor

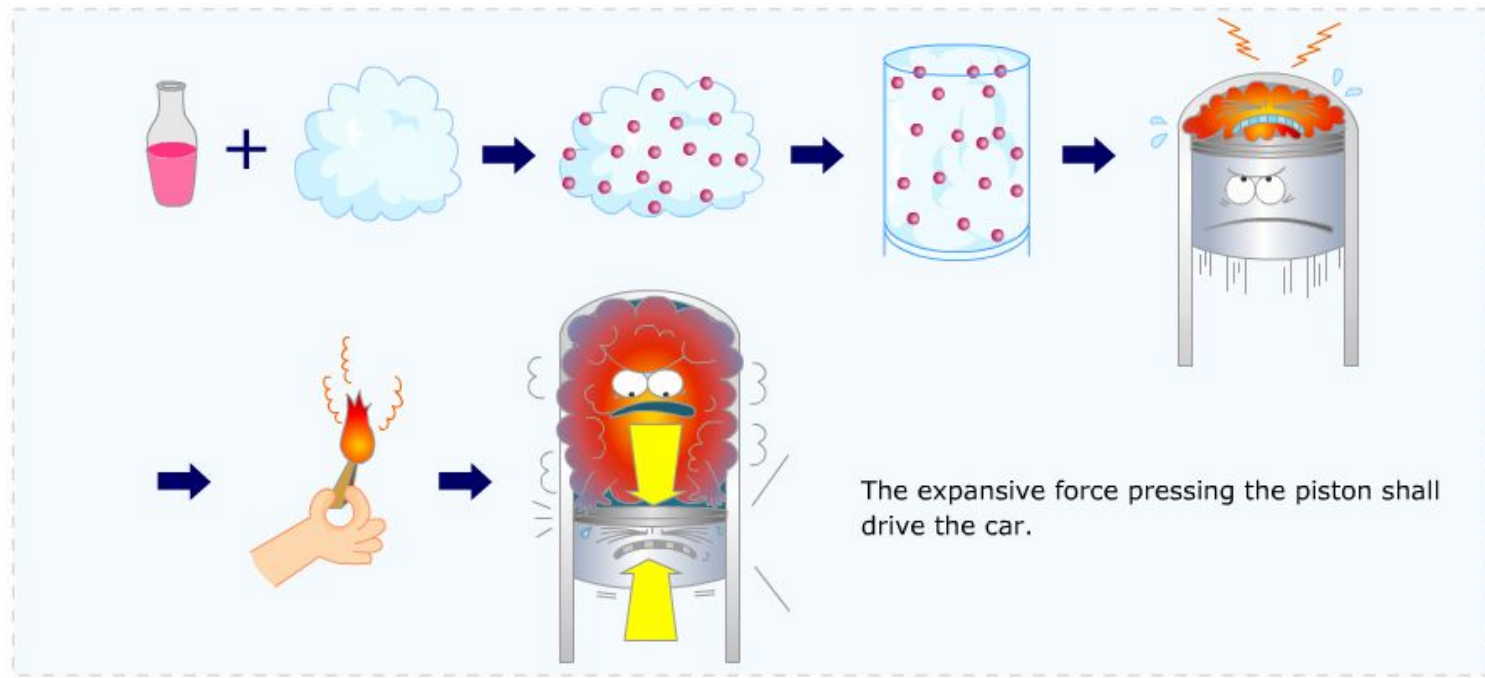
The **carburetor** is a device used to mix proper amounts of air and fuel together in such a way that the greatest amount of heat energy is obtained when the mixture is compressed and ignited in the combustion chamber of the engine.

The function of the carburetor is to mix the correct amount of fuel with sufficient air so the fuel atomizes (breaks up), allowing it to become a highly volatile vapor.



When this vapor enters the combustion chamber of the engine and is compressed by the action of the piston, a spark ignites it, enabling combustion and creating the power to operate the engine.

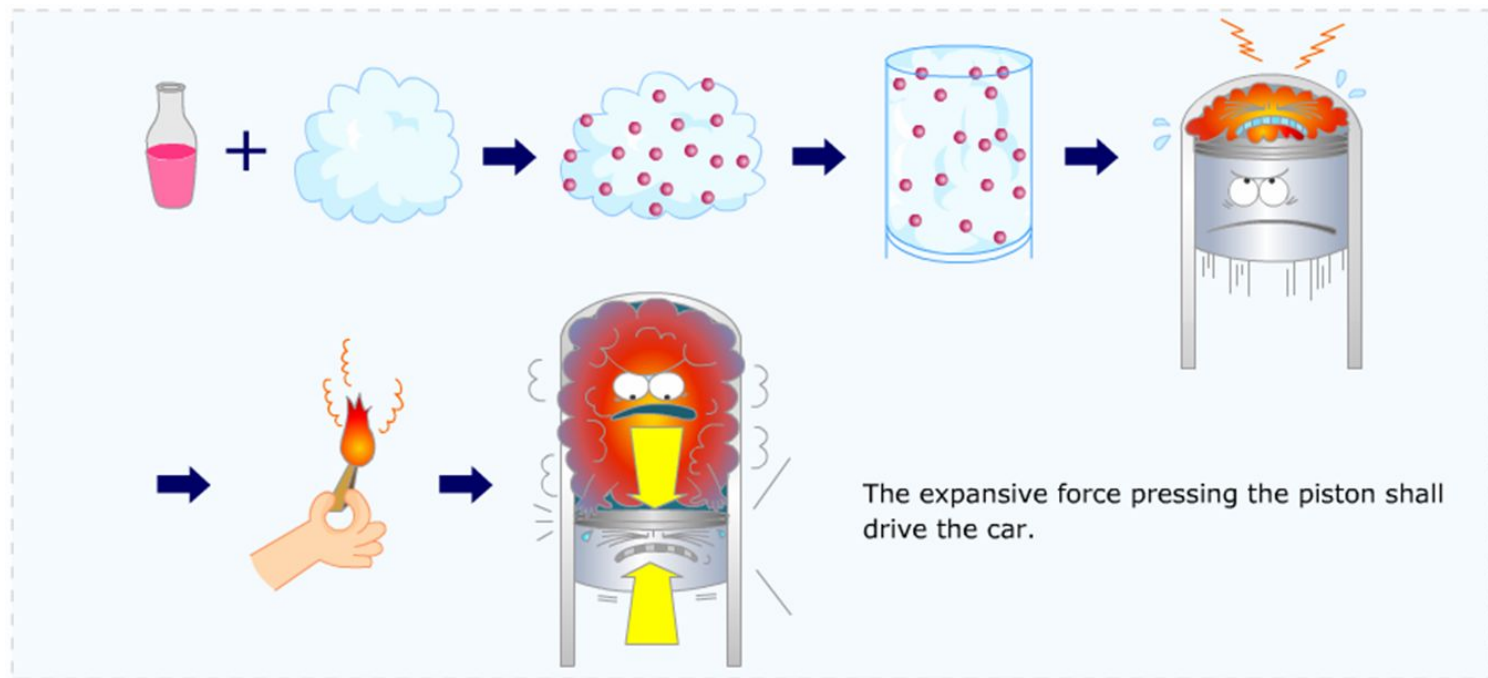
Maximum power from the fuel supplied will be obtained only if exact proportions of air and gas reach the combustion chamber of the engine in vapor form of precisely the right consistency.



When the fuel and air are combined within the engine's combustion chamber, a chemical balance is created, known to be the **stoichiometric ratio**.

A **stoichiometric mixture** is the working point that modern engine designers attempt to achieve in their design of fuel induction systems.

- The term **stoichiometric ratio** describes the chemically correct air-fuel ratio necessary to achieve complete combustion of fuel.



- The ratio of air to fuel in a theoretically perfect stoichiometric mixture is approximately 15:1; that is, the mass of air is 15 times the mass of the fuel. This means that, in a perfect situation, there would be 15 parts of air for each part of fuel.
- Any mixture in which the ratio is less than 15:1 is considered to be a **rich mixture**;
- any mixture in which the ratio is more than 15:1 is considered to be a **lean mixture**.
- It's important to note that this ratio is measured by mass and not by volume.

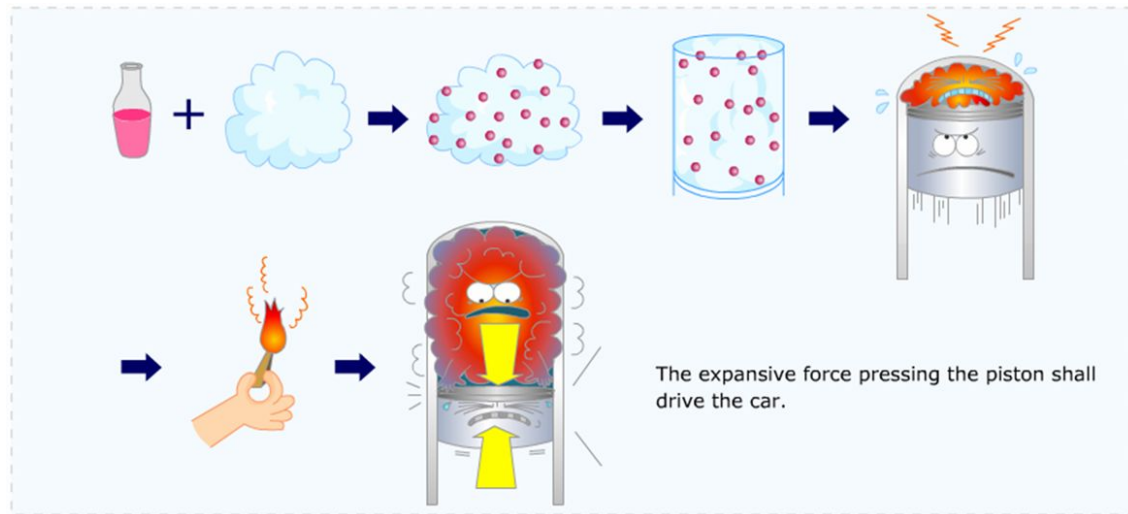


Table lists the proper amounts of air and fuel, with regard to different engine running conditions

**Table 1 Air–fuel mixtures at different engine running conditions**

Engine running condition	Ratio of the air–fuel mixture (mass)
Starting, cold engine	10:1
Accelerating	9:1
Idling (no load on the engine)	11:1
Partly open throttle	15:1
Full load, wide-open throttle	13:1

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Gasoline is a liquid. Oxygen, on the other hand, is a gas and has the ability to burn.

The most efficient combustion of gasoline and oxygen occurs only when they're combined and turned into a vapor from the heat produced by the engine.

This is a delicately balanced mixing process accomplished by the carburetor. Two primary principles are involved in carburetion operation:

- The principle of atomization
- The Venturi principle

Let's look at each of these principles in detail.

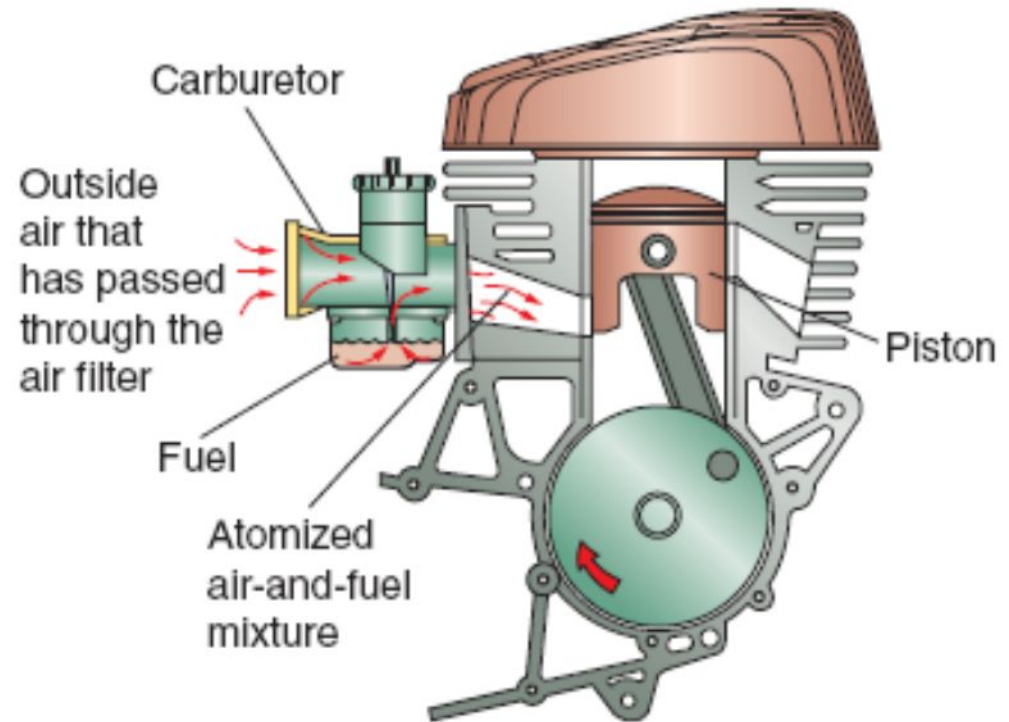


# Principle of Atomization

**Atomization** is the process of combining air and liquid, in this case fuel, to create a mixture of liquid droplets suspended in air.

As the piston begins the intake stroke, the air pressure in the cylinder is reduced. The pressure difference causes the higher-pressure, outside air to flow through the air filter and carburetor, and into the engine.

Atomization takes place when the carburetor meters gasoline into the fastmoving air passing through it using the same principle of pressure difference (Figure 1).

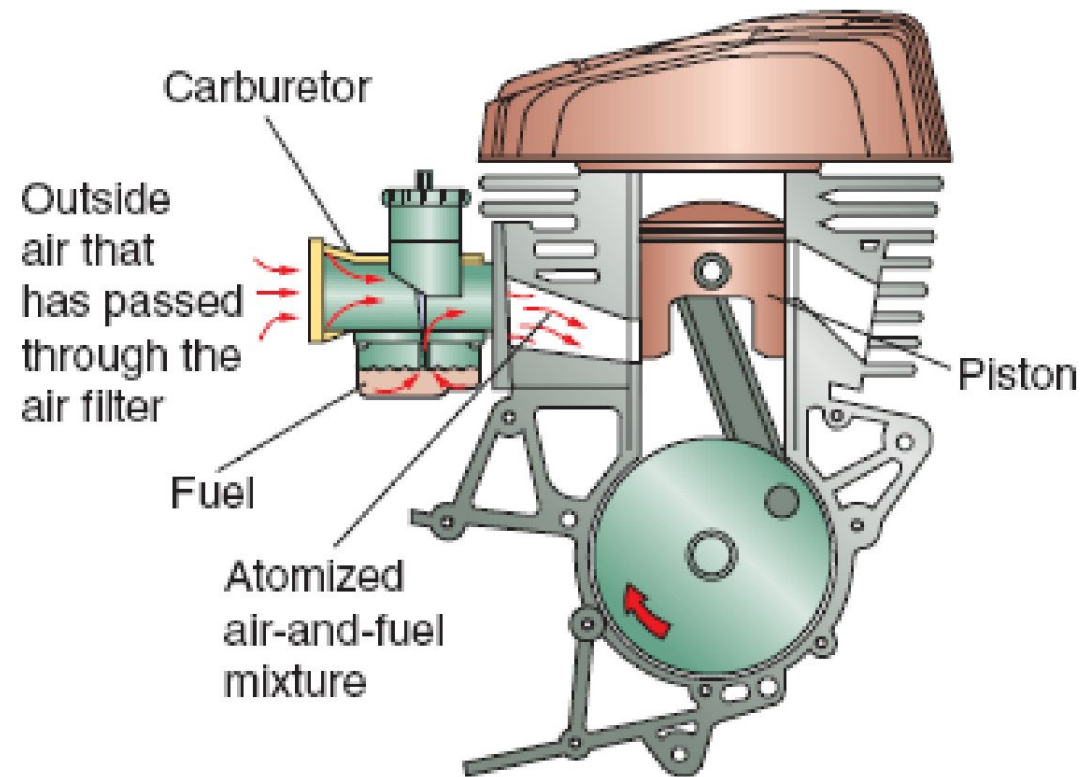


**Figure 1** This illustration shows how atomization takes place in an engine.

Atomization is the process of combining air and liquid to create a mixture of liquid droplets suspended in air.

Air at high pressure from the outside becomes air at low pressure in the carburetor, which allows the high-pressure air at the fuel source to be pushed into the throat of the carburetor.

The primary function of the carburetor is to atomize the fuel to create an air–fuel mixture.

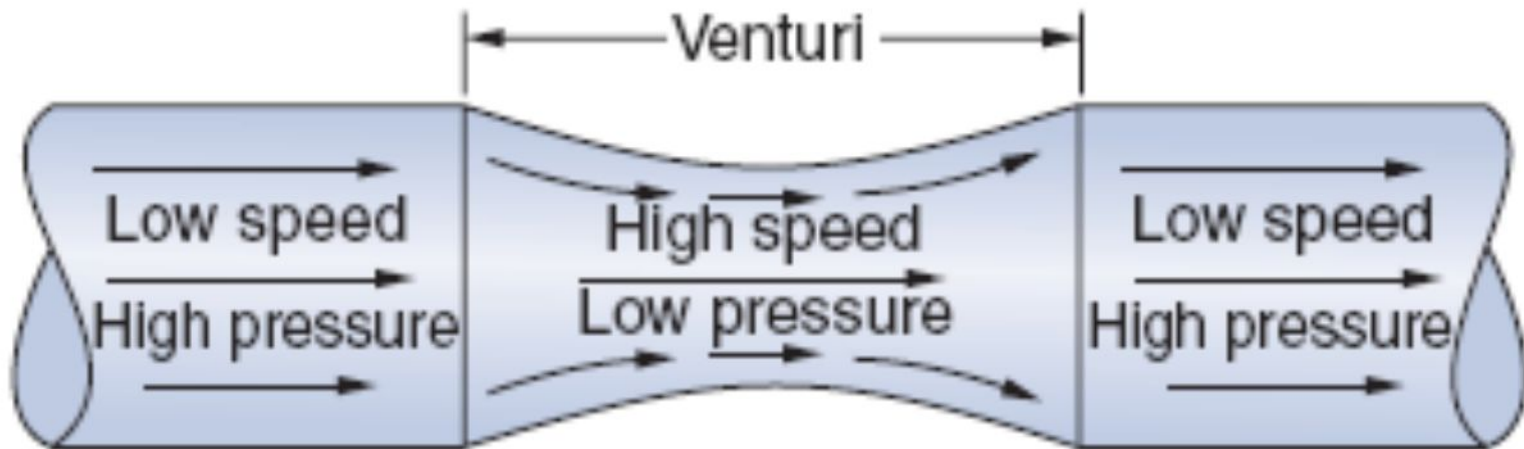


**Figure 1** This illustration shows how atomization takes place in an engine.

# The Venturi Principle

Carburetor design is based on the Venturi principle.

The **Venturi principle** simply states that a gas or liquid that's flowing through a narrowed-down section (venturi) of a passage will increase in speed and decrease in pressure compared with the speed and pressure in wider sections of the passageway (Figure 2).

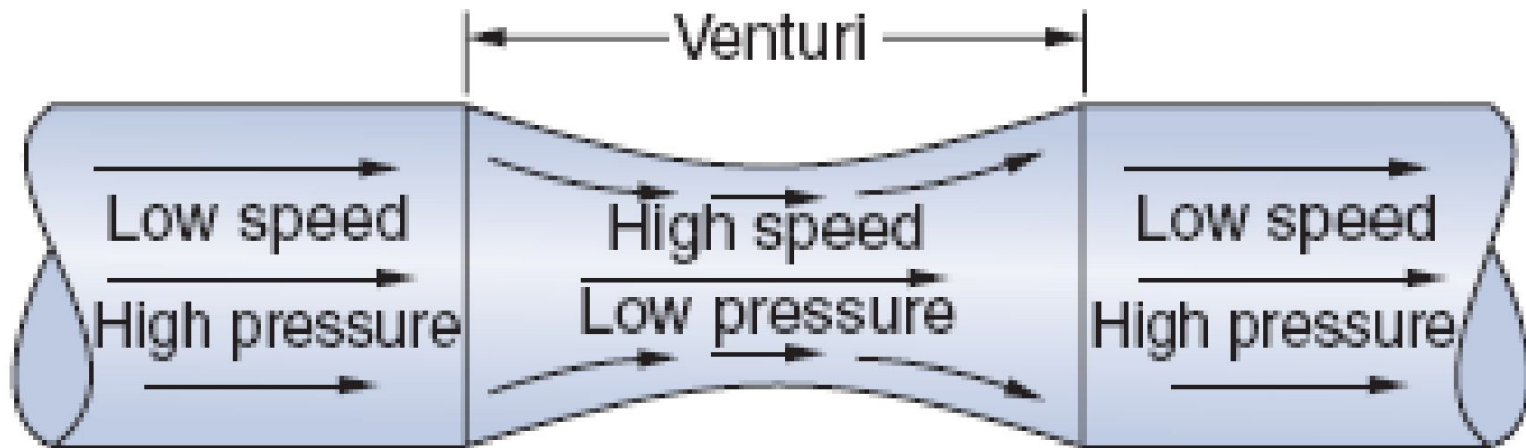


**Figure 2** The Venturi principle.

A venturi has a particular shape—a modified hourglass figure, you might say. Air from the carburetor, on its way to the combustion chamber, passes through the venturi.

The hourglass shape of the venturi causes the stream of air to increase in speed and decrease in pressure, creating a pressure difference in the venturi.

This pressure difference is important, as it allows for fuel to be drawn into the air stream and atomized.

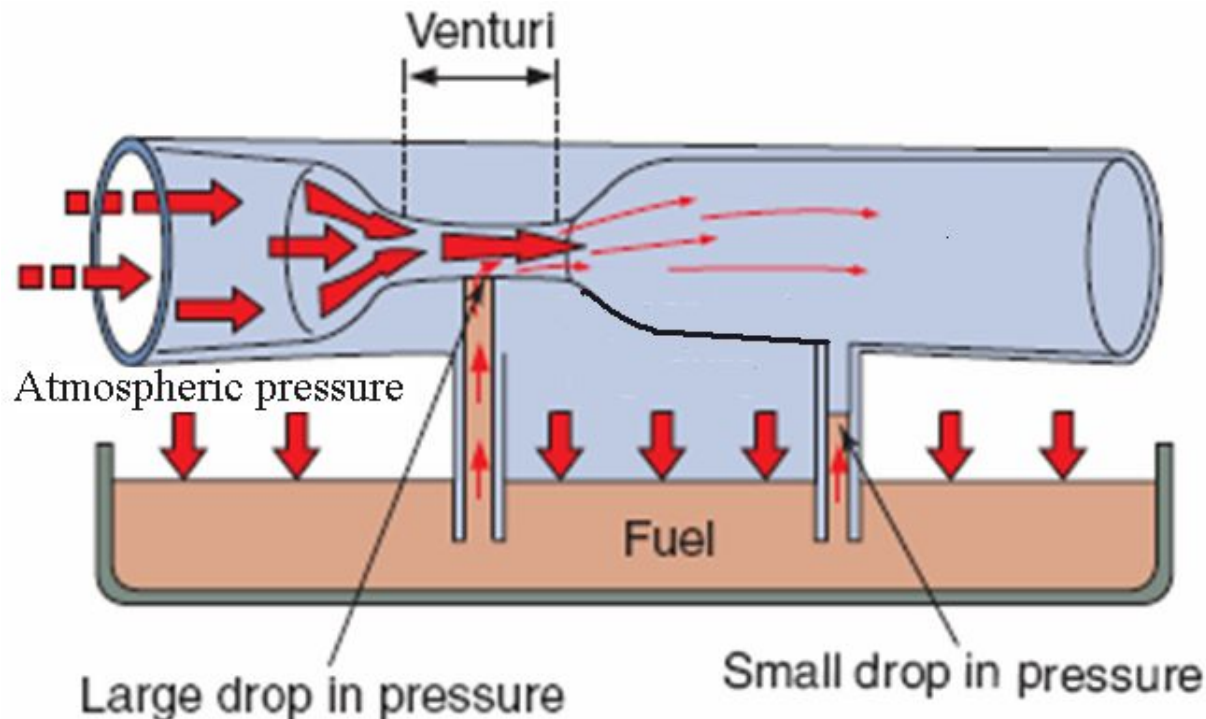


**Figure 2** The Venturi principle.

The major air passage in the carburetor body is called the carburetor bore. The air entering the carburetor bore is controlled by its speed and by the size of the venturi.

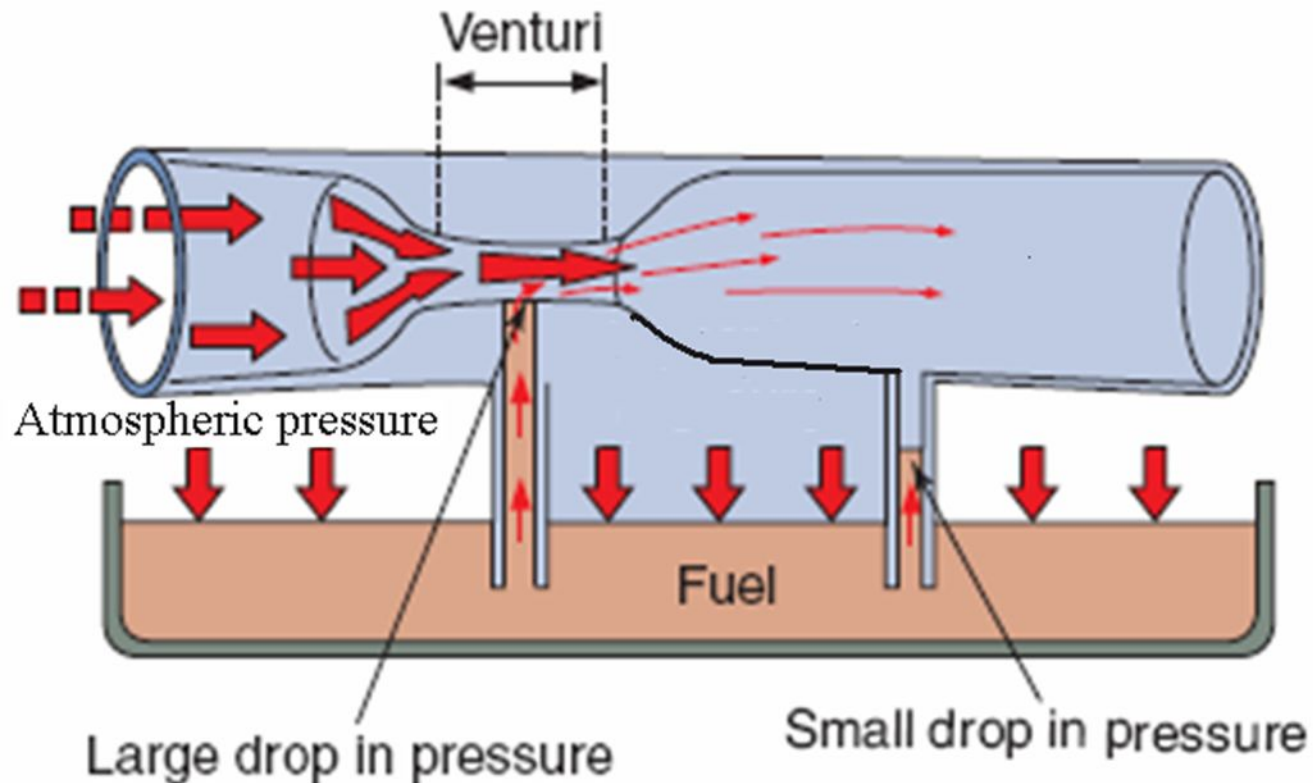
A typical main carburetor bore may have a diameter of 1 inch, compared with a venturi diameter of  $\frac{3}{4}$  inch.

When air rushes to fill the cylinder, the speed of the air is faster if it must pass through a small opening than if it must pass through a large opening.



**Figure 3** The effect of low pressure in a venturi.

As mentioned earlier, as air speed increases, air pressure decreases. The speed of air as it passes through the carburetor is an important factor in the breaking up (or atomization) of the fuel, as well as controlling the amount of fuel that's delivered into the venturi. You can see from Figure 3 that air is drawn into the carburetor through the venturi, where it gains considerable speed. This increase in air speed is directly related to a fall in air pressure in the venturi, which then draws fuel from an outlet nozzle.



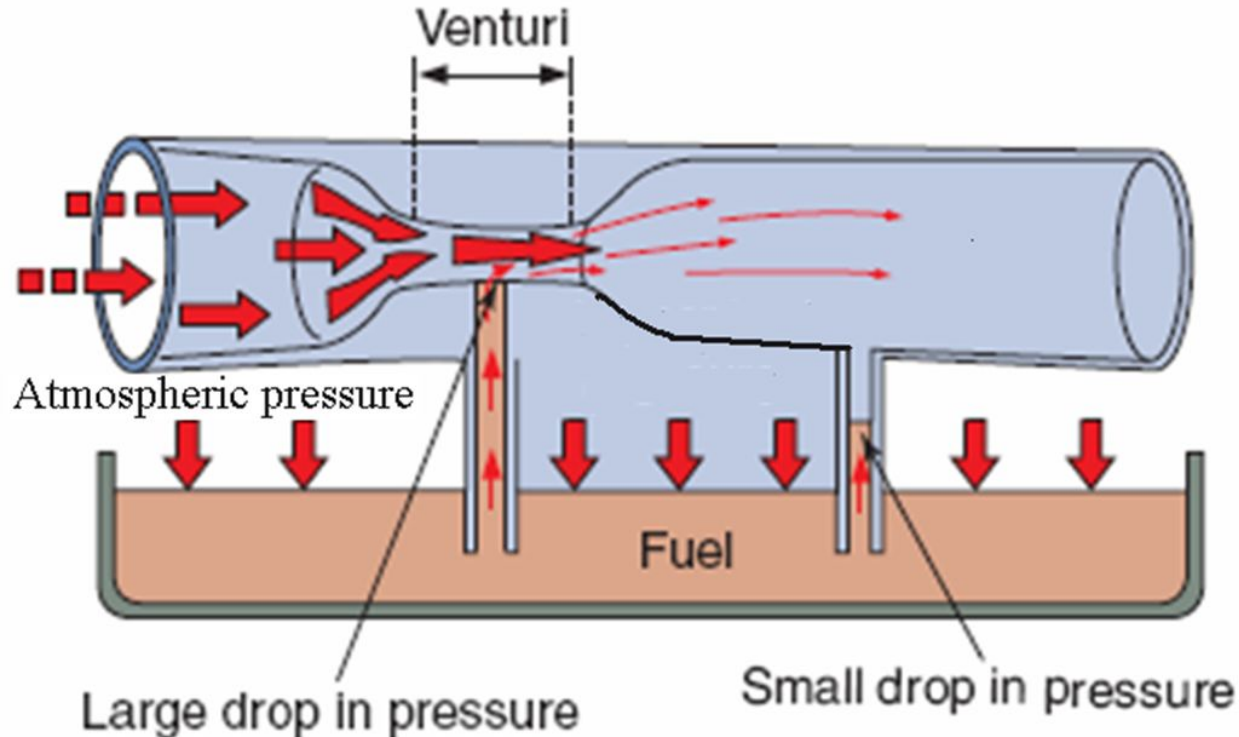
**Figure 3** The effect of low pressure in a venturi.

The fuel is atomized under the influence of atmospheric pressure as it's mixed with the incoming air.

Venturi size and shape are of considerable importance.

If the venturi is too large, the flow of air is slow and won't atomize sufficient fuel to make a balanced mixture.

If the venturi is too small, not enough air passes through to fill the vacuum created by the engine inside the cylinder.

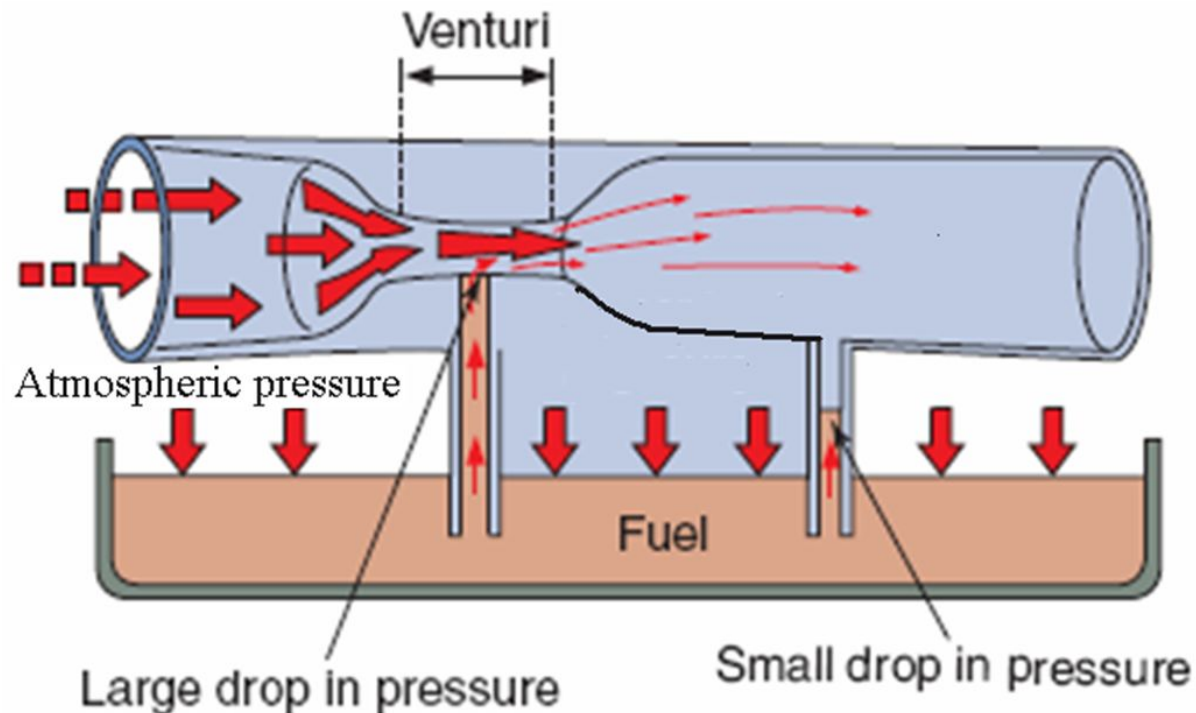


**Figure 3** The effect of low pressure in a venturi.

A large engine that creates a high vacuum uses a carburetor with a large venturi. A small engine requires a smaller venturi to be most effective.

Carburetors are equipped with mechanisms for regulation of the air and fuel volumes that are allowed to pass through the venturi. All carburetors have a venturi that operates on the same basic principle.

Variations are in size, method of attachment, or in the system used to open and close the venturi. The principle of operation is the same for all carburetors.



**Figure 3** The effect of low pressure in a venturi.



# FUEL DELIVERY SYSTEMS

The various components of the fuel delivery system of most gasoline-powered engines will be discussed in this section.

## Fuel Tank

The fuel tank is designed to store fuel (gasoline). Fuel tanks can be made of steel, aluminum, or plastic. Fuel tanks of almost all modern power equipment engines are made of a light, thin steel or plastic.

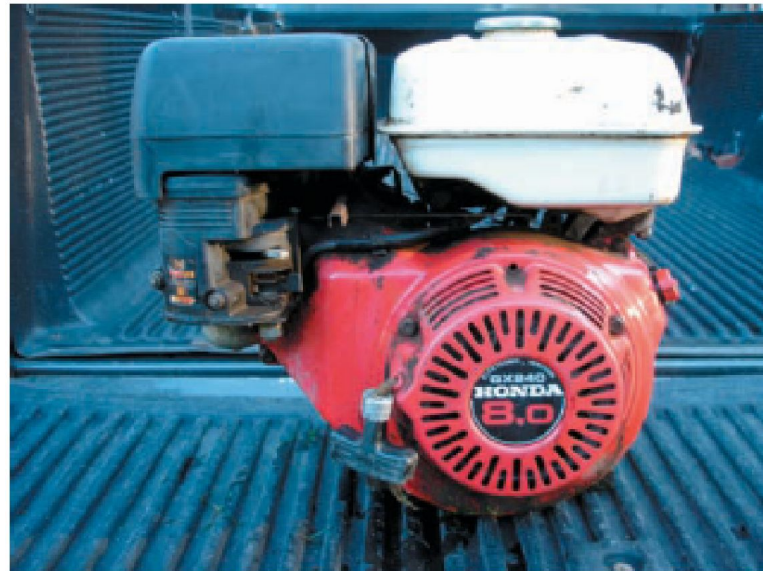
The important thing to remember is that the fuel tank is a reservoir that safely stores a supply of fuel for the carburetion system (Figure 4).



**Figure 4** A typical fuel tank. Note that the fuel tank is placed higher than the carburetor and therefore uses a gravity feed system.

In many cases, the fuel tank uses a gravity feed system to allow fuel to flow into the carburetor. The fuel tank will always be placed higher than the carburetor when using the gravity feed system.

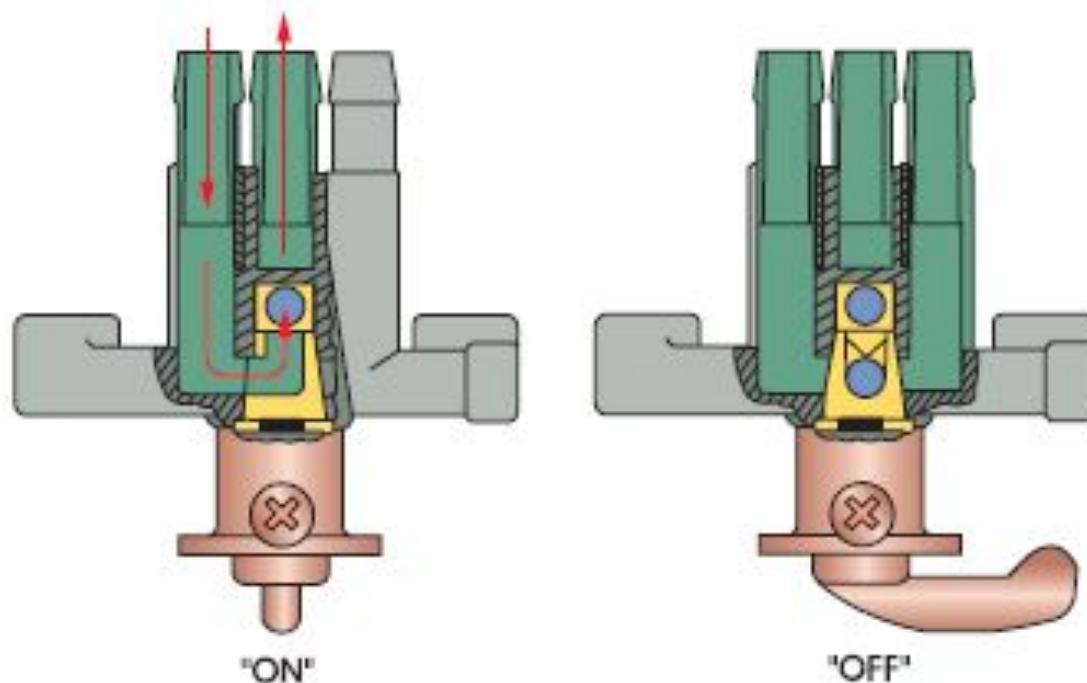
Typically, the fuel tank is vented to the atmosphere, but some states (California, for example) require fuel tanks to be vented into a charcoal canister. This canister retains the hydrocarbon vapors, keeping them from entering the air we breathe.



**Figure 4** A typical fuel tank. Note that the fuel tank is placed higher than the carburetor and therefore uses a gravity feed system.

# Fuel Valves

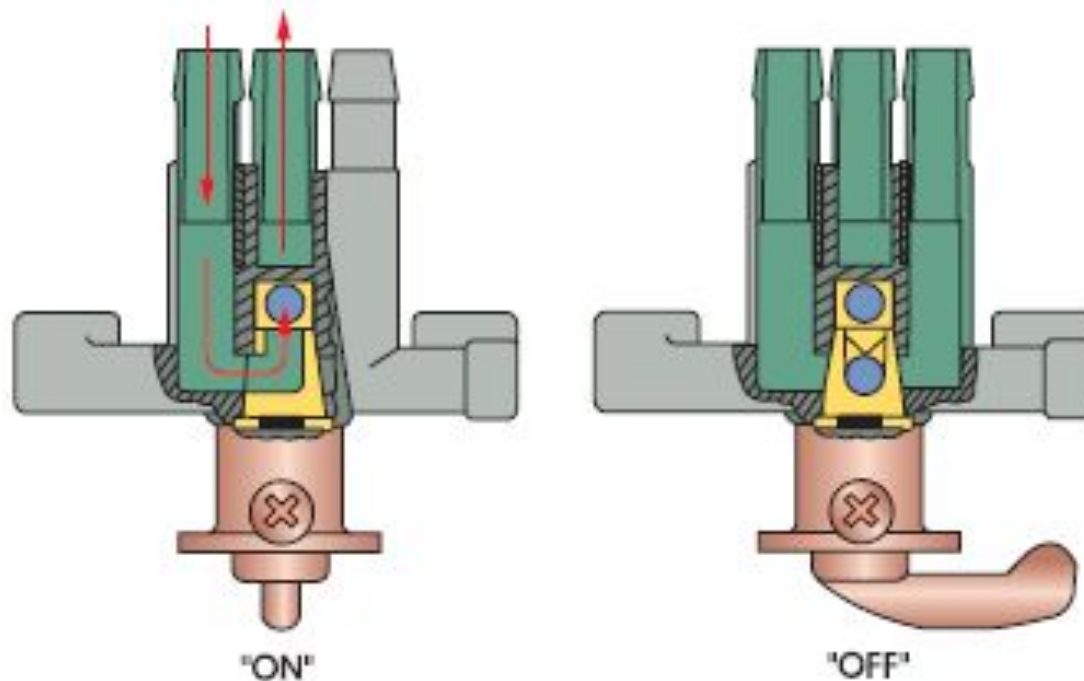
**Fuel valves**, also known as fuel petcocks, are on/off valves that control the flow of gasoline from the fuel tank to the carburetion system (Figure 5). Fuel valves are generally operated manually by turning the valve either on or off.



**Figure 5** Fuel valves are designed to open and close the flow of fuel to the carburetor.

When turned to the “on” position, fuel flows to the carburetor from the main fuel tank. When turned to the “off” position, the flow of fuel stops.

These valves are useful when the engine is being transported or if the engine isn't going to be used for a long period of time.



**Figure 5** Fuel valves are designed to open and close the flow of fuel to the carburetor.

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# Fuel Lines

**Fuel lines** are used to flow gasoline from the fuel valve to the carburetion system and are usually made of metal or neoprene, which is a synthetic rubber material.

It's important to use manufacturer-recommended fuel lines. Because of some additives and alcohol (in certain cases where it's used as an additive) in gasoline manufactured nowadays, inferior fuel line hose can be affected or damaged.



# Fuel Pumps

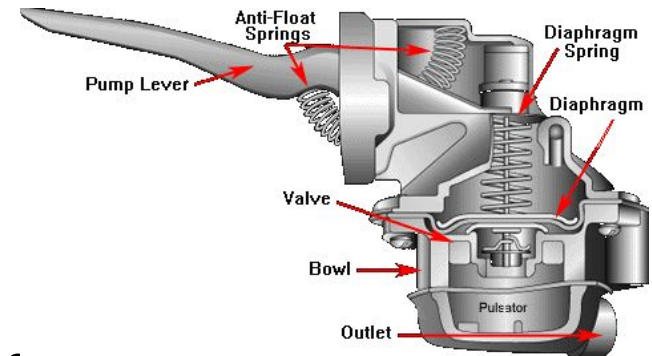
Some power equipment engines use a fuel pump. The purpose of a fuel pump is to deliver fuel from the fuel tank to the carburetion system. A fuel pump is also required when the power equipment engine's fuel tank is placed lower than the carburetor. The fuel pump supplies fuel under pressure to keep the carburetor filled with fuel.

Fuel pumps are found always in engines with fuel injection systems. Fuel injection is a type of carburetion and is discussed later.

There are three types of fuel pumps:

- mechanical,
- vacuum,
- electric.

Although some larger power equipment diesel engines use mechanical fuel pumps, two types of pumps are commonly seen on modern power equipment engines: vacuum and electric.

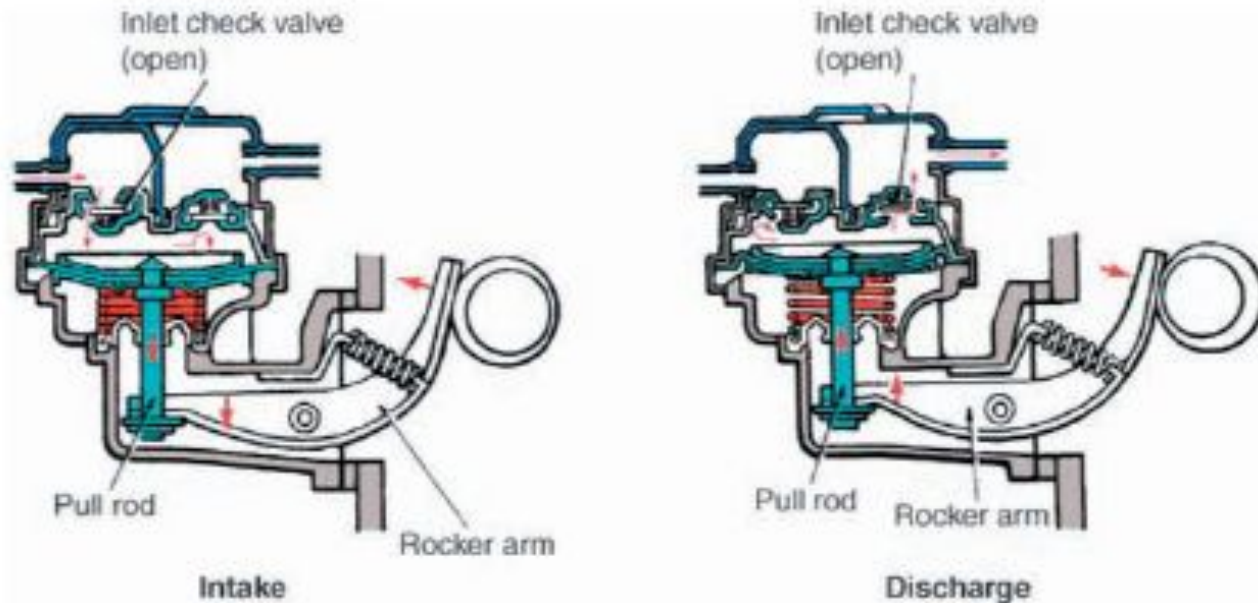


# Mechanical Fuel Pumps

The mechanical fuel pump is a pump that uses a diaphragm operated by a rocker arm.

The rocker arm is opened by the camshaft and closed by a spring to pump fuel from the tank to the carburetor (Figure 6).

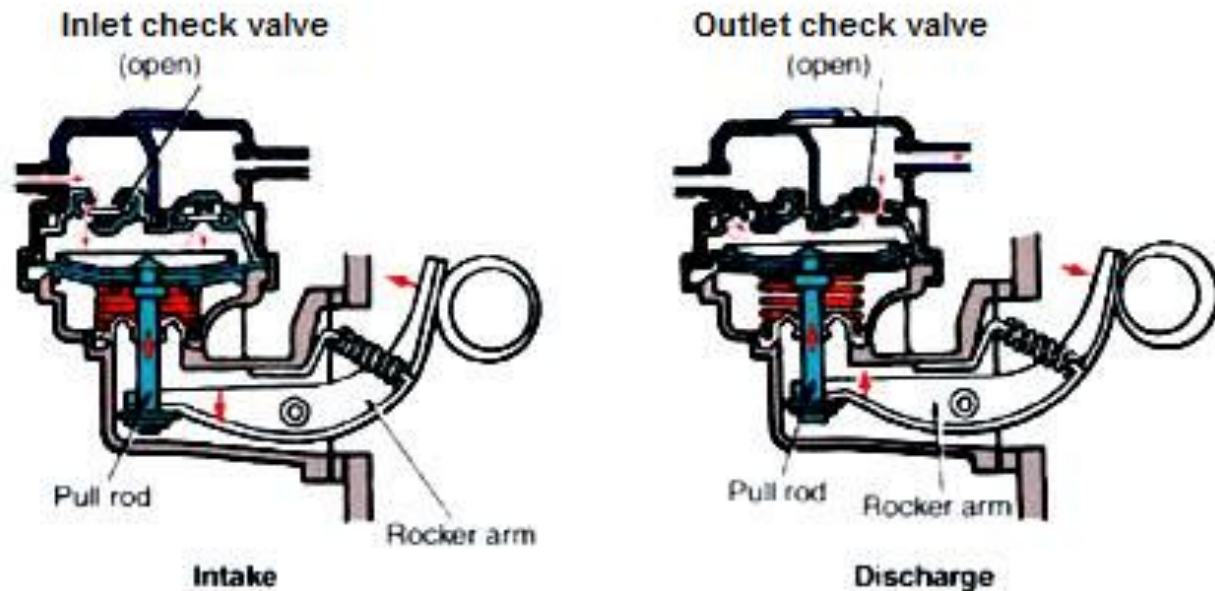
Mechanical pumps are generally located on the side of the engine block. The rocker arm enters the engine and rides on a camshaft lobe.



**Figure 6** A mechanical fuel pump.

As the cam rotates, the rocker arm moves up and down. The lever is connected to a diaphragm. A diaphragm is a flexible pumping element in the pumping chamber that, when moved, changes the volume of the chamber. There is an inlet and an outlet check valve located in the pumping chamber.

Pumping occurs when the diaphragm is moved up and down by the rocker arm. When the diaphragm is pulled down, the pressure difference pulls in fuel from the tank, and when the diaphragm is pushed back up, the check valve in the inlet side closes and the fuel is delivered to the carburetor.



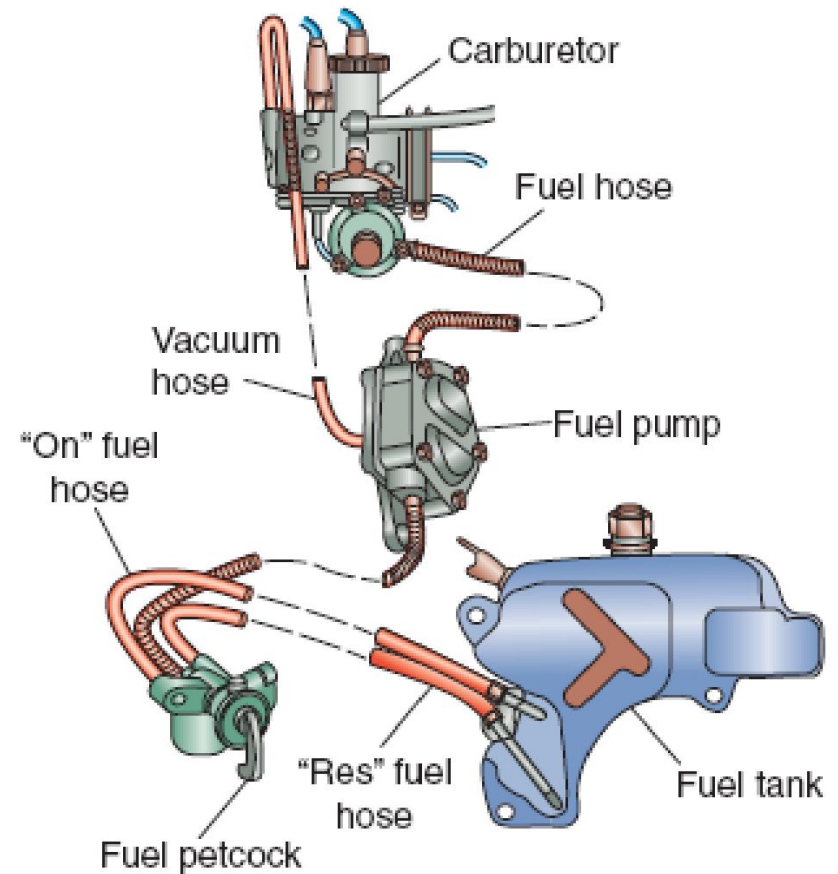
**Figure 6** A mechanical fuel pump.



# Vacuum Fuel Pumps

The vacuum fuel pump (Figure 7), also called an impulse fuel pump, uses a diaphragm that's moved by the pressure differences of engine vacuum and atmospheric pressure.

It works in the same manner as the mechanical fuel pump but instead of a mechanical lever, the diaphragm is moved by pressure and vacuum made by the engine.

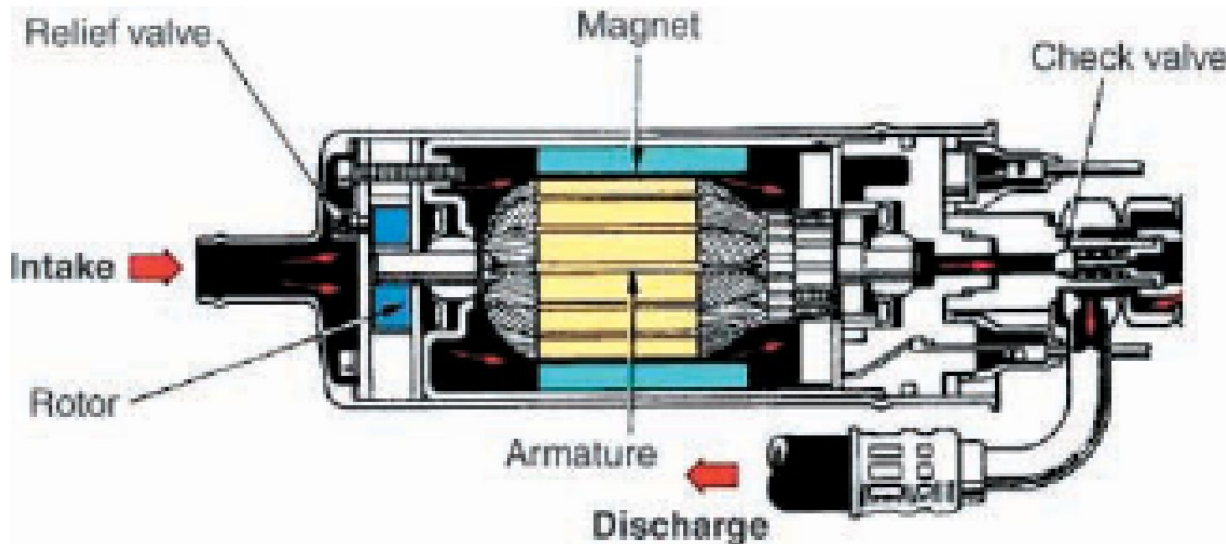


**Figure 7** A vacuum-operated fuel valve uses engine vacuum to allow fuel to flow by use of a diaphragm, as shown here.

# Electric fuel pump

The electric fuel pump is operated electronically by the use of an electric motor and solenoid that pumps the fuel from the fuel tank to the carburetor (Figure 8).

An electric fuel pump operates only when the power equipment engine is running, unless it's bypassed.



**Figure 8** A typical electric fuel pump.

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# CARBURETOR TYPES AND OPERATION

The carburetor has the task of combining the air and fuel into a mixture that produces power for the engine.

- First, the engine draws in air.
- The pressure difference between the outside atmosphere (higher pressure) and the inside of the cylinder (lower pressure) forces the air to pass through the carburetor. The air mixes with a predetermined amount of fuel, which is also moved by pressure differences, into the air stream of the carburetor venturi. Carburetors use different fuel metering systems, which supply fuel for the air–fuel mixture in regulated amounts. These metering systems are called **fuel circuits**, and their operating ranges overlap.

We'll discuss these circuits as well as the operation of the common carburetors that you'll see in power equipment engines.

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# Cold Start Systems

For the cold start phase of engine operation, a rich fuel mixture is needed because the engine metal is cold. When the engine is cold, the air–fuel mixture is also cold and won't vaporize or combust readily.

To compensate for this reluctance to burn, the amount of fuel in proportion to the amount of air must be increased.

This is accomplished by the use of a cold start system. Cold start systems are designed to provide and control a richer-than-normal air–fuel mixture, which is necessary to quickly start a cold power equipment engine.

Most carburetor cold-start mixtures are designed to operate at a ratio of approximately 10:1, that is, 10 parts of air to 1 part of fuel. Carburetors manufactured today usually include one of two types of cold start devices.

# Primer Cold Start System

A primer cold start system is a rubber squeeze bulb used to force fuel into the combustion chamber past the carburetor to help start a cold engine (Figure 9).



**Figure 9** A primer cold start system pushes fuel directly into the engine.

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There are two different types of the primer cold start system in power equipment engines:

- wet bulb;
- dry bulb.

They can be mounted to the side of the carburetor or as a separate assembly mounted elsewhere in the engine.

To start a cold engine with a wet bulb primer, the operator squeezes the bulb, which forces fuel out of the bulb-holding chamber past a check valve through the carburetor and into the engine. When the bulb is released, fuel is refilled back into the bulb from the fuel source.

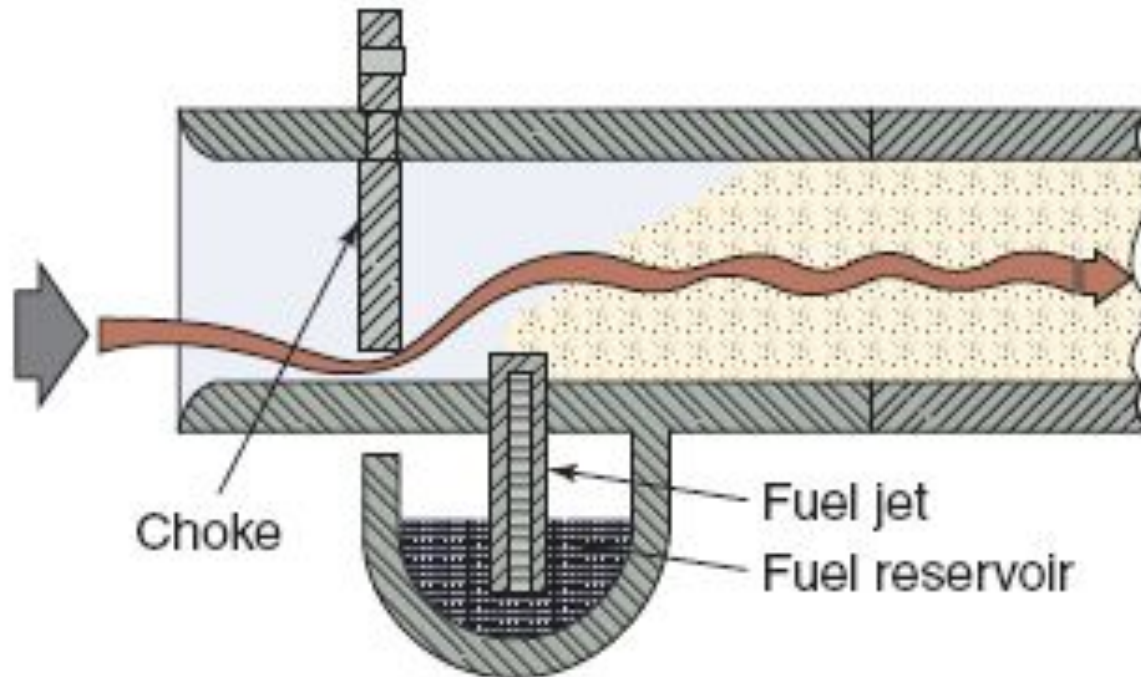
There are two check valves on a wet bulb primer: one to prevent fuel from entering the engine under low pressure (when the bulb is released) and one to prevent fuel from entering into the source under high pressure (when the bulb is being pushed).

When used, the engine receives raw fuel in the intake port for an easier cold engine start.

The dry bulb primer pushes air into the carburetor bowl, which increases pressure in the bowl. The increase in pressure forces fuel through the carburetor and into the engine.

# Choke Plate Cold Start System

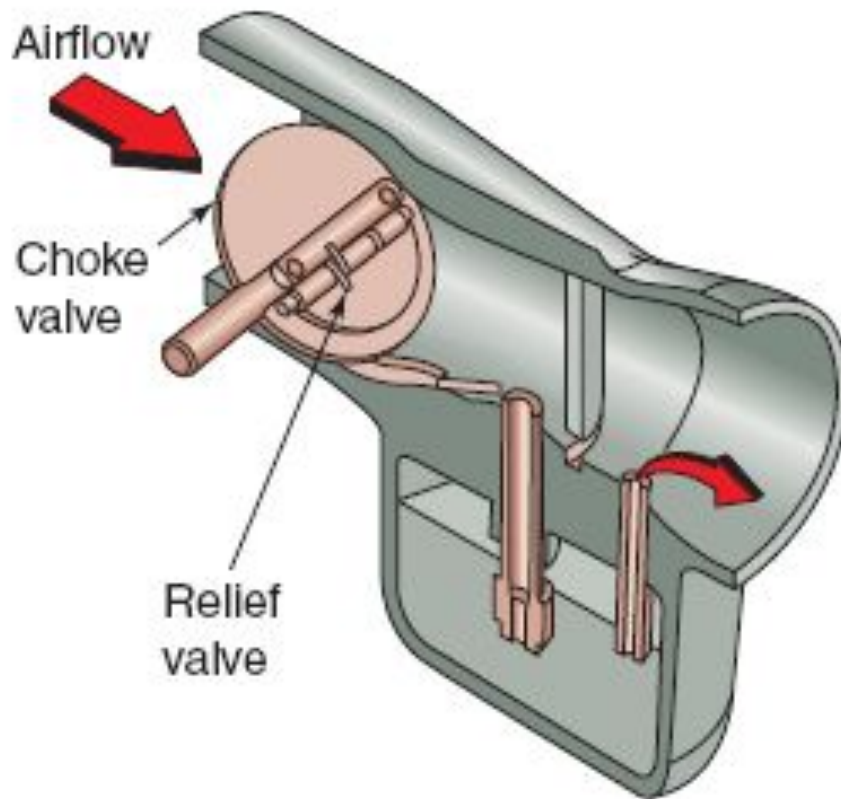
The choke plate cold start system is an air restriction system that controls the amount of air available during a cold engine start. This system uses an operator-controlled plate, called a choke valve, to block air to the carburetor venturi at all throttle openings (Figure 10).



**Figure 10** The choke plate cold start system closes off air to the engine.

This plate has a small hole cut into it, a cut out in the plate, or both to allow some air into the carburetor venturi (Figure 11).

This gives the engine enough air to run, by creating a very rich mixture, in comparison with the mixture created had the plate been in the open position. The choke valve is located on the air-filter side of the carburetor.



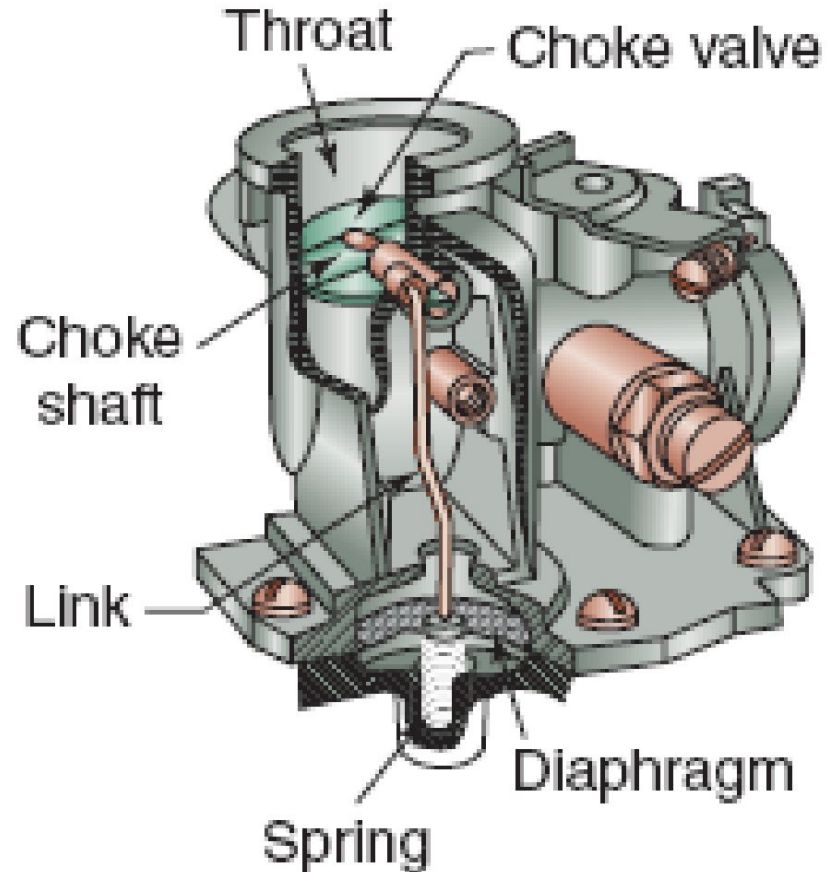
**Figure 11** The choke plate cold start system allows a predetermined amount of air to flow into the intake tract.



# Choke Plate Operation

The choke plate can be operated manually or by an automatic choke, as in some engines. An automatic choke is a valve connected to a diaphragm or bimetal spring that automatically opens or closes the choke valve.

The diaphragm-type automatic choke uses a diaphragm mounted to the carburetor (Figure 12). It's connected to the choke valve shaft by a link. A spring under the diaphragm holds the choke valve closed when the engine isn't running.



**Figure 12** A diaphragm type automatic choke and its related components.

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When the engine is started, low pressure is created in the cylinder during the intake stroke. The low pressure acts on the bottom of the diaphragm through a small passage and pulls the diaphragm down. The link attached to the diaphragm also travels down. The link pulls the choke valve into the open position.

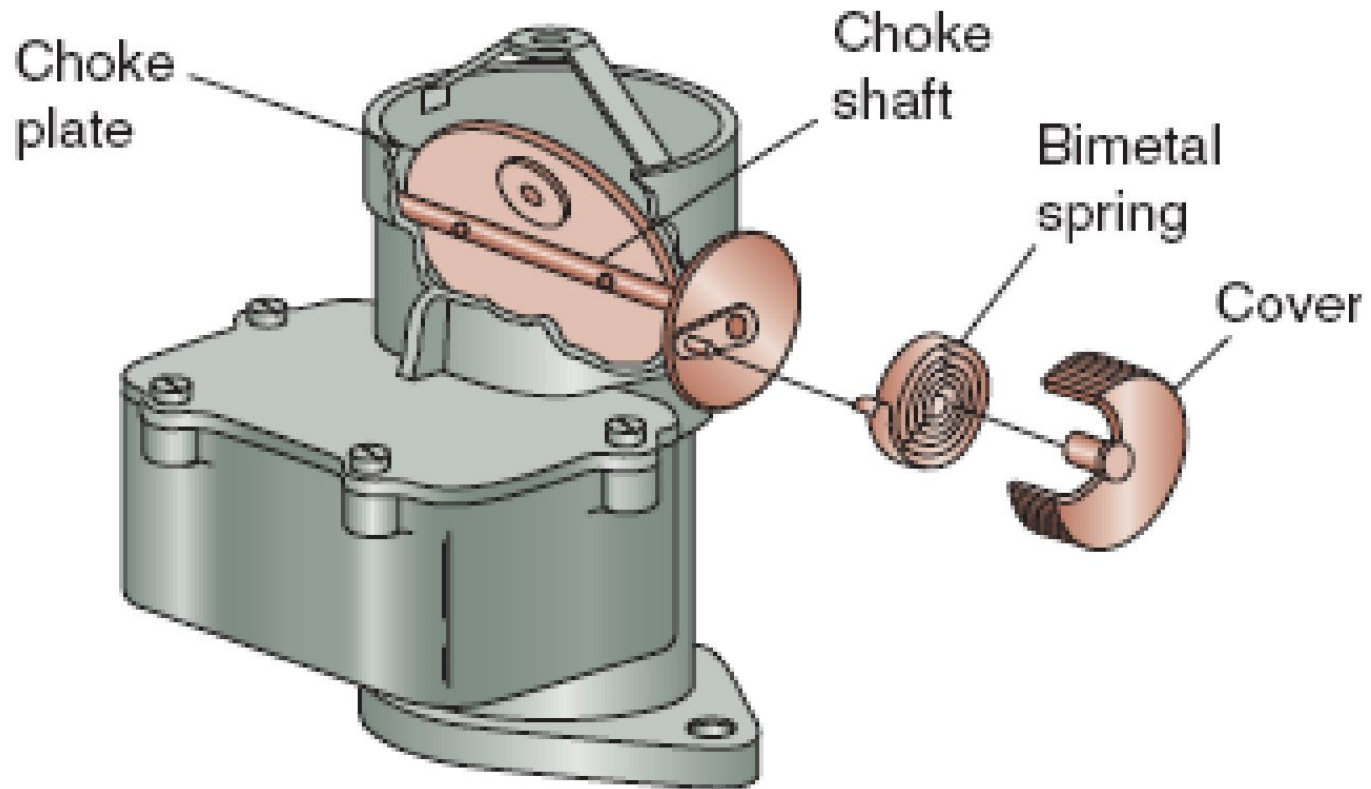
The vacuum under the diaphragm leaks away when the engine is stopped. The spring moves the diaphragm in a direction to close the choke valve. The choke is ready for another starting cycle.

The bimetal-type automatic choke uses a spring (Figure 13) made from two metals, which have different amounts of heat expansion.

The two metals cause the spring to move as it changes temperature. The choke spring is mounted in a small housing next to the choke valve. One end of the choke spring is connected (directly or by linkage) to the choke valve. The other end is anchored to the housing.

When the engine is cold, the bimetal spring contracts. The end of the spring moves the choke valve to a closed position. As the engine warms up, the spring expands. The expanding spring moves the choke valve into an open position.

The spring is located near the muffler to heat quickly and turn the choke off at a predetermined temperature.



**Figure 13** A bimetal type automatic choke and its related components.

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# Types of Carburetors

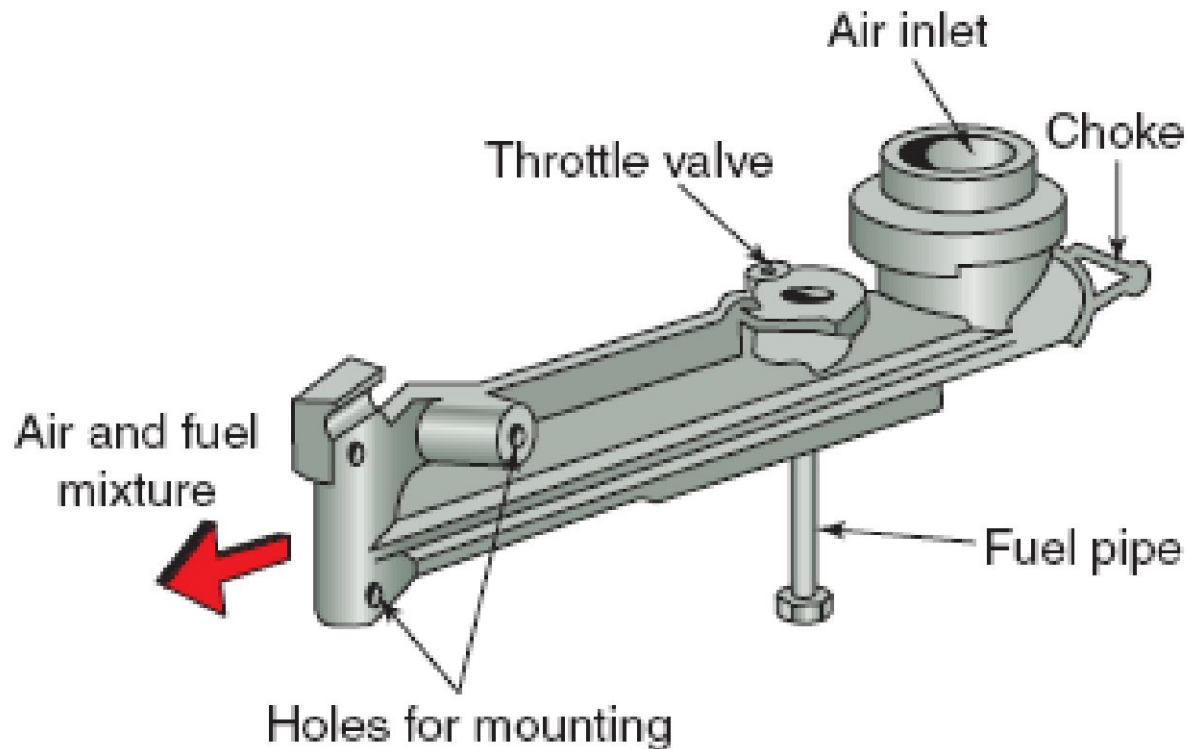
There are many types of carburetor designs, but as you've learned, the fundamental operation is the same for each design. Carburetors must atomize the fuel before the fuel reaches the engine. Proper atomization ensures that the air–fuel mixture is vaporized so that the engine performs at its best. Most carburetors used in power equipment engines have a fixed venturi, meaning that the venturi remains the same size at all engine running speeds, in contrast to carburetors used on motorcycles or all-terrain vehicles (ATVs), where a variable venturi carburetor is used by implementing a slide that moves up and down at different engine speeds.

The carburetors used in power equipment engines can be grouped into four categories:

1. Vacuum
2. Float
3. Diaphragm
4. Suction feed diaphragm

# 1. Vacuum Carburetors

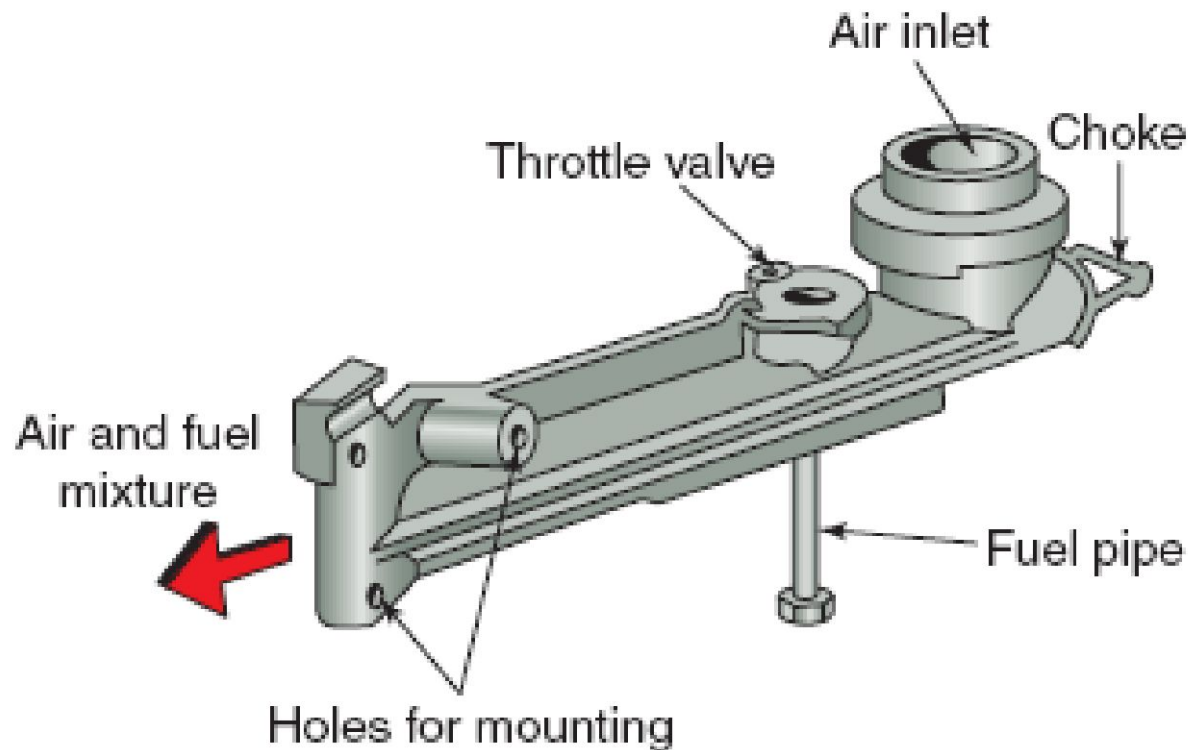
The vacuum carburetor, also called the suction carburetor, is a common carburetor often found installed in smaller, less expensive engines (Figure 14). A vacuum carburetor uses vacuum to pull fuel out of the fuel tank and mixes it with air entering the engine. These carburetors are always mounted on top of the fuel. All vacuum carburetors work the same basic way.



**Figure 14** The vacuum type carburetor uses a simple, one-piece housing.

A vacuum carburetor has a simple one-piece housing. The housing is basically a tube with an opening at one end for intake air to enter. A choke valve in the air opening can be opened or closed to regulate air flow.

The other end of the housing acts as an outlet for the air–fuel mixture. The mixture goes through the outlet and enters the engine intake port. This end has holes to mount the carburetor to the engine.

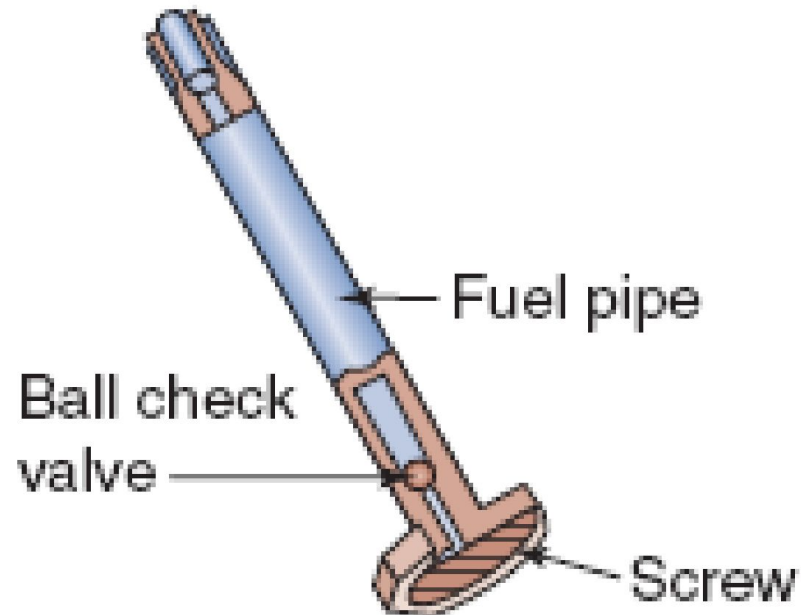


**Figure 14** The vacuum type carburetor uses a simple, one-piece housing.

There is a throttle valve inside the carburetor just past the air entrance. Below the throttle valve is a tube called the fuel pipe (Figure 15).

The fuel pipe brings fuel up into the carburetor from the fuel tank. The bottom of the fuel pipe has a small screen that filters dirt from going up the pipe and into the carburetor. A small ball check valve fits in the bottom of the pipe. The ball check valve allows fuel to go up the pipe but will not let fuel run back out of the pipe.

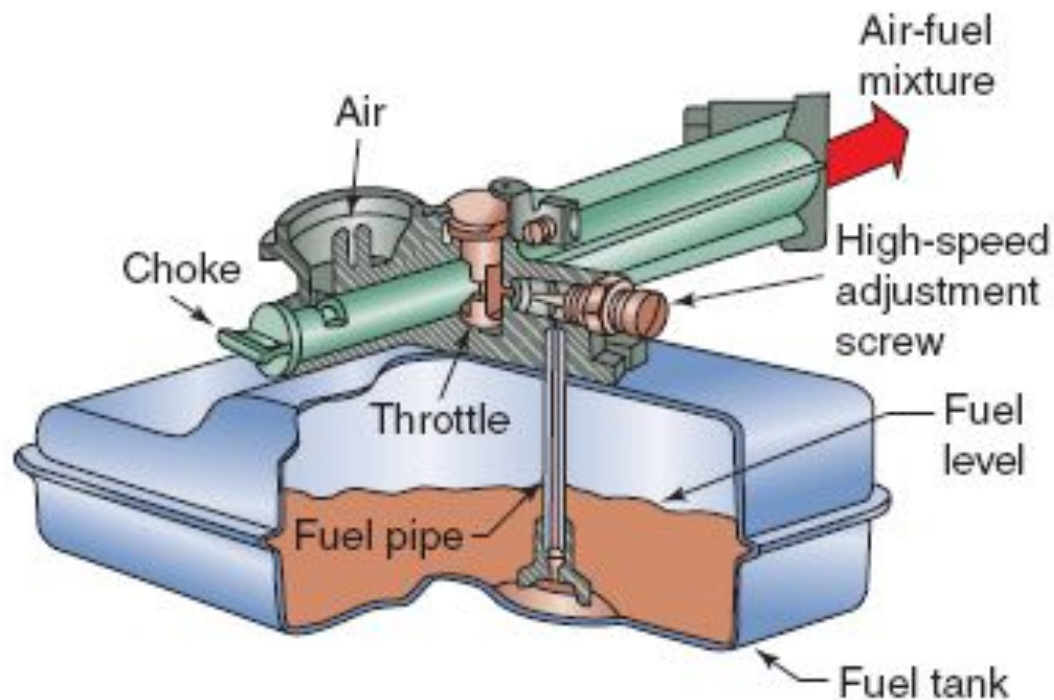
The fuel tank fits on the bottom of the carburetor. The carburetor fuel pipe goes down into the bottom of the fuel tank. The cap on the fuel tank is vented to allow atmospheric pressure into the tank. Without a vent, a vacuum could form in the tank, which would prevent fuel from going up the fuel pipe.



**Figure 15** A typical fuel pipe.

A low pressure (vacuum) is created inside the carburetor as the piston moves down on the intake stroke. This low pressure pulls fuel up the fuel pipe (Figure 16).

The throttle valve is in the way of the flow of air entering the carburetor. It creates a low pressure area, as in a venturi. The low pressure helps pull fuel up the fuel pipe. The fuel is mixed with the intake air passing through the carburetor housing. The amount of fuel that comes out the fuel pipe is regulated by a high-speed fuel adjustment screw.

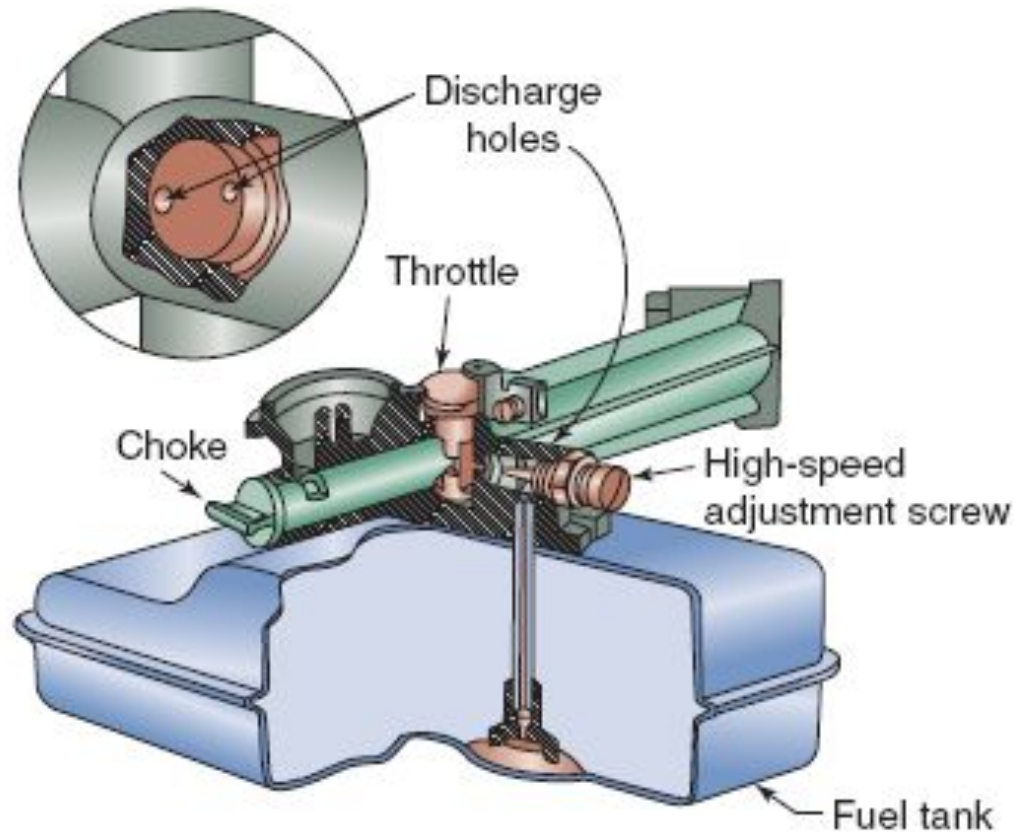


**Figure 16** Fuel delivered to the engine with a vacuum type carburetor.



There are two circuits in the carburetor housing: low speed and high speed (Figure 17).

Fuel flows through either or both these circuits, depending on the speed of the engine. When the throttle plate is open, there is maximum flow out of both circuits. When the throttle plate is closed, only the slow-speed circuit allows fuel to flow. This circuit allows a small amount of fuel flow for idle, which allows the engine to run with a nearly closed throttle.



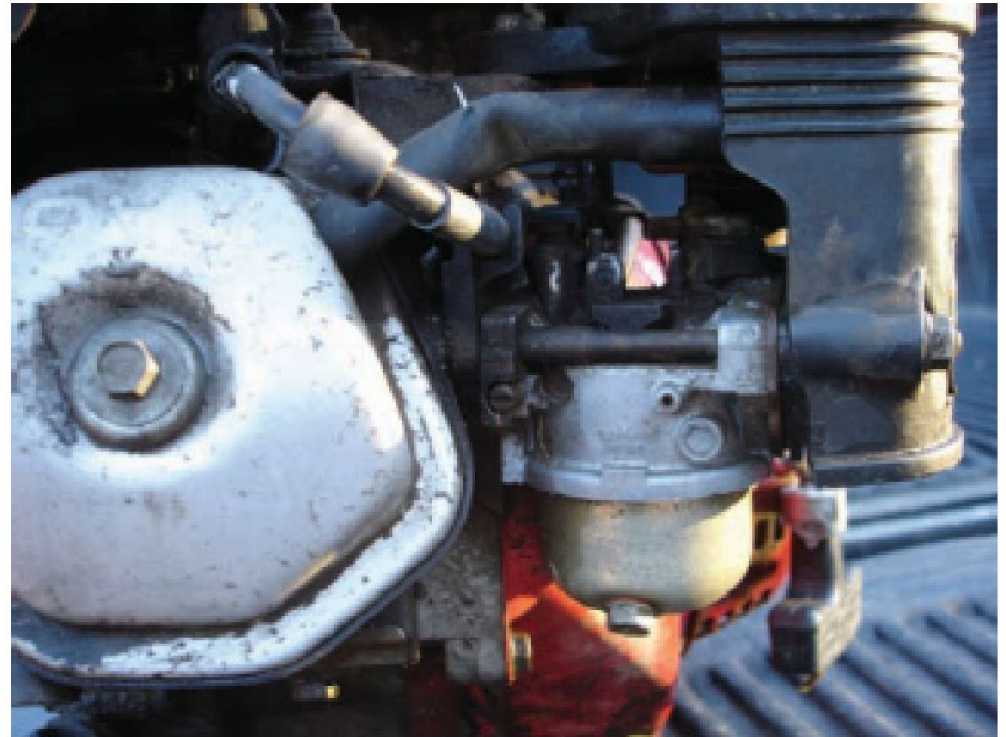
**Figure 17** Discharge holes are used in low and high-speed circuits for the fuel system in a vacuum type carburetor.

## 2. Float Carburetors

Many power equipment engines use a float carburetor (Figure 18), which is a carburetor that has an internal fuel storage supply controlled by a float assembly.

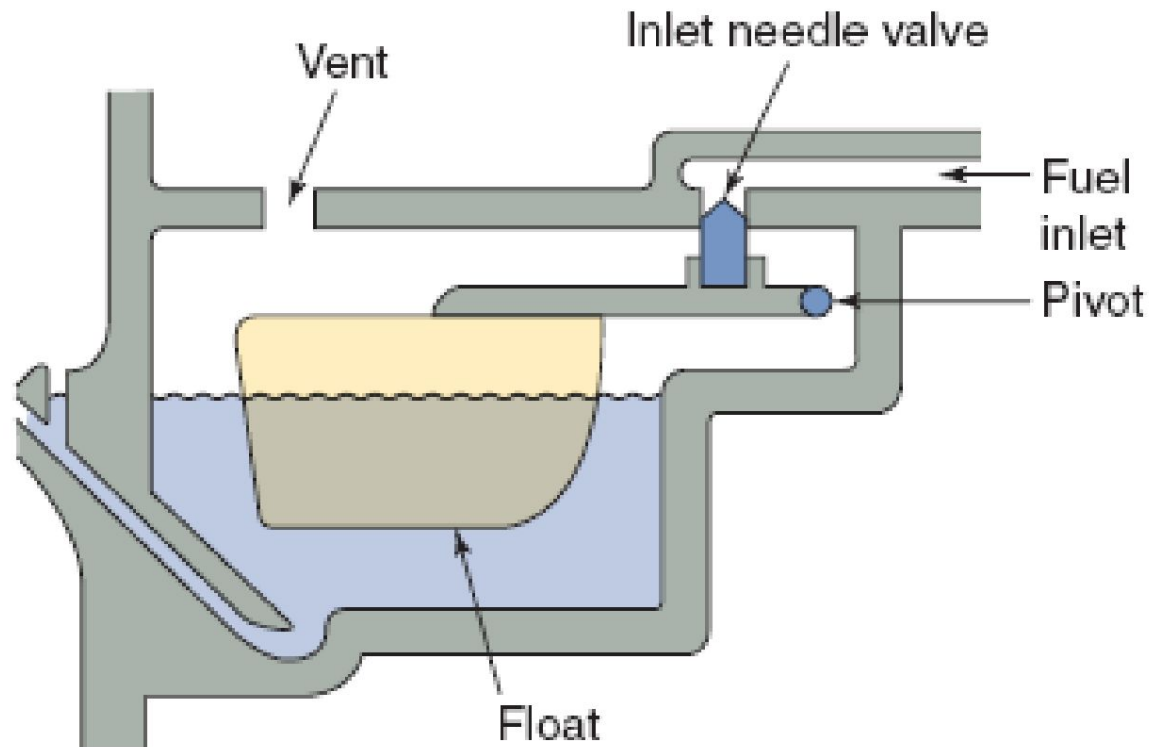
The fuel tank on the float carburetor system is attached to another part of the engine, often mounted higher than the carburetor.

Gravity causes fuel to flow from the tank through a fuel line to the carburetor. Some engines use a fuel pump to transfer the fuel from the tank, to the carburetor. A float assembly in the carburetor controls the flow of fuel from the tank.



**Figure 18** A float type carburetor.

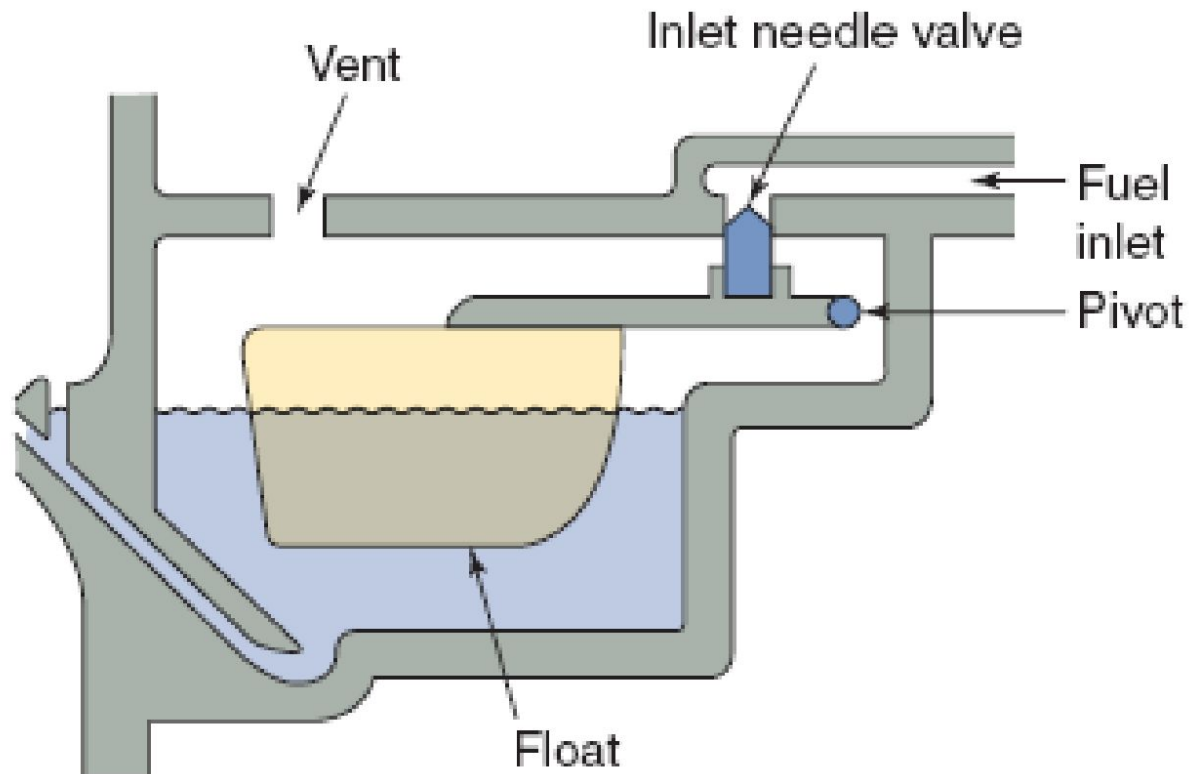
The fuel line from the fuel tank provides fuel to the carburetor. The fuel line is connected to a carburetor fuel inlet fitting. The fuel flows past an inlet seat. The inlet seat is a carburetor part that houses and provides a matching seat for the tapered end of a float needle valve. The fuel goes through the inlet seat into the carburetor float bowl. The valve is used to allow fuel to flow or stop the flow of fuel into the float bowl. A float pivots against the needle valve (Figure 19).



**Figure 19** A typical float chamber.

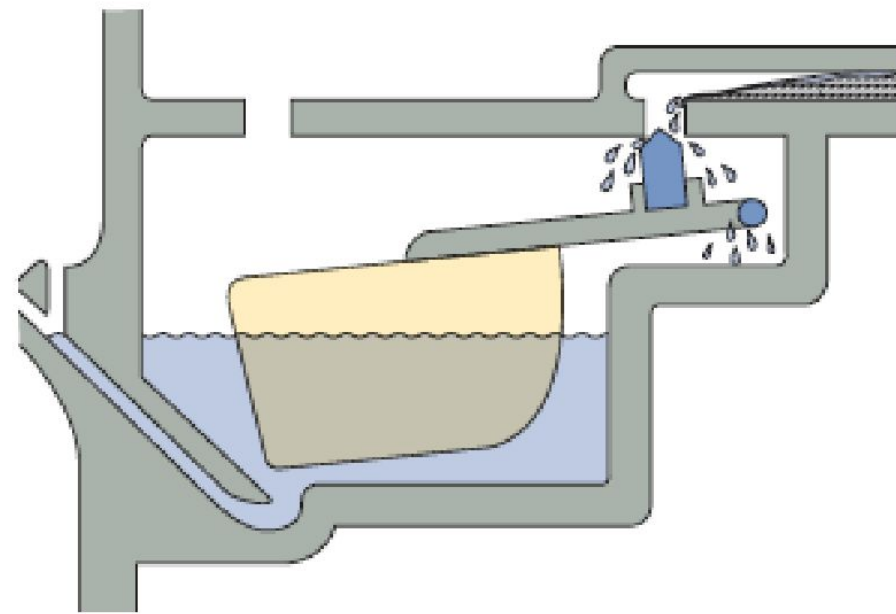
The float bowl is a component that provides a storage area for fuel in the carburetor. There is a small vent in the top of the bowl to allow atmospheric air in.

The float is a component that floats on top of the fuel and controls the amount of fuel allowed into the float bowl. It shuts off the flow of fuel once the float rises far enough and “seats.” Once the float rises and the needle seats, fuel is no longer allowed to flow into the float bowl.

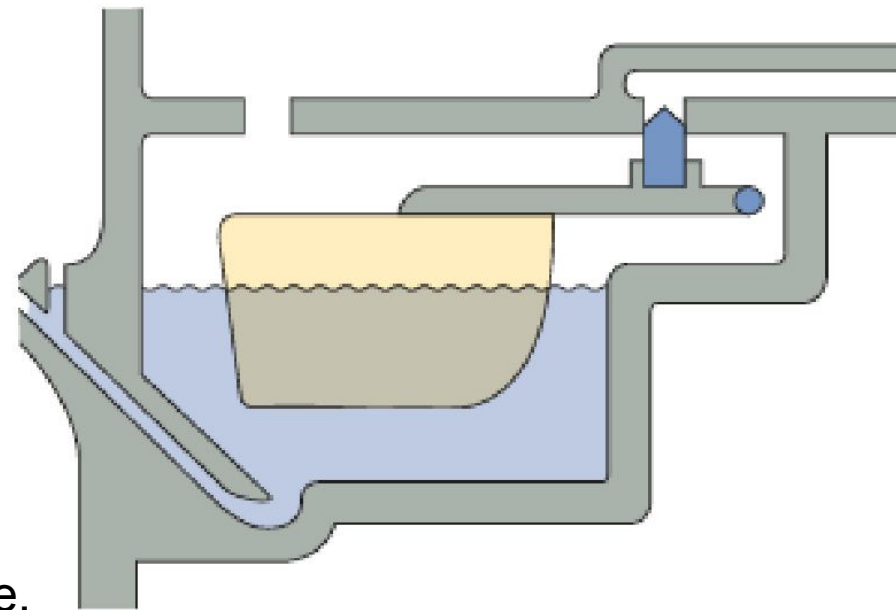


**Figure 19** A typical float chamber.

As the engine runs, fuel in the float bowl is used up. The fuel level in the bowl drops. As the fuel level drops, the float drops. When the float moves down, the inlet needle valve connected to it moves out of the inlet seat. Fuel is allowed to come in through the inlet passage from the fuel tank. The fuel level rises as more fuel comes into the bowl. The float also rises, pushing the inlet needle valve into the inlet seat. This action repeats itself to maintain the required level of fuel in the float bowl (Figure 20).



Inlet valve open



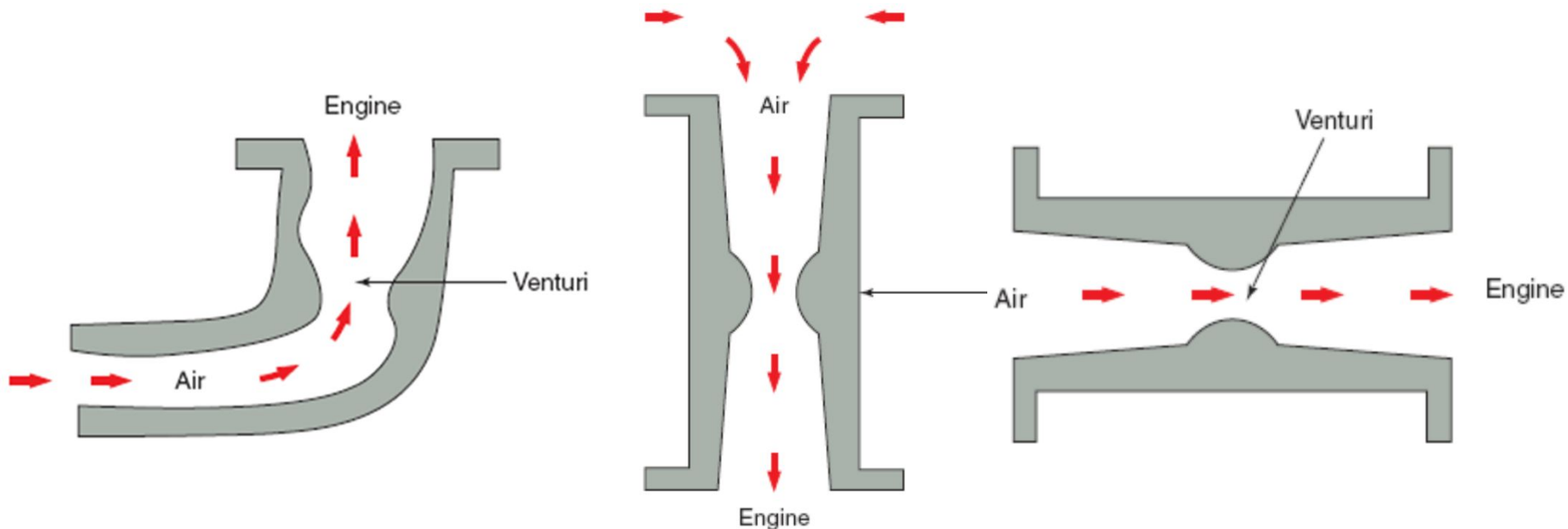
Inlet valve closed

**Figure 20** A functioning of a typical float valve.

# Float Carburetor Types

All float carburetors use a float to control the fuel level. There are, however, different styles of float carburetors.

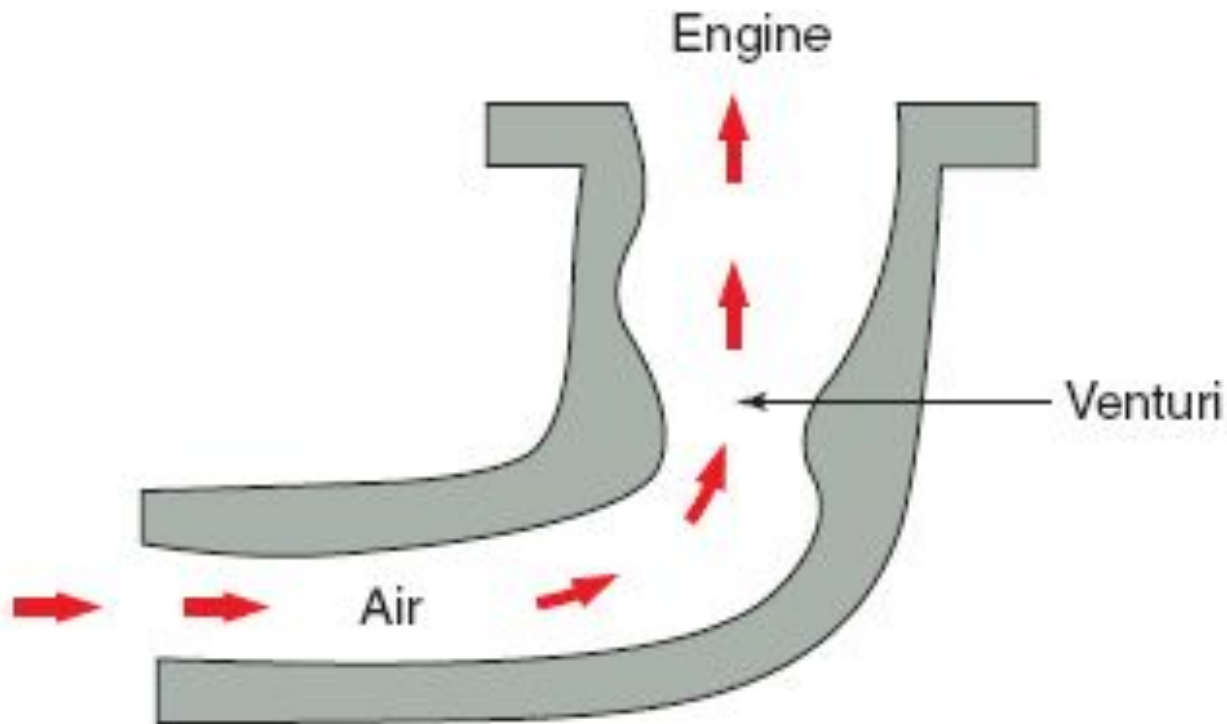
These carburetors are identified commonly by the direction of air flow into the carburetor throat. A carburetor throat is the part of the carburetor that directs air flow in toward the venturi.



Updraft, downdraft, and sidedraft are common float carburetor designs.

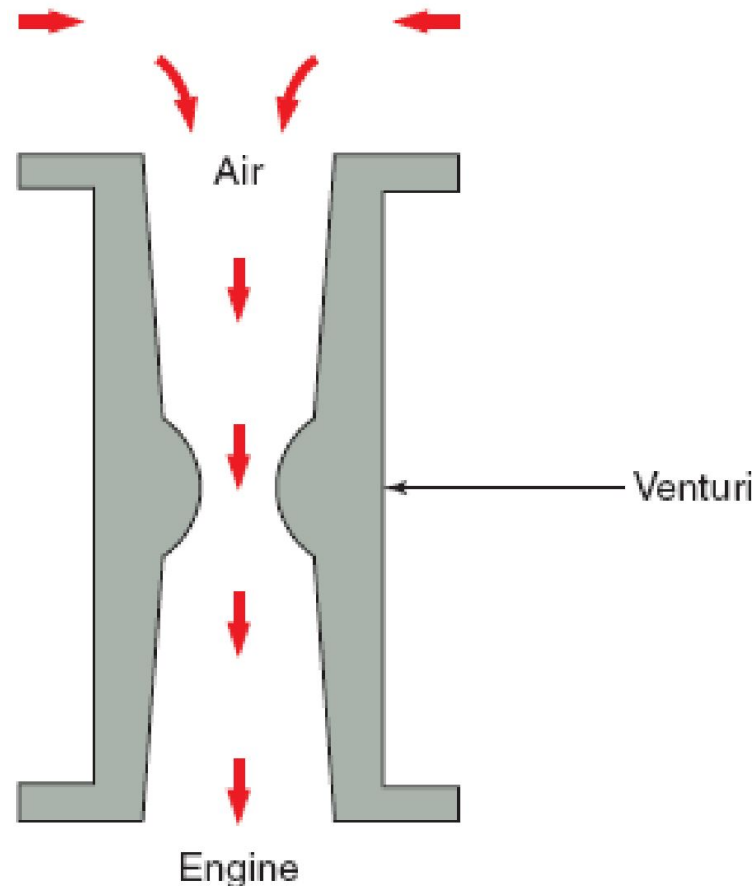
An updraft carburetor (Figure 21) is a carburetor in which the air flows into the venturi in an upward direction.

Updraft carburetors are installed commonly in older, larger engines.



**Figure 21** An updraft float carburetor system.

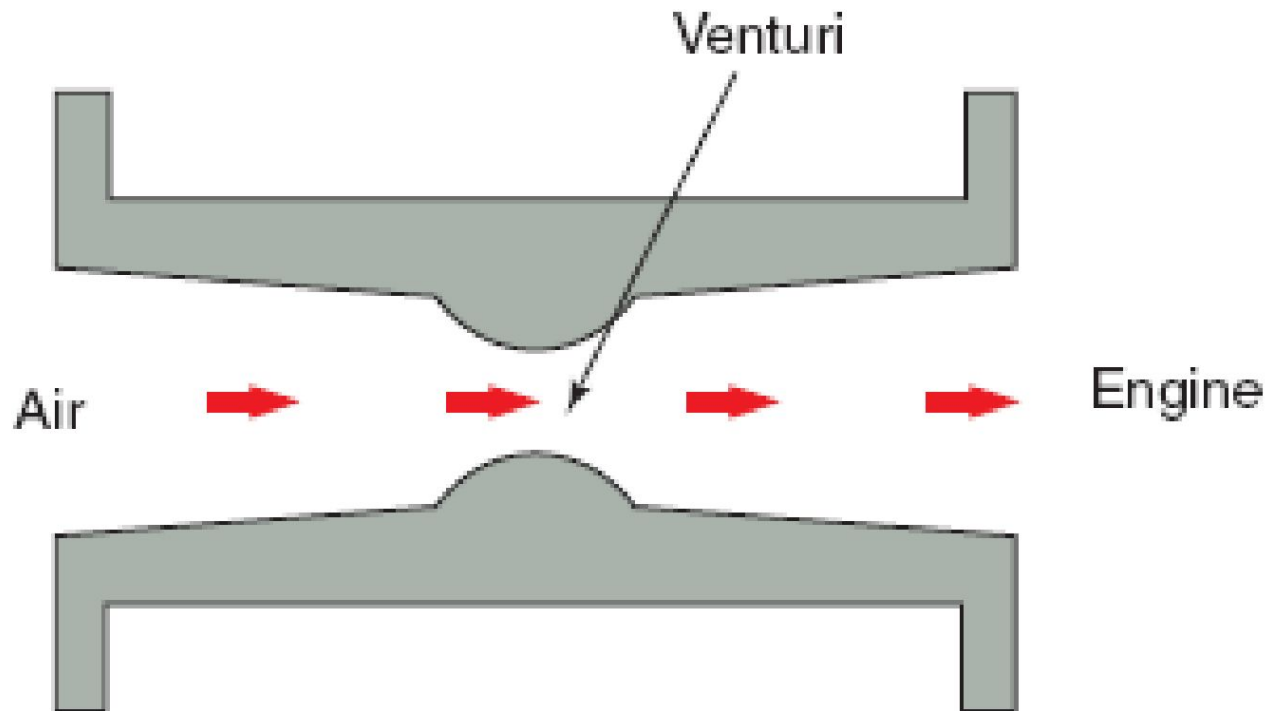
A downdraft carburetor (Figure 22) is a carburetor in which the air flows into the venturi in a downward direction. Downdraft carburetors are used in some multiple cylinder engines. An intake manifold is used to connect a downdraft carburetor to the intake ports of each cylinder.



**Figure 22** A downdraft float carburetor system.



A sidedraft carburetor (Figure 23) is a carburetor in which the air flows into the venturi from the side. The sidedraft carburetor is common and is used in many sizes and styles of engines.



**Figure 23** A sidedraft float carburetor system.

# Float Carburetor Operation

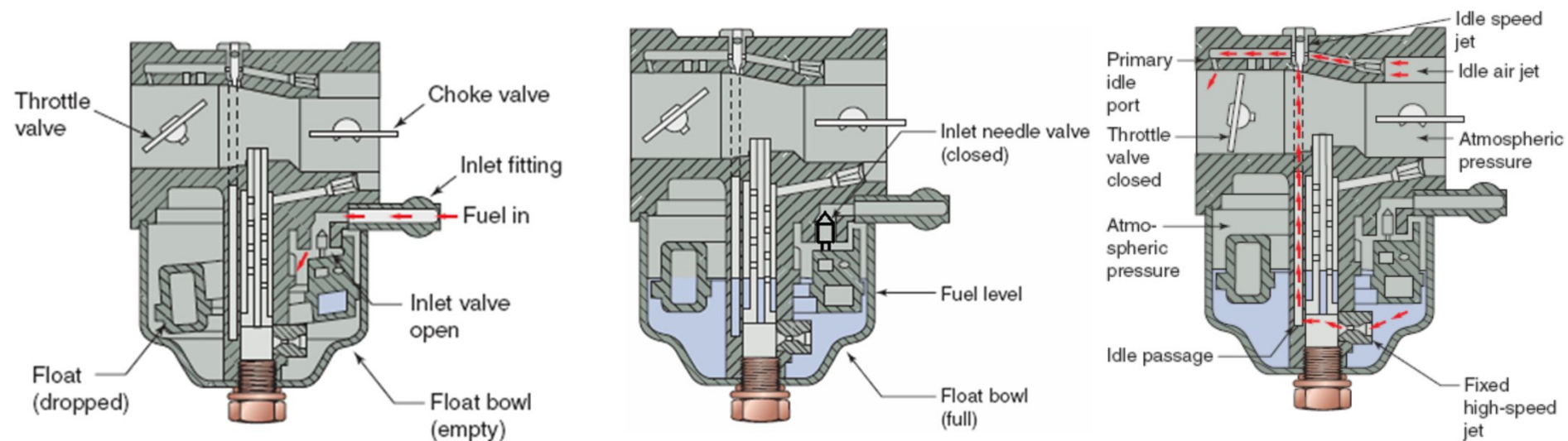
Most float carburetors operate in the same fashion. The operation of the carburetor can be divided into different systems:

Float operation

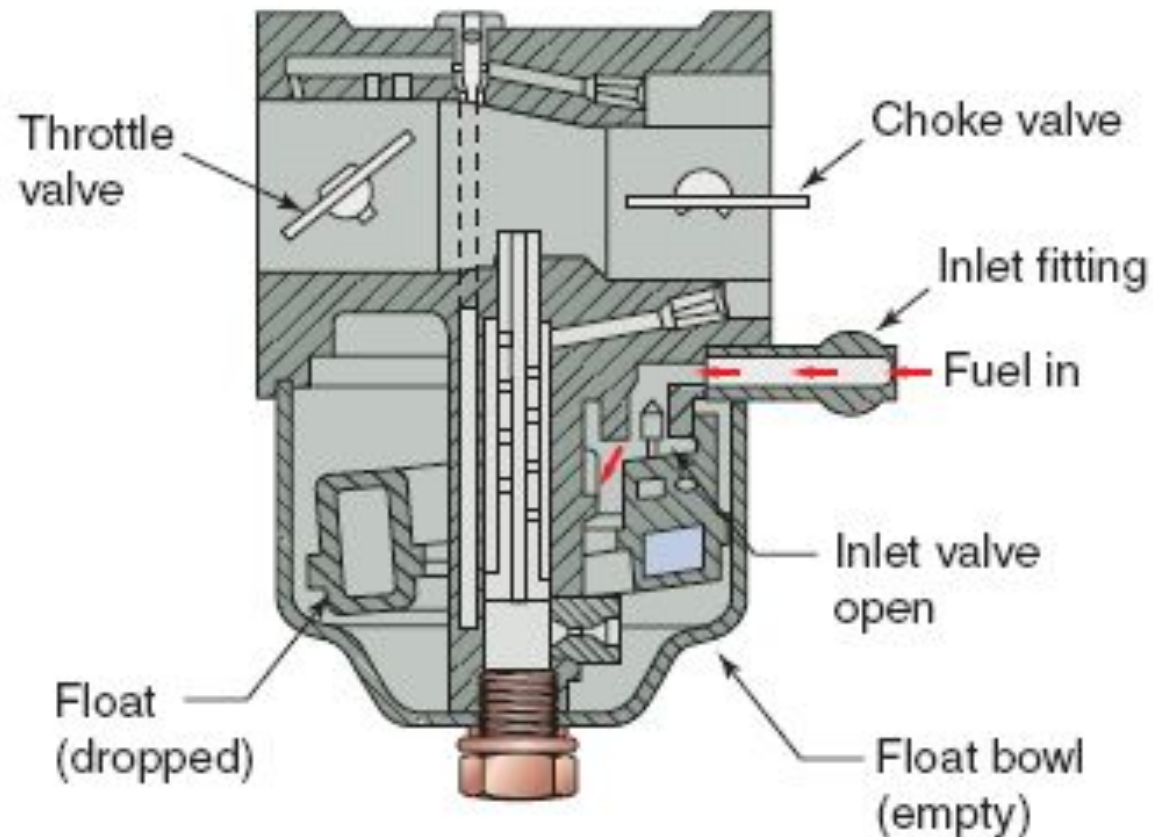
Idle (low-speed) circuit operation

Part throttle circuit operation (transition from low speed to high speed)

Main (high-speed) circuit operation

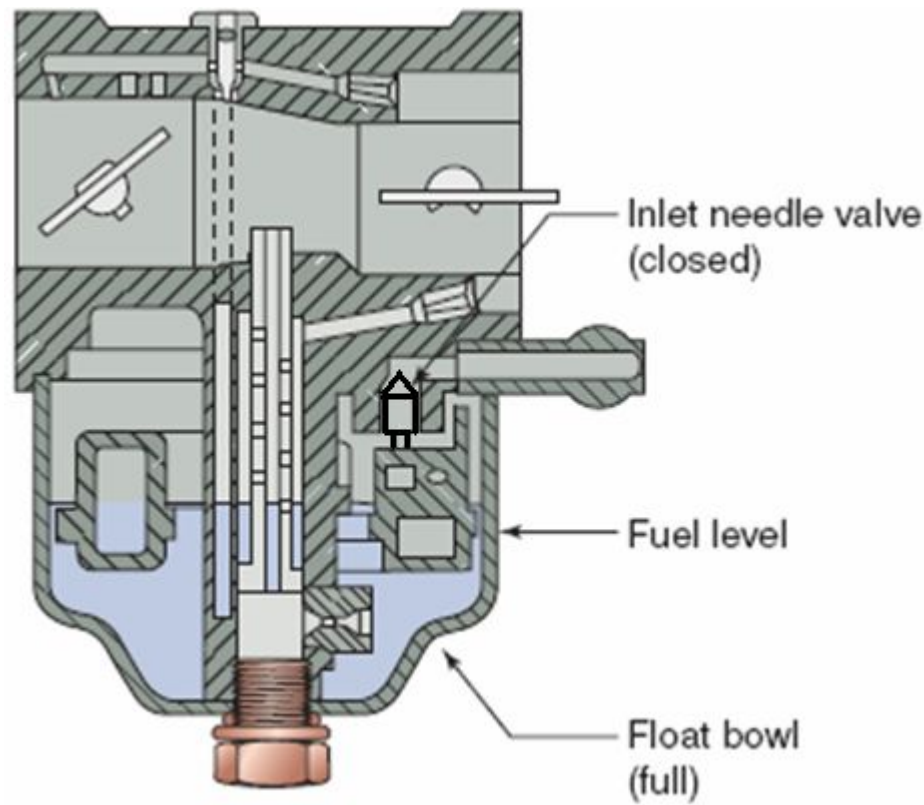


The float system operates at all times and at all engine speeds (Figure 24). It provides fuel for all the carburetor circuits. Fuel flows from the fuel tank to the carburetor by gravity or a fuel pump. Fuel enters the carburetor through the inlet fitting. It goes past the inlet needle valve and begins filling the carburetor bowl.



**Figure 24** Fuel flows into the float bowl when the float bowl is low (dropped).

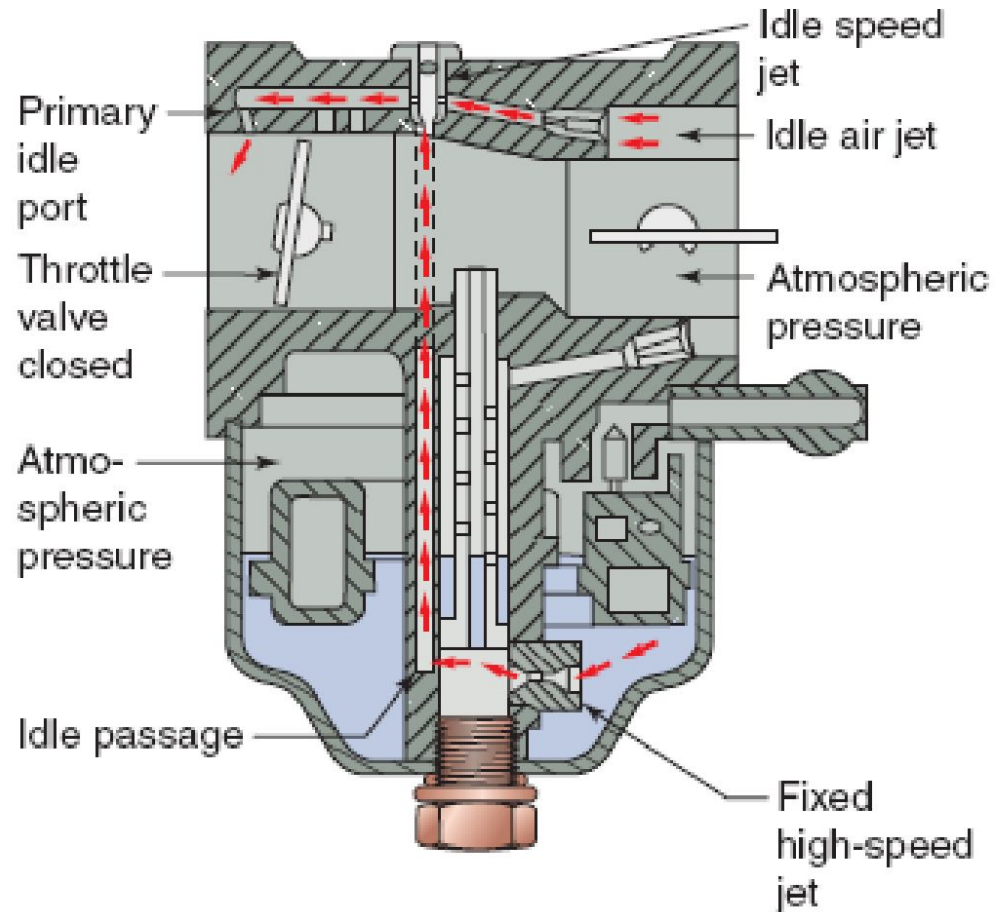
As the bowl fills, the float rises, raising the inlet needle valve toward the inlet seat (Figure 25). When the inlet needle closes, fuel flow into the bowl stops. Fuel remains at this level until engine operation begins to draw fuel from the bowl. When the fuel level drops again, the float moves down, causing the inlet needle valve to move away from the inlet seat. Fuel again flows into the float bowl. This happens over and over to provide a constant fuel supply.



**Figure 25** When the float bowl is filled, the flow of fuel is stopped.

When the engine is idling, the throttle valve is in the closed (or nearly closed) position. The idle circuit delivers air–fuel mixture to the intake port side of the throttle valve (Figure 26). Without this system, the engine would not run at idle speed.

When the cylinder is on an intake stroke, a low-pressure area is created in the intake port. The carburetor throttle plate area also has low pressure at this time. Higher atmospheric pressure in the carburetor bowl pushes fuel through a fixed-sized, high-speed jet through the low pressure area. Fuel continues up a small passage called the idle passage.

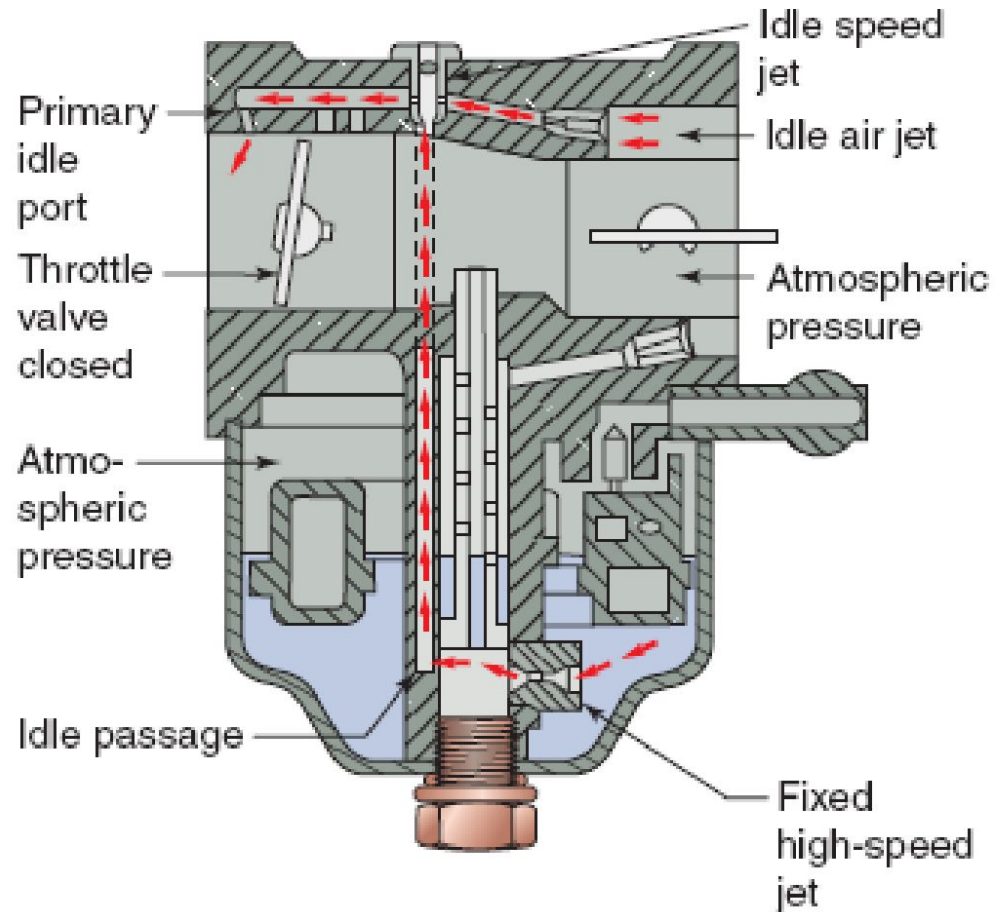


**Figure 26** A typical idle circuit.

The atmospheric pressure from the intake stroke also pulls air into the throat of the carburetor. Some of this air goes through a passage called the idle air bleed. As the fuel comes up the idle passage, it enters the center of the idle speed jet.

Here it mixes with air from the idle air bleed. The air–fuel mixture is then pulled through a passage, called the primary idle port.

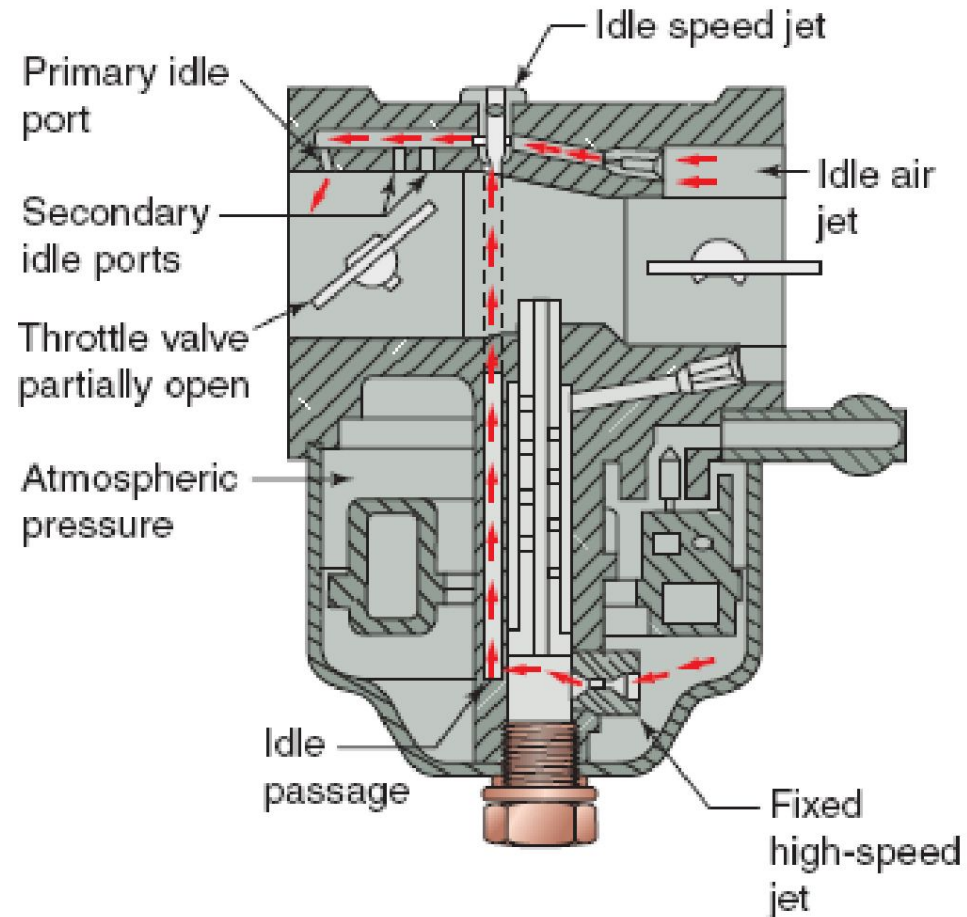
It then goes into the carburetor throat. Here, it mixes with air flowing through the carburetor throat and goes into the engine's cylinder.



**Figure 26** A typical idle circuit.

When an operator wants a speed increase, the throttle linkage is used to open the throttle valve. The carburetor uses the part throttle system (Figure 27) when the throttle valve is open part of the way. The part throttle system has the same air–fuel flow as the idle system, with one exception. There are several secondary idle ports in the carburetor throat.

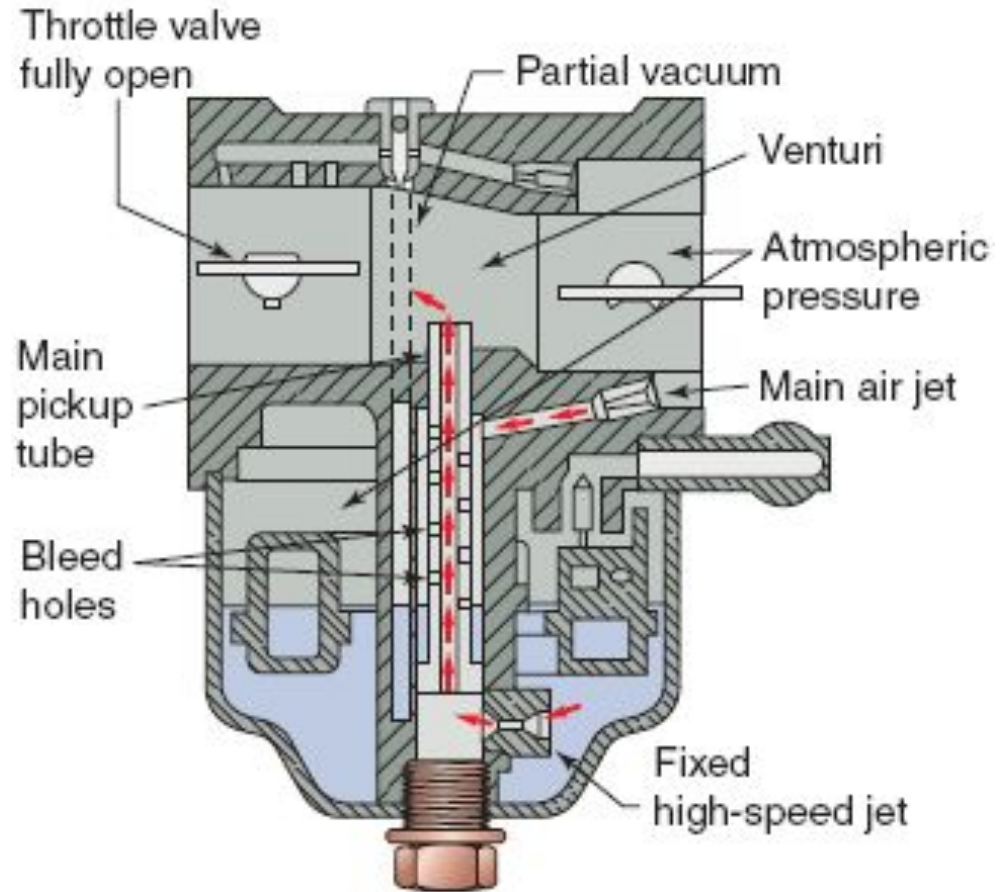
These are uncovered as the throttle plate opens. The secondary ports give additional routes for the air–fuel mixture for part throttle engine speeds. The part throttle system can operate momentarily as the throttle passes from idle to high speed. It can also operate continuously if the throttle stays in the part throttle position.



**Figure 27** The secondary idle ports are used to assist when the user applies an increase in throttle.

When the operator moves the throttle linkage past the part throttle position to more fully open position, the carburetor uses the high-speed system (Figure 28). The intake stroke causes a low pressure in the carburetor throat.

Atmospheric pressure pulls air through the venturi in the middle of the carburetor throat. There is a drop in pressure at the venturi. Atmospheric pressure pushes fuel through the fixed high-speed jet. From there, it goes through a large passage called the main pickup tube.

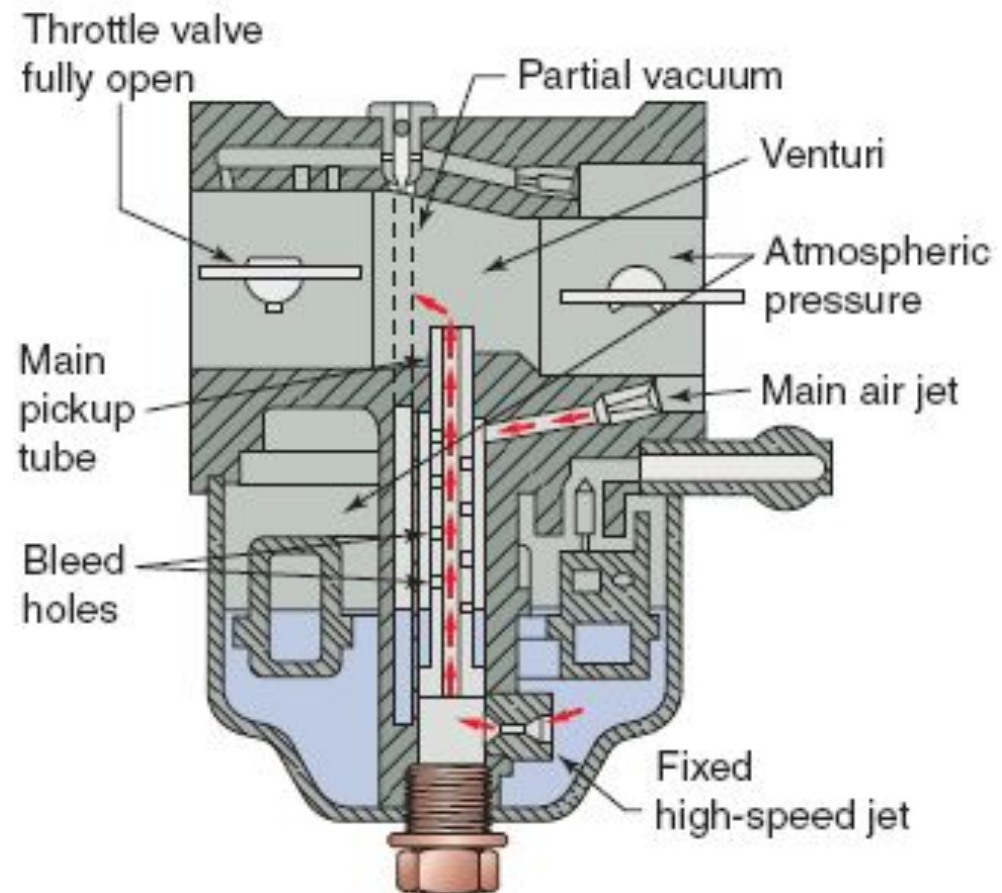


**Figure 28** The high-speed circuit comes into play when the throttle valve is opened over half way.



Atmospheric pressure also pushes air through a large air passage, called the main air bleed. From this, air flows to the outside of the main pickup tube.

This air enters through the main pickup tube bleed holes. There, it mixes with the fuel coming up the inside of the main pickup tube. The air–fuel mixture is pushed up and out of the main pickup tube into the incoming air at the venturi.



**Figure 28** The high-speed circuit comes into play when the throttle valve is opened over half way.

### 3. Diaphragm Carburetors

A diaphragm carburetor (Figure 29) is a carburetor that has a flexible diaphragm to regulate the amount of fuel available inside the carburetor. It can be operated in any position.

Float- and vacuum-type carburetors work only in engines that are used in the upright position. For this reason, an engine equipped with a float or vacuum carburetor cannot be turned on its side or upside down, in which case the float or fuel tube would not be able to regulate the fuel level, and the engine would run out of fuel and stop.



**Figure 29** A diaphragm carburetor can be turned in any angle without impairing operation

# *Diaphragm Carburetor Operation*

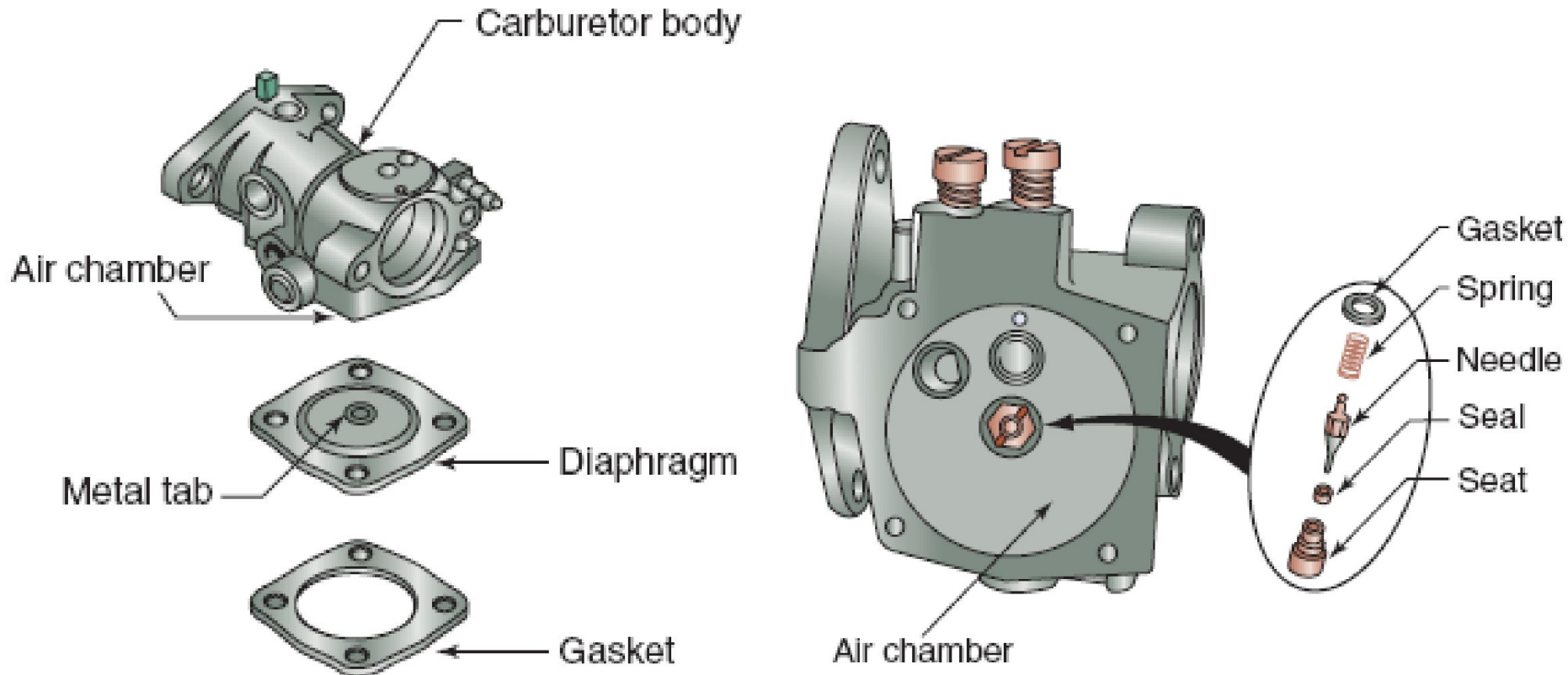
Handheld outdoor power equipment such as chainsaws, leaf blowers, and string trimmers, which must work in any position, use engines equipped with diaphragm carburetors, as they can operate in any position.

The diaphragm carburetor is, in many ways, very much the same as a float carburetor. It has a throat, throttle valve, and venturi. But the diaphragm carburetor does not have a float bowl.



**Figure 29** A diaphragm carburetor can be turned in any angle without impairing operation

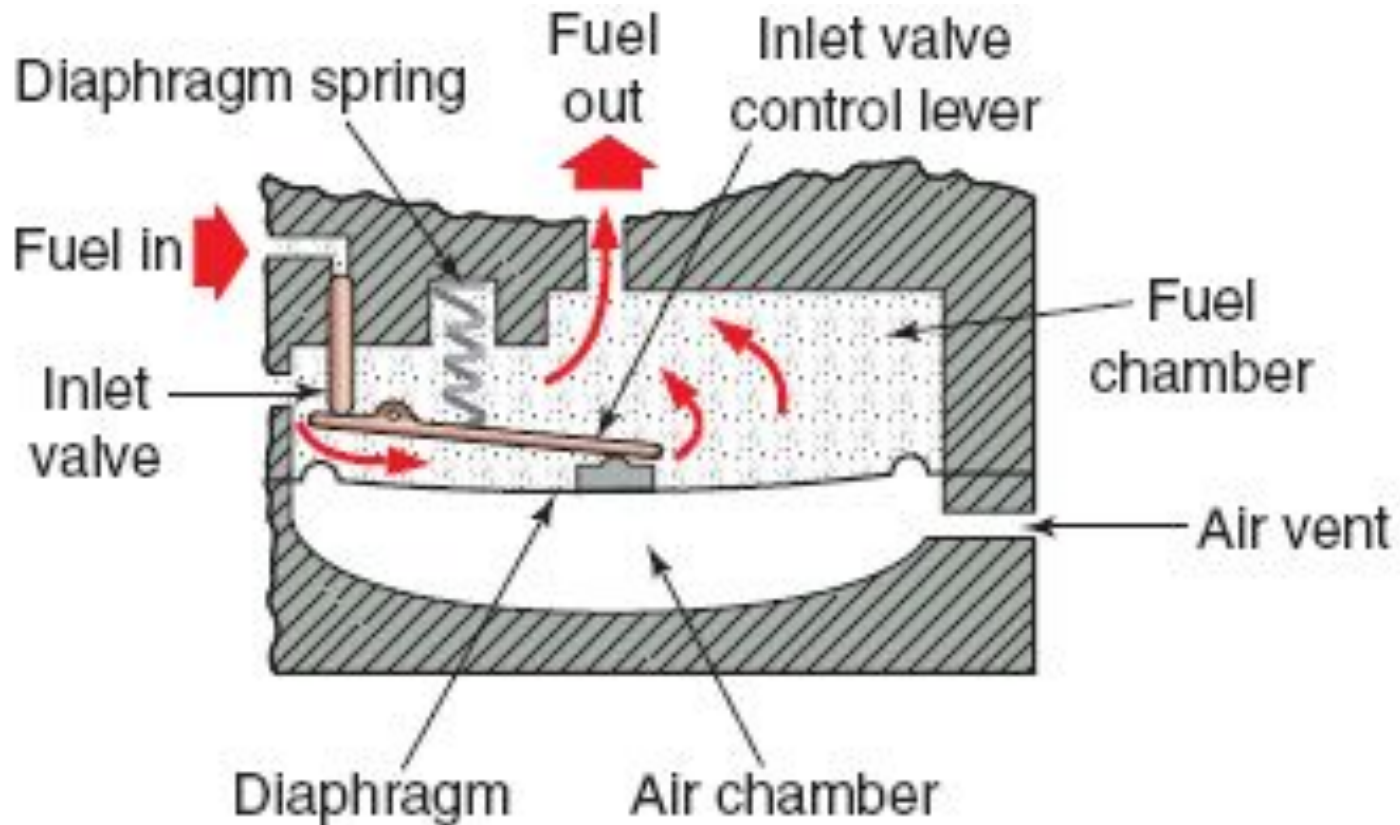
Instead, it uses a diaphragm similar to that used in a fuel pump. The diaphragm controls a small amount of fuel in a fuel chamber. A fuel inlet needle valve similar to that in a float carburetor is used to control fuel flow into the carburetor (Figure 30).



### Diaphragm parts

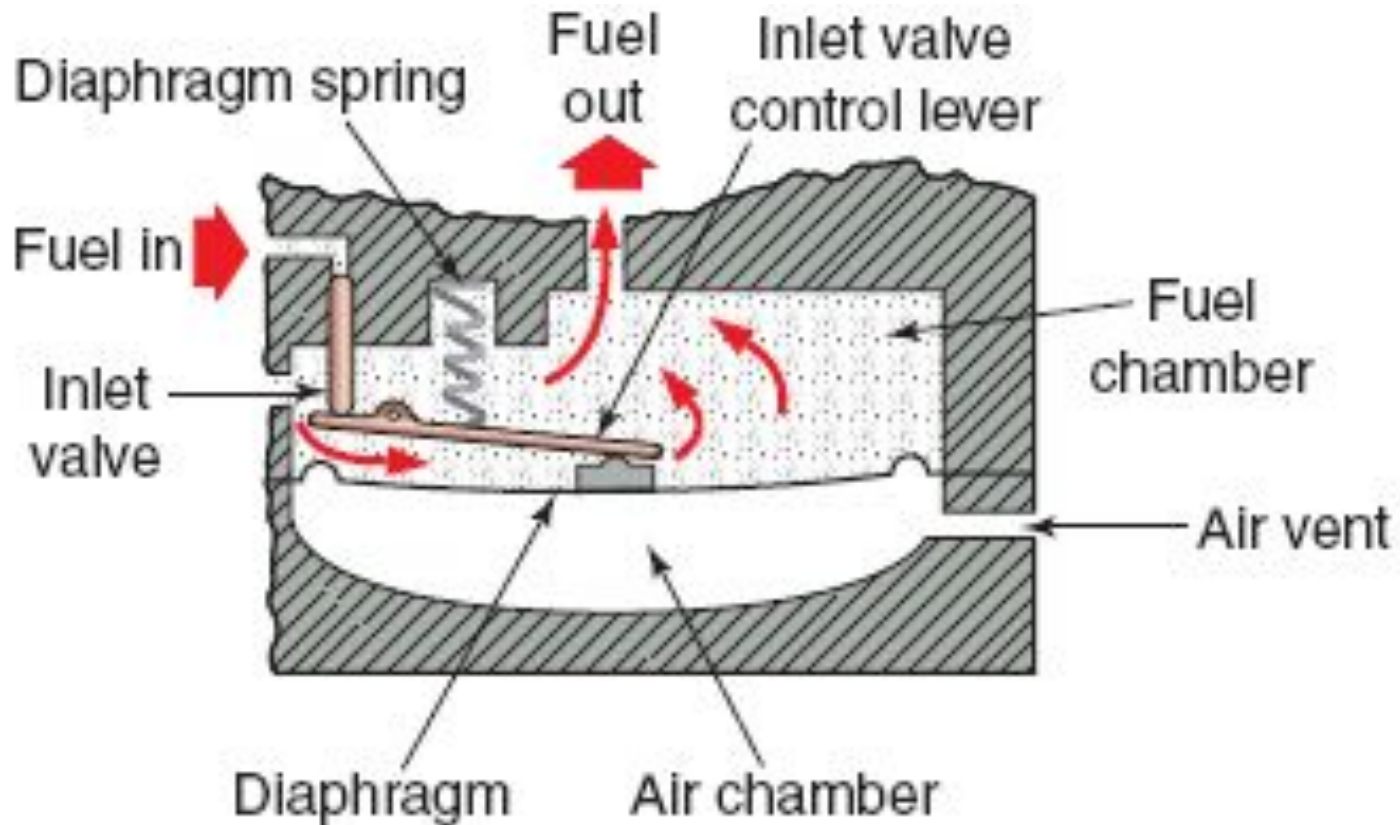
**Figure 30** The parts of a diaphragm carburetor

The diaphragm is made from a flexible, rubber-like material. It's stretched across a small space above the diaphragm, called a fuel chamber. The center of the diaphragm has a metal tab (or lever in some designs) that contacts the inlet needle valve (Figure 31).



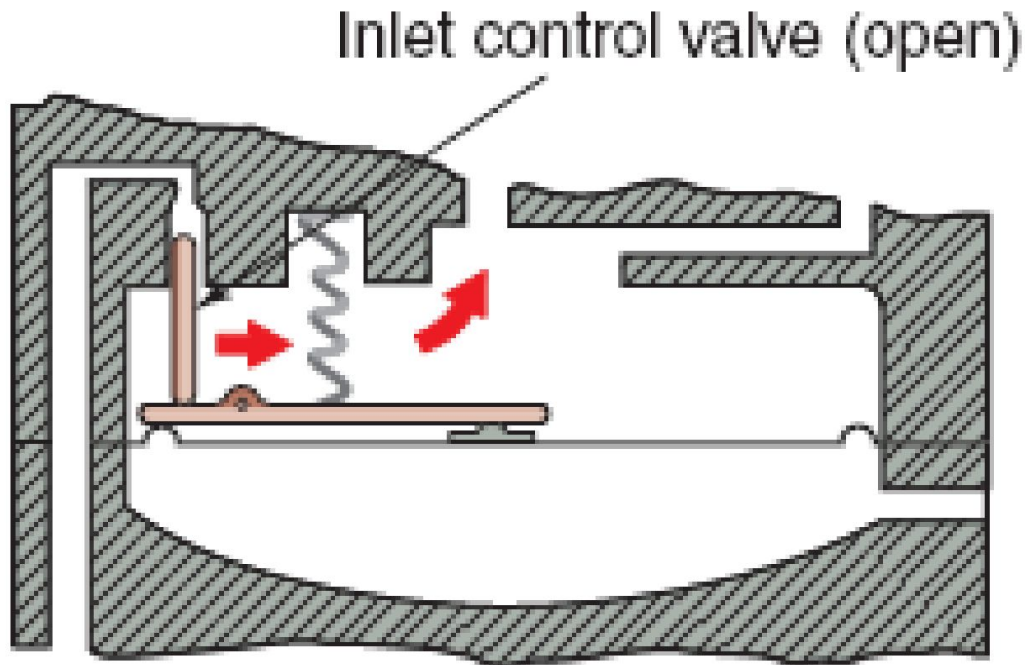
**Figure 31** A diaphragm carburetor has two chambers: one for fuel and one for atmospheric pressure

The inlet needle valve works the same way as the needle valve in a float carburetor. The space below the diaphragm is called an air chamber, which has an air vent that allows air at atmospheric pressure below the diaphragm. The air chamber provides the space for diaphragm up-and-down movement



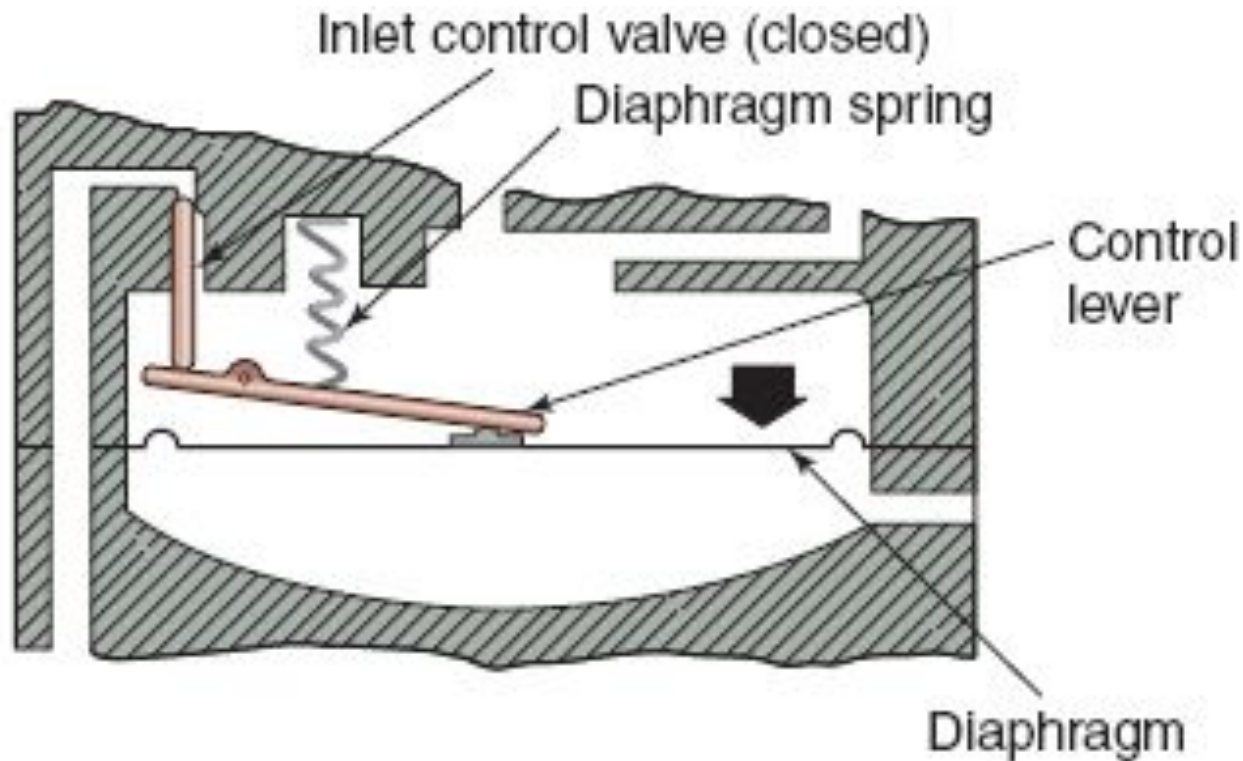
**Figure 31** A diaphragm carburetor has two chambers: one for fuel and one for atmospheric pressure

As fuel flows from the fuel tank to the fuel inlet, the spring pushes down on the control lever, causing the needle valve to drop down and allowing fuel to come in around the inlet needle valve. As the fuel fills up the chamber, its weight pushes down on the diaphragm (Figure 32).



**Figure 32** The inlet valve of the diaphragm carburetor in the open position. As fuel enters the chamber, it pushes down on the diaphragm

Downward movement of the diaphragm causes the control lever to pivot upward. This movement pushes up on the inlet needle valve, closing the fuel inlet (Figure 33). When fuel is used up, the diaphragm comes back up, allowing the inlet needle valve to open to let fuel in again.

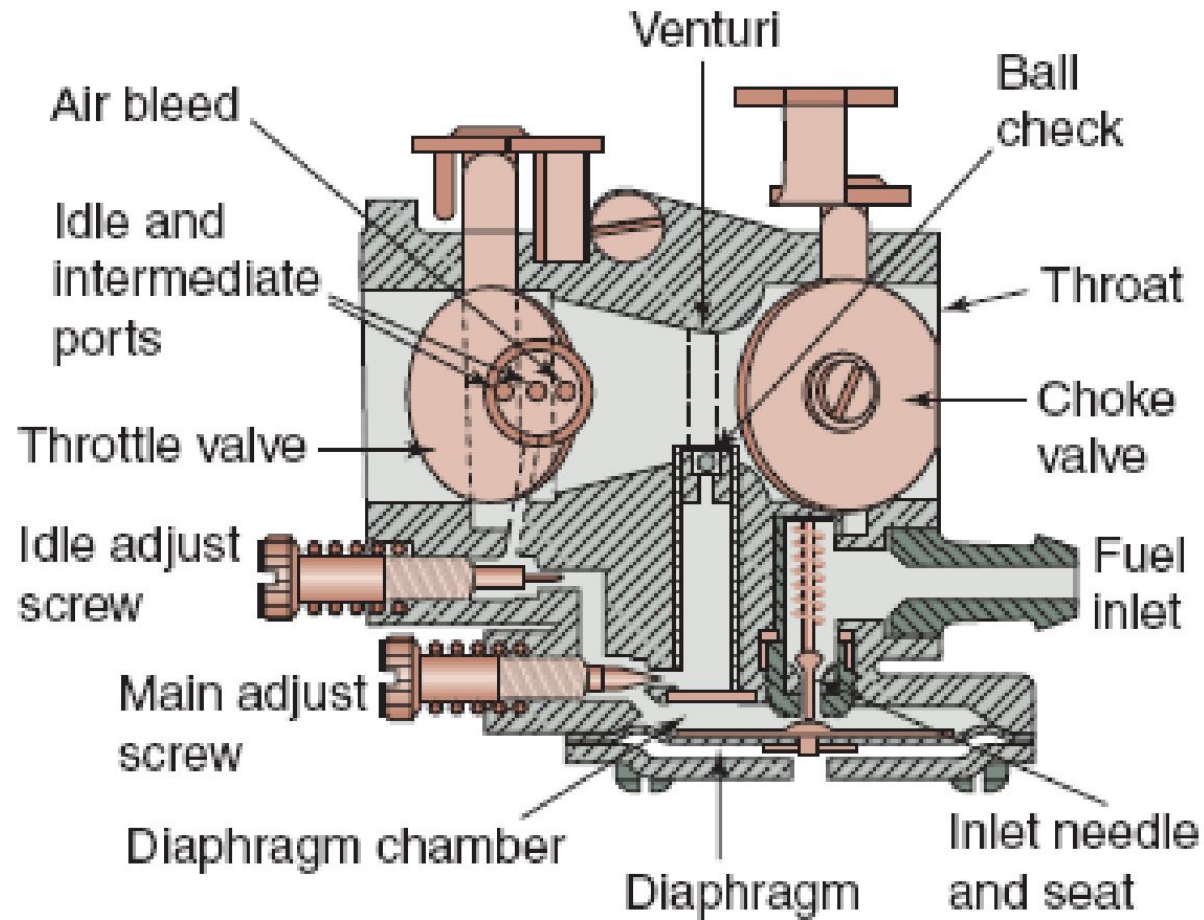


**Figure 33** Once fuel has filled the chamber of the diaphragm carburetor, the inlet control valve closes off the flow of fuel, just as on a float type carburetor



# *Modes of Operation of a Diaphragm Carburetor*

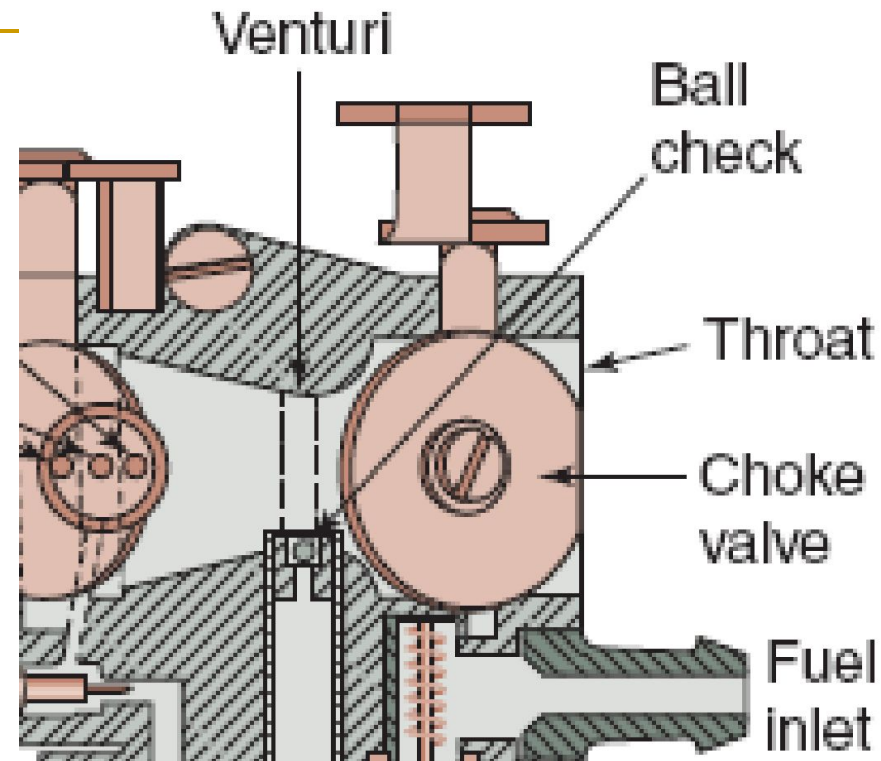
Just as with every other type of carburetor, the diaphragm carburetor provides the correct air-fuel mixtures for several modes (circuits) of operation (Figure 34).



**Figure 34** The various circuits of a diaphragm carburetor

## ■ Cold starting

When the engine is cold, a rich mixture is required for starting. The choke system has a valve in the carburetor throat, as we had discussed earlier in this chapter. In the choke mode, the choke valve is closed.



The only air that can get into the engine enters through openings around the choke valve. When the engine is cranked during starting, the intake stroke creates a low pressure in the venturi. The low pressure pulls fuel from the diaphragm chamber up the main nozzle. The fuel mixes with the air that passes around the choke valve. A very rich air–fuel mixture is used to start the cold engine.

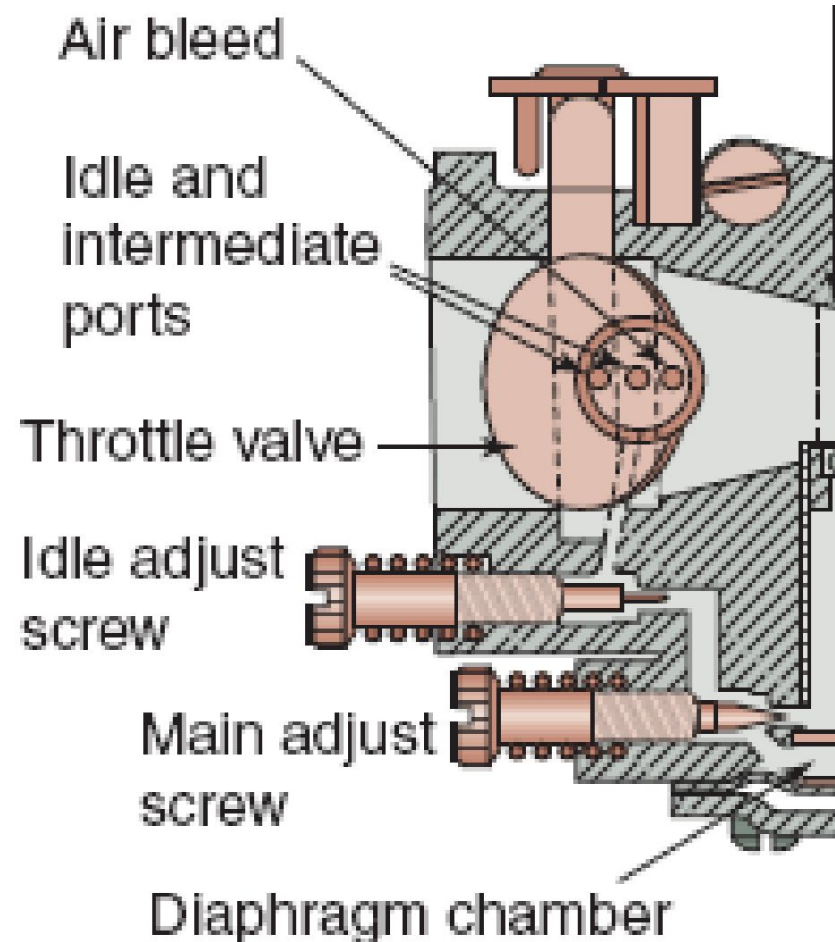
During idle speeds, only a small amount of fuel is needed to keep the engine running. The throttle valve is almost closed during idle.

A small idle discharge port is located on the engine side of the closed throttle valve. The low pressure in this area pulls fuel from the diaphragm chamber. Fuel goes past an idle adjusting screw and is delivered behind the throttle valve.

The fuel is mixed with air that gets through the almost closed throttle valve. Additional air comes through an idle air bleed passage.

The idle adjusting screw adjusts the amount of fuel that is delivered out the idle discharge port.

## ■ Idle



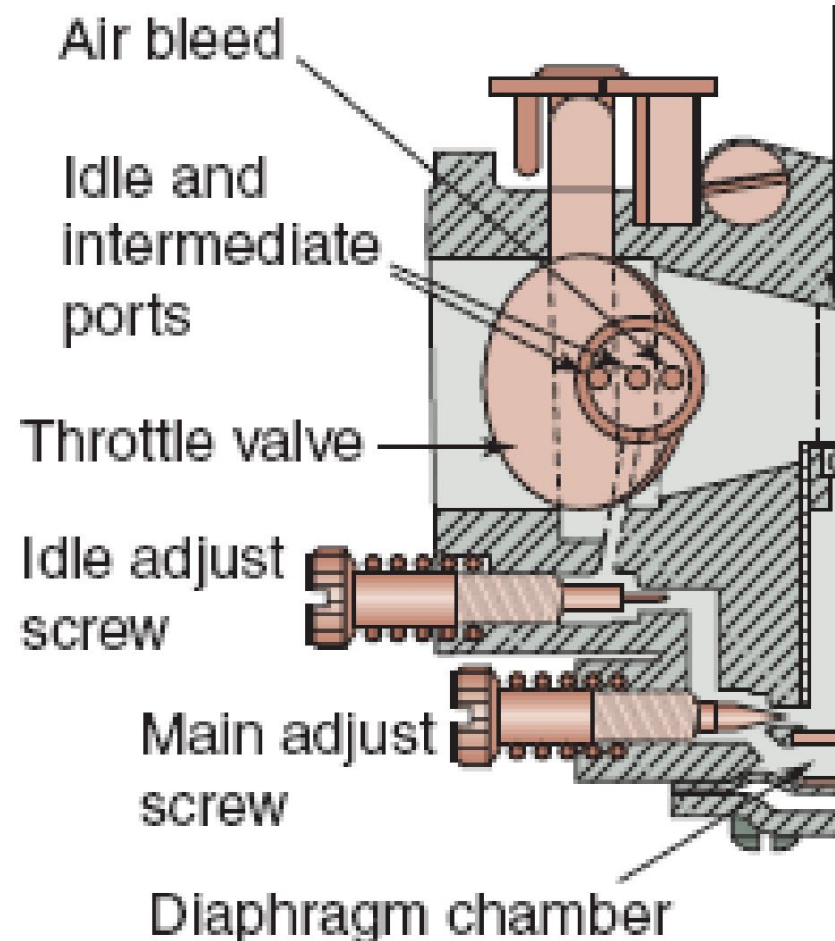
## ■ Intermediate speed

When the throttle valve is moved past the idle position, it uncovers one more discharge port, called the intermediate port. It provides more fuel to mix with the air flowing into the engine.

The fuel flows from the diaphragm chamber past the idle mixture adjusting screw.

Fuel and air flows are the same as in the idle mode.

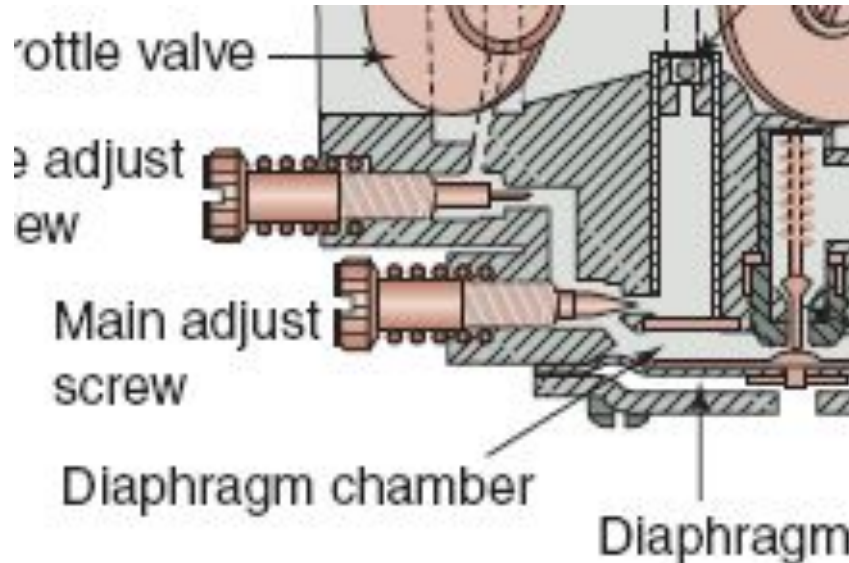
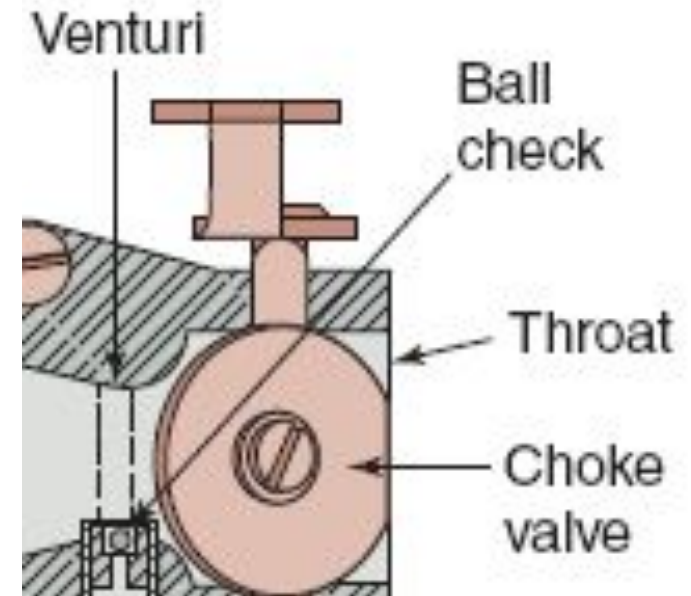
The additional fuel from the intermediate ports allows the engine to operate at higher speeds.



## ■ The high-speed circuit

The high-speed circuit is used when the throttle valve is opened further. Air flows through the carburetor throat at high speed.

The venturi further accelerates the air flow and creates a low pressure in the venturi area. This low pressure pulls fuel into the air stream through a delivery tube called the main nozzle.



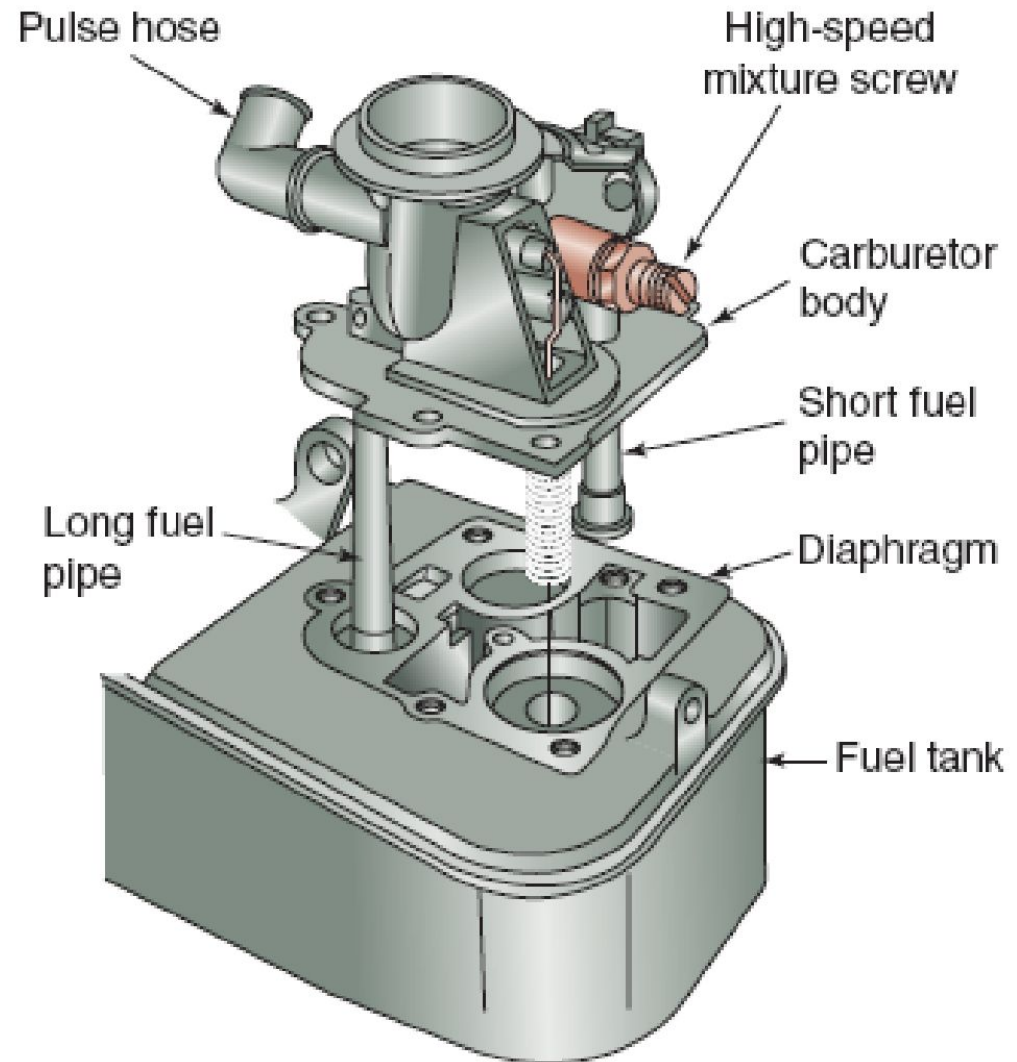
Fuel flows into the main nozzle through a passageway from the diaphragm chamber. Fuel going up the main nozzle must pass the main adjusting screw, which is used to adjust the amount of fuel for high-speed operation.

# 4. Suction Feed Diaphragm Carburetors

The suction feed diaphragm carburetor is a carburetor that combines the features of a vacuum carburetor and the impulse fuel pump (Figure 35).

This carburetor is used primarily in four-stroke engines. These engines are not usually used in a variety of positions.

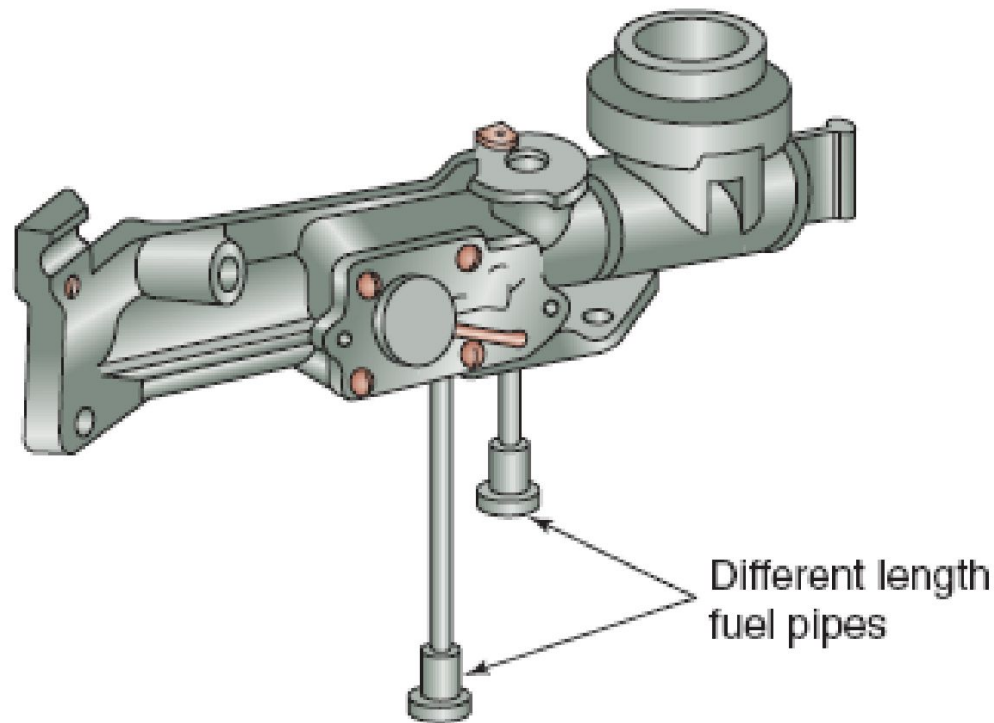
The carburetor is mounted on the top of the fuel tank. It meters fuel the same way as the vacuum carburetor.



**Figure 35** The suction feed diaphragm carburetor is one that combines the features of a vacuum carburetor and the impulse fuel pump

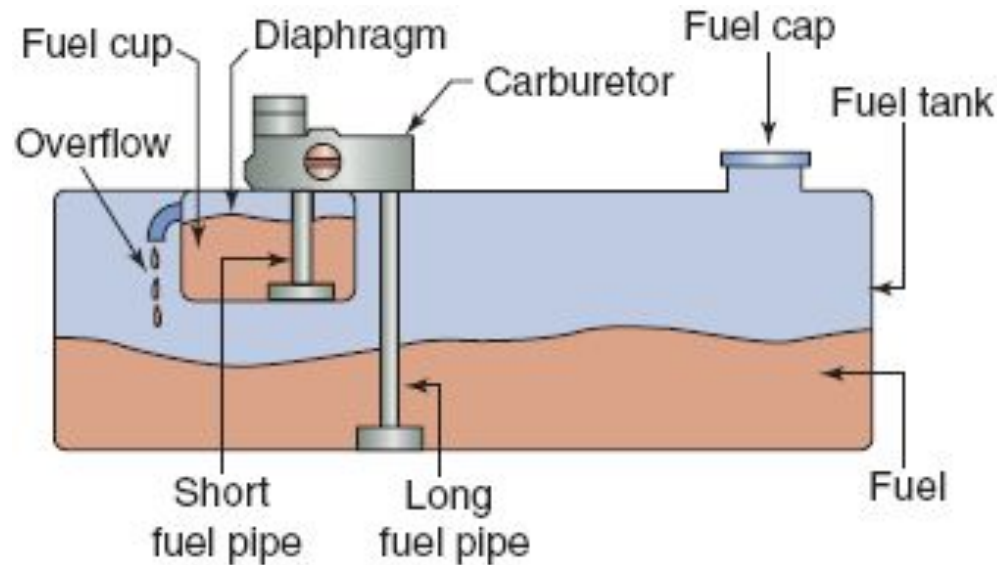
Some carburetors have the diaphragm mounted in a side chamber. Others have the diaphragm located between the carburetor body and the fuel tank.

This carburetor is different from the vacuum carburetor. It has two different-length fuel pipes (Figure 36). The longer fuel pipe goes into the fuel tank and is used to pull fuel out of the tank and into a small chamber. The shorter fuel pipe goes into a small chamber of the fuel tank. The chamber is called the fuel cup or fuel well.



**Figure 36** The suction feed diaphragm carburetor has two, different-length fuel pipes

A diaphragm fits between the carburetor and the fuel cup. The diaphragm works like an impulse fuel pump, transferring fuel between the tank and the fuel cup (Figure 37). This system gives a constant level of fuel, regardless of fuel tank level.



A pulse hose connects the pumping chamber to the intake manifold (or crankcase in some designs). When the engine is running, the pulse hose transmits a pulse to the diaphragm chamber.

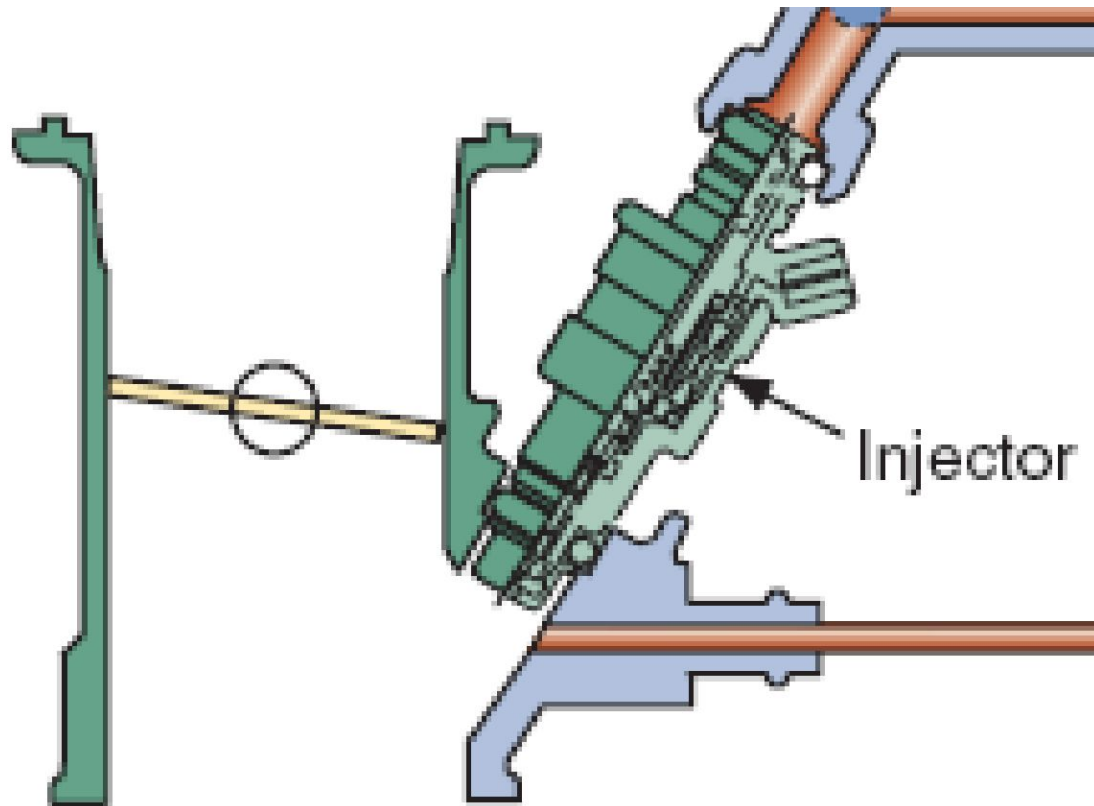
The diaphragm moves up and down with the pressure pulses, pumping fuel up the long fuel pipe into the fuel tank cup. Fuel goes out of the fuel cup into the venturi through the short fuel pipe.

**Figure 37** The suction feed carburetor drawing fuel from the fuel tank.



# FUEL INJECTION

## Fuel Systems



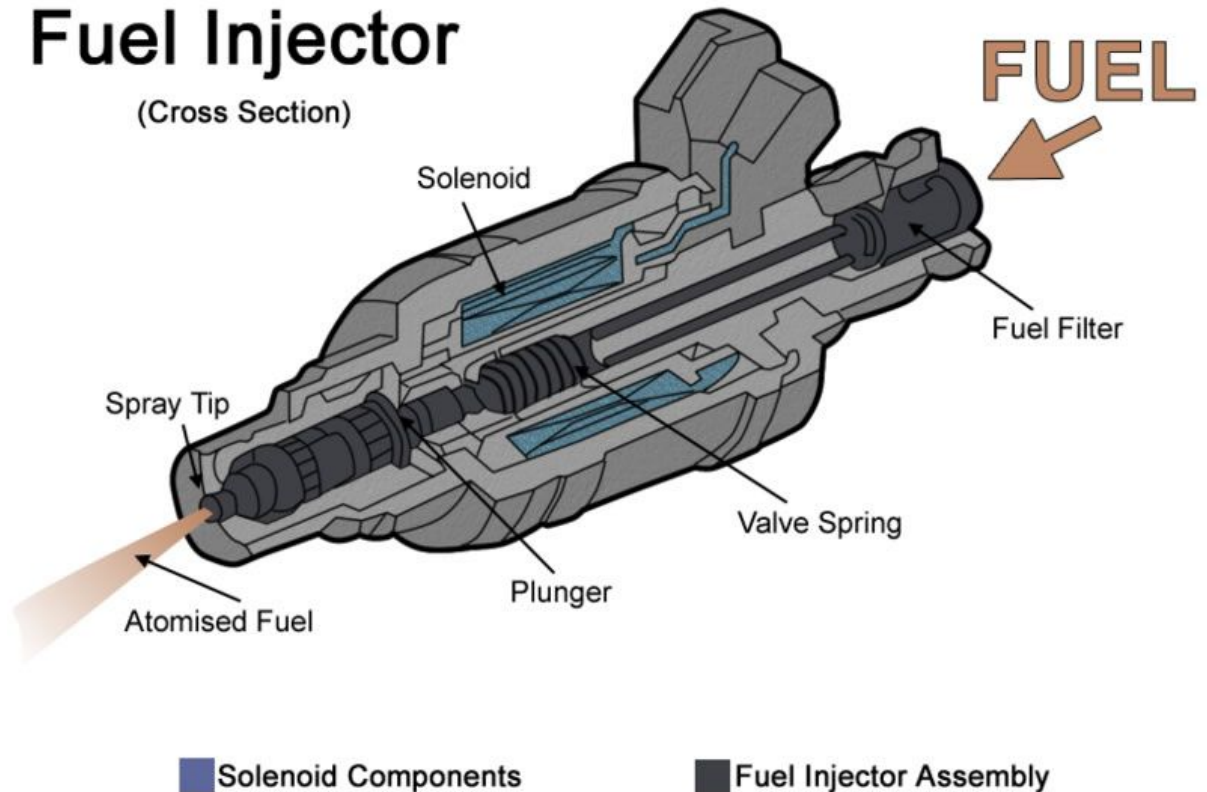
# FUEL INJECTION

Fuel injection is the most modern method for carburetion in today's power equipment engines. The purpose of fuel injection is to allow a precise metering of air–fuel mixture ratios at any given engine condition.

This results in the engine getting only the amount of fuel it needs at all times, instead of a preset amount being delivered at all times, as with traditional carburetors. Other than the method of getting fuel into the engine, the basic components of this system aren't much different from those of a standard carburetor engine.

## Fuel Injector

(Cross Section)

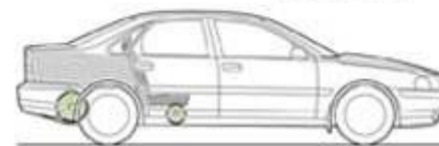
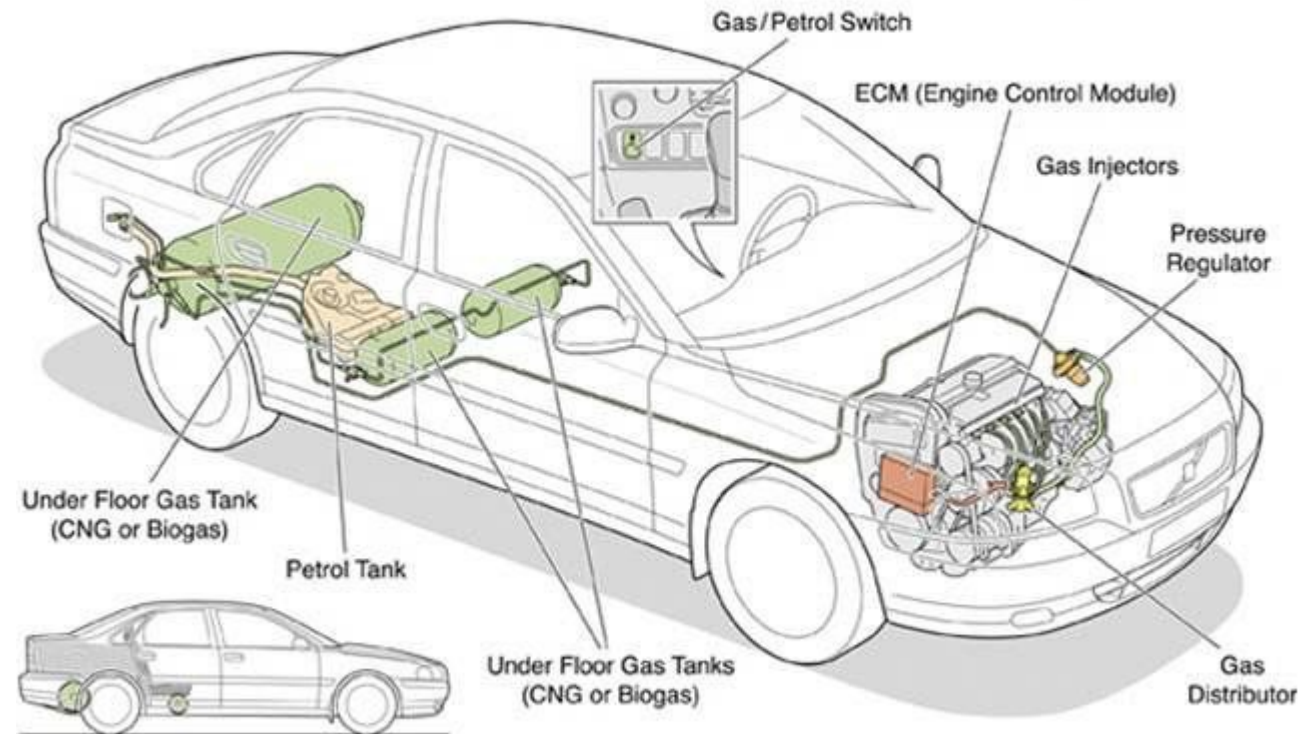


# FUEL INJECTION

In today's power equipment engines, fuel injection is becoming popular as using it leads to easier compliance with the strict guidelines of the environmental requirements.

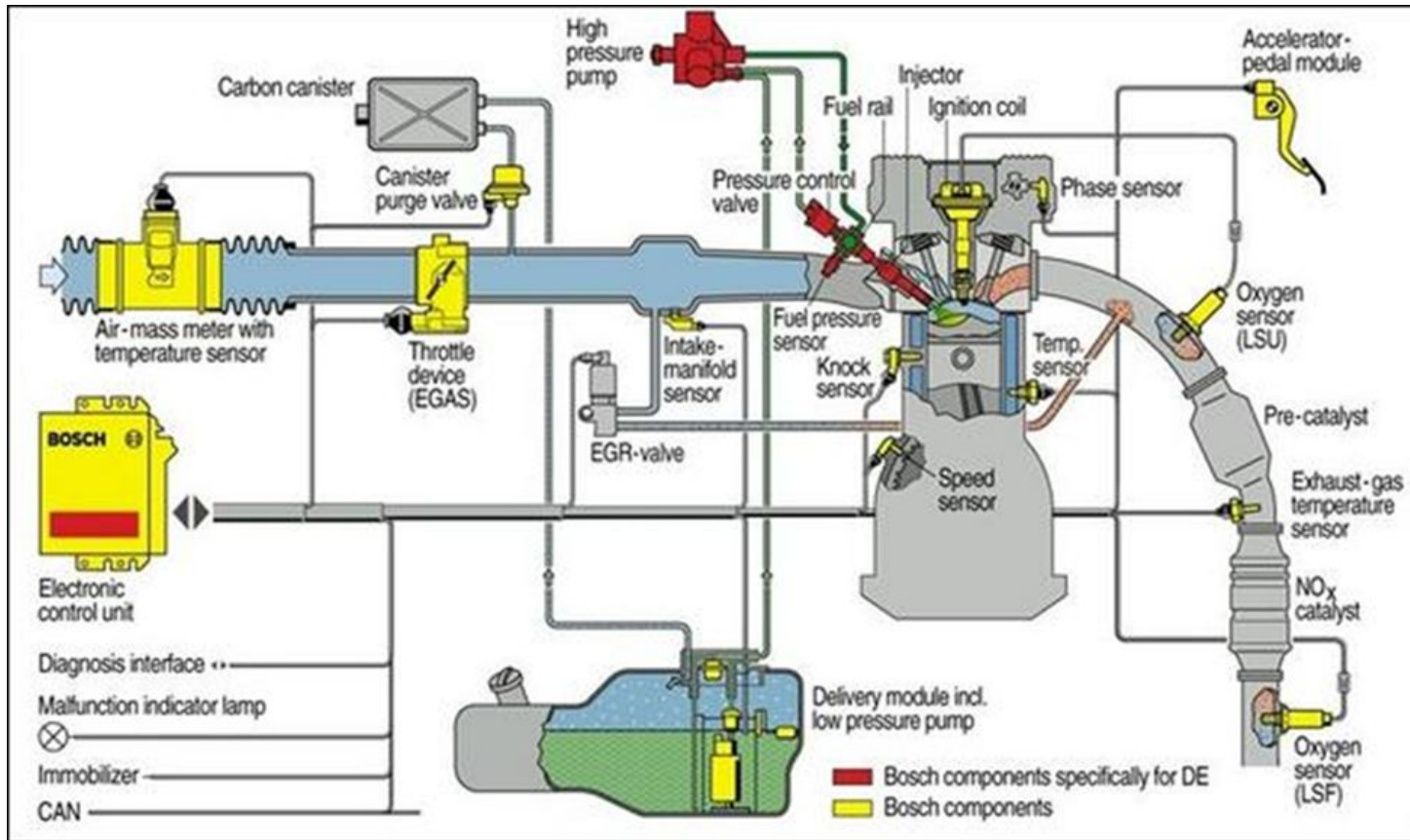
The primary advantage of fuel injection over traditional carburetion is the ability of a fuel injected engine to automatically adjust to the constantly changing atmospheric conditions to which it's exposed.

## Bi-Fuel System (CNG, Biogas)



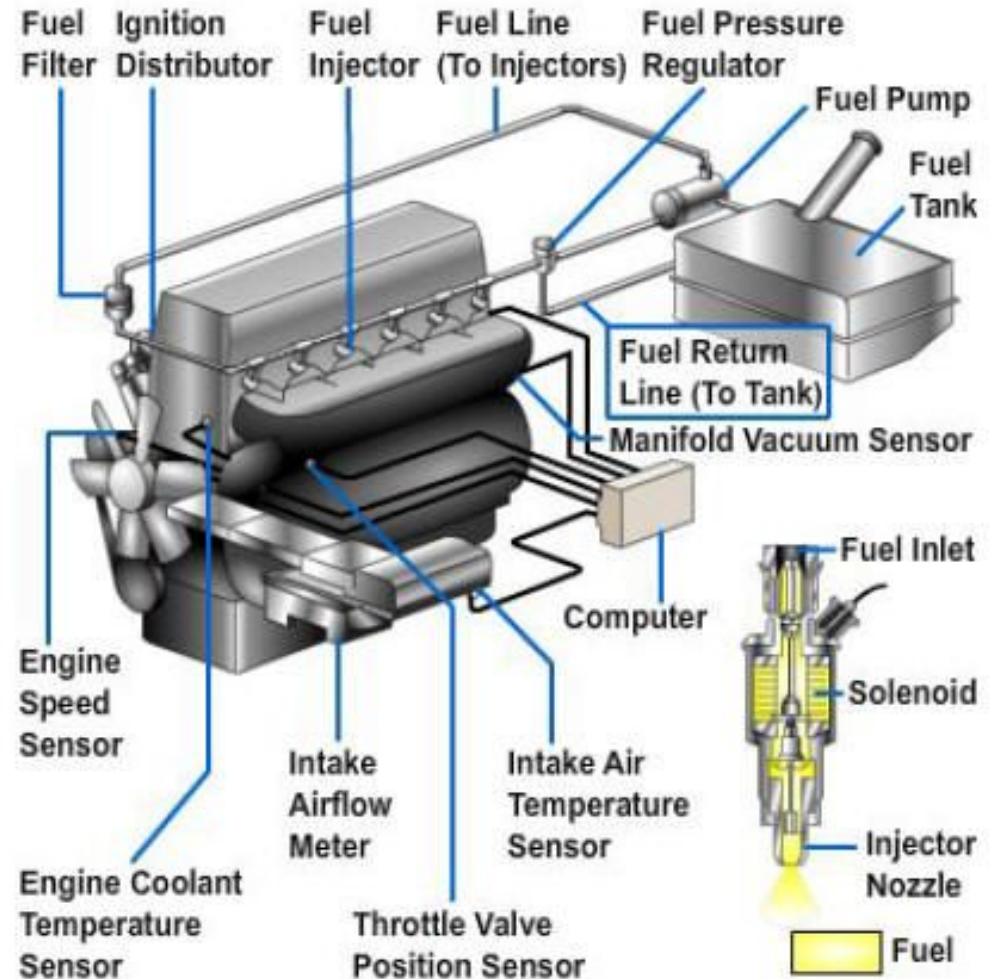
Volvo S80

Conditions such as temperature, humidity, and altitude affect traditional carburetion, altering the efficiency of a carbureted power equipment engine, unless one were to make physical adjustments to the carburetor settings. But with an engine using fuel injection systems, these conditions are compensated for by the use of sensors found within the fuel injection system.



The disadvantage of fuel injection?

Cost. Due to the high cost of fuel injection systems, almost all small power equipment engines continue to use carburetors, whereas larger engines are beginning to move up to the higher technology of fuel injection.



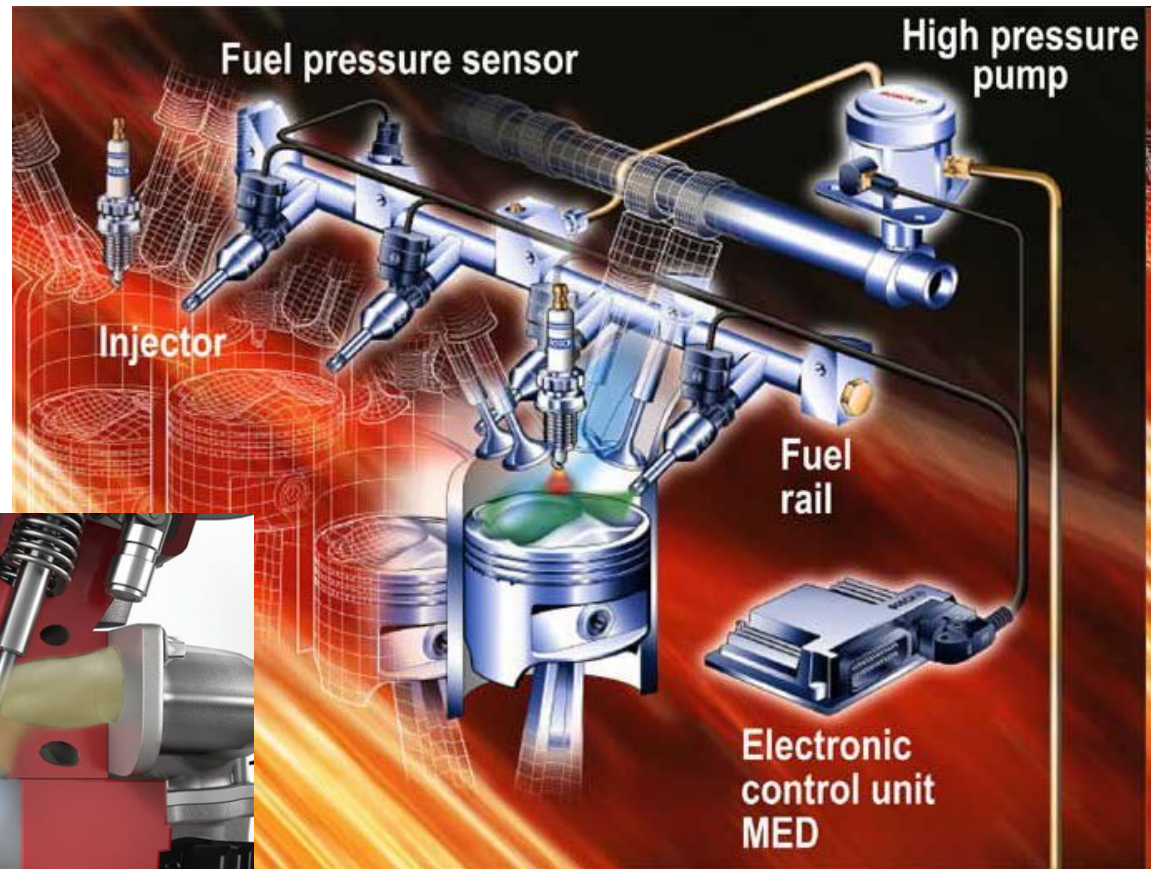
The primary type of fuel injection found in today's power equipment engines is called **indirect fuel injection**.

There is also another type of system known as **direct fuel injection**.

# Direct Fuel Injection

With the direct fuel injection system, fuel is injected directly into the combustion chamber. This type of fuel injection is found primarily in diesel engines and not generally found in power equipment engines.

The direct system injects an extremely fine mist of fuel into the combustion chamber just prior to the top-dead center (TDC) of the engine's compression stroke.



# Indirect Fuel Injection

The indirect fuel injection system is the most common type of fuel injection system found in power equipment engines. When an indirect fuel injection system is used, fuel is injected into the intake tract before the intake valve.



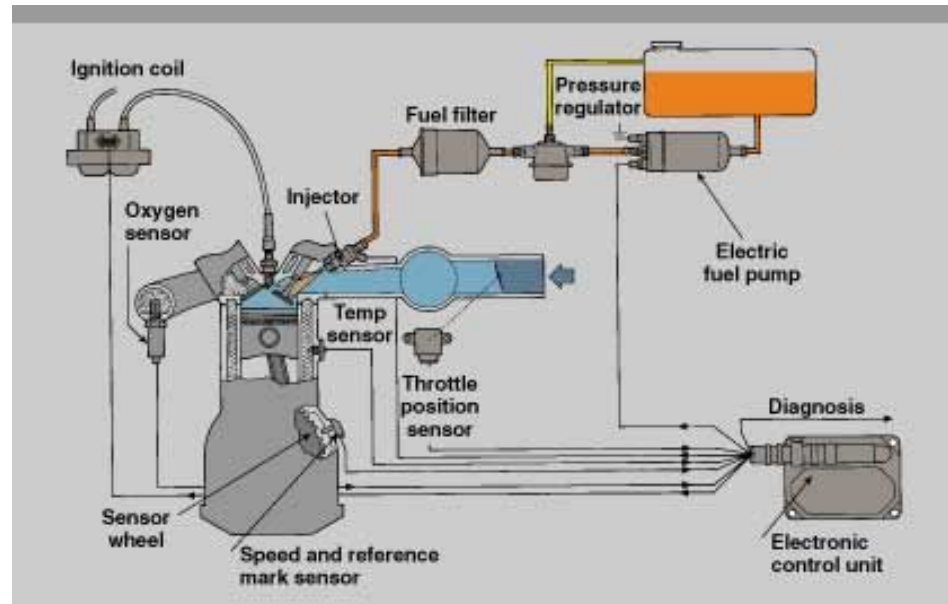
# Indirect Fuel Injection

All modern fuel-injected power equipment engines use a type of **electronic fuel injection (EFI)**. Some manufacturers may use different terms to refer to EFI:

- computerized fuel injection (CFI) or
- programmed fuel injection (PGM-FI).

All these systems use an electronic control module (ECM) to control the amount of fuel being delivered to the engine.

Indirect EFI systems give engines the ability to provide excellent performance as well as meet future EPA (Environment Protection Agency) standards—standards that are getting tougher to achieve with each passing year.





# Fuel Injection System Components

Although many small power equipment engines don't use fuel injection now, their use in future is inevitable. Therefore, we'll summarize a description of the components found in a typical EFI system.

Let's start our discussion on EFI-related system components with the area of fuel delivery.



# Fuel Pumps

Fuel pumps used with electronic fuel-injected power equipment engines have three primary requirements:

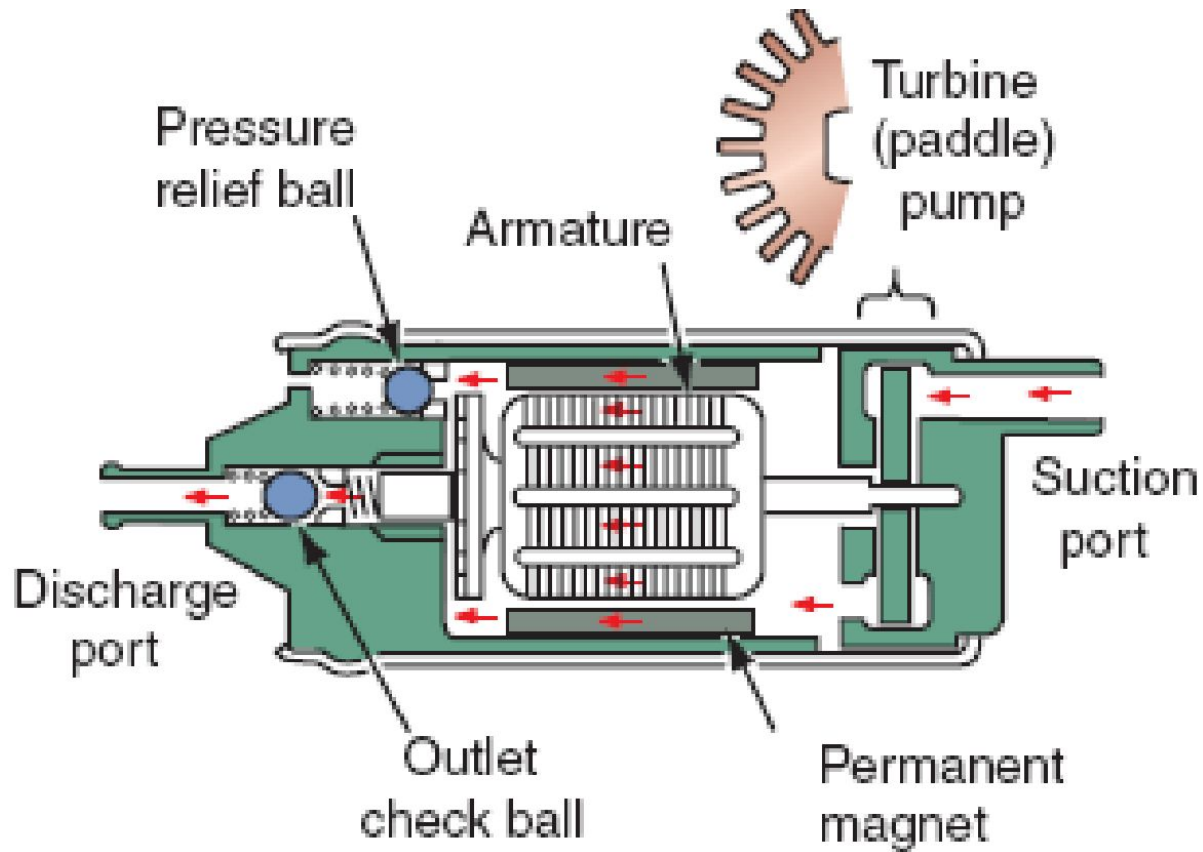
- They must be electric powered.
- They must have the ability to handle a high volume of fuel.
- They must have the ability to supply high pressure to the injectors.

Many modern power equipment engine EFI fuel pumps are located inside the fuel tank of the power equipment engine to save space as well as to prevent vapor lock, a condition that is caused when gasoline overheats and begins to actually boil within the fuel pump.

An ECM (Electronic Control Module) controls the operation of the fuel pump. The fuel pump will generally operate for a couple of seconds after the key is first turned on to pressurize the fuel injectors.



The fuel pump consists of an electric armature that spins between two magnets and turns an impeller that draws fuel in and through the pump (Figure 38).

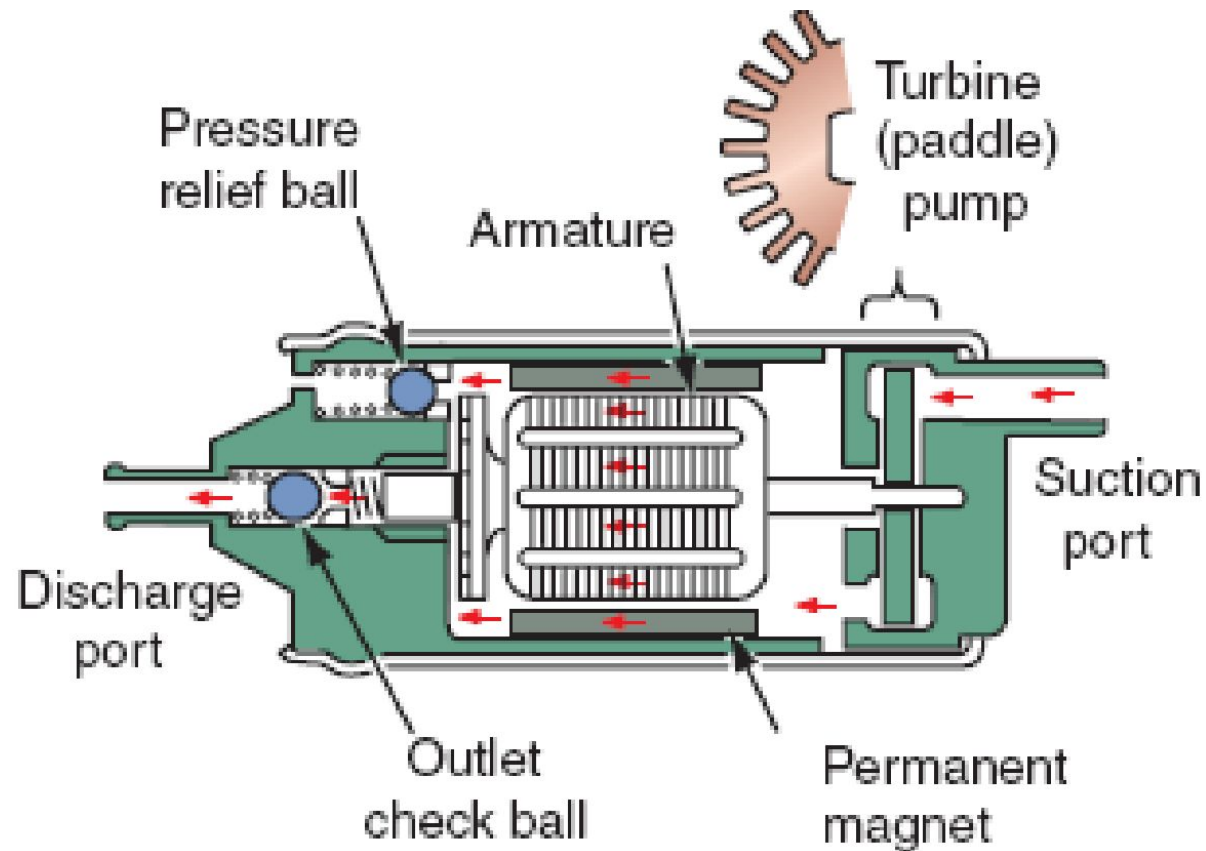


**Figure 38** The components of an electronic fuel pump for a fuel injection system.

A check valve (outlet check ball) is incorporated to maintain pressure at the fuel injectors to allow for quick engine starts.

Fuel is sealed in this system and therefore cannot evaporate or deteriorate during long periods of nonuse, as during winter months.

A relief valve (pressure relief ball) is also located within the fuel pump and is opened to send fuel back into the fuel tank if a fuel line were to become restricted and cause excessive pressure buildup.

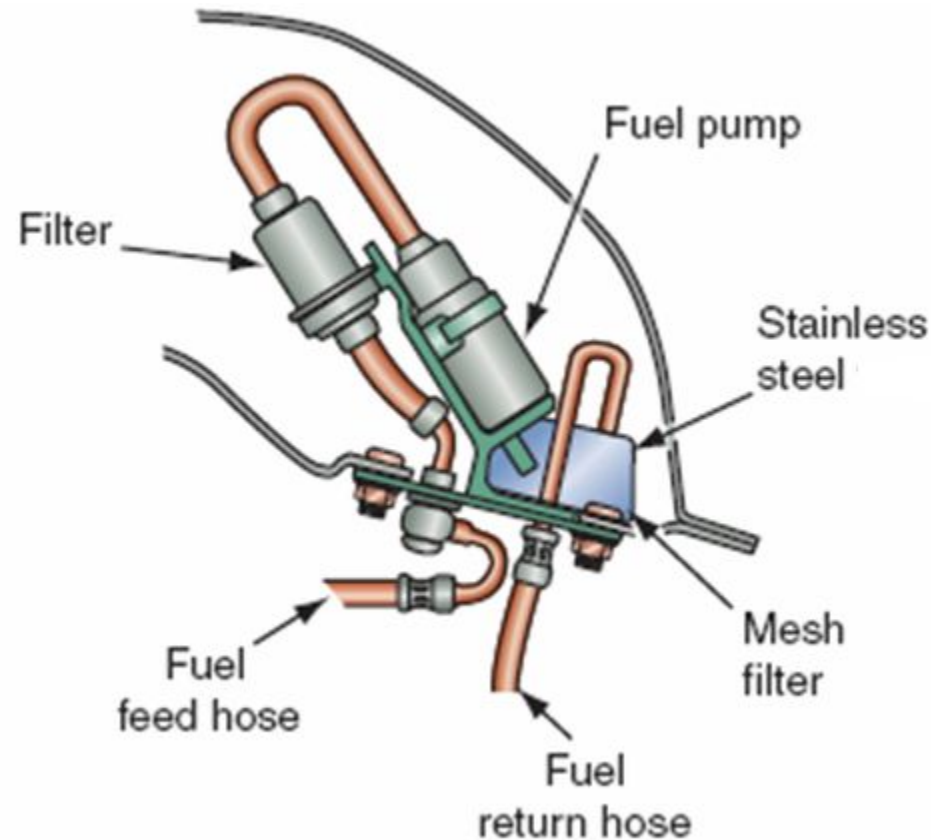


**Figure 38** The components of an electronic fuel pump for a fuel injection system<sub>84</sub>

# Fuel Filters

There are generally at least two fuel filters used in EFI systems.

Before fuel enters the fuel pump, it must go through a mesh filter that prevents grit and rust from entering the pump and damaging it. Another filter used is a large inline type and can be mounted inside or outside the fuel tank (Figure 39). The operation of fuel filters is critical in a fuel-injected system because clogged fuel injectors won't function properly.



**Figure 39** The fuel filters located inside the fuel tank.

# *Fuel Lines*

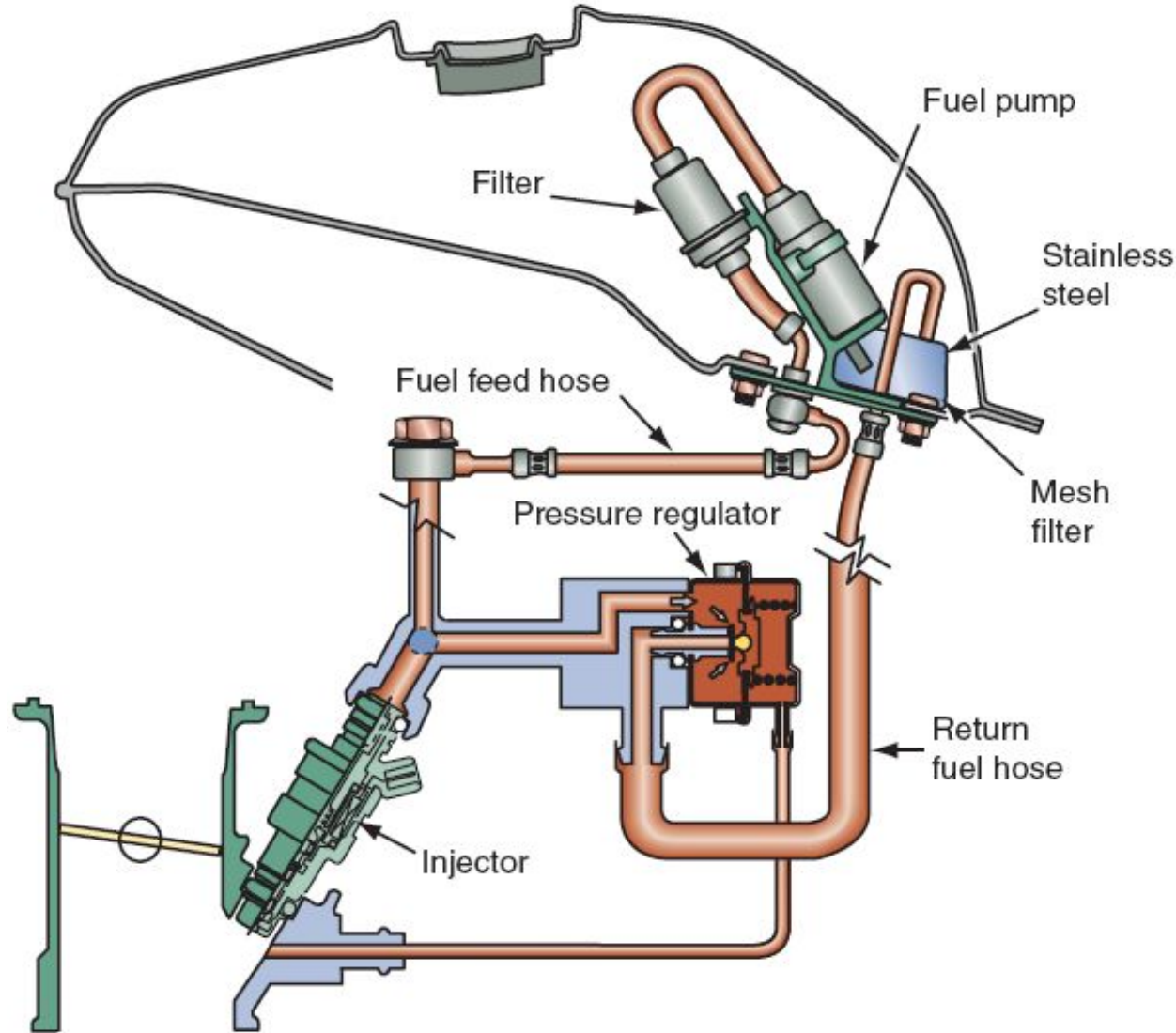
EFI systems use special, high-pressure fuel lines from the fuel pump to the injectors, which can be damaged by mishandling due to excessive bending or stretching.

The damage in many cases will be internal and therefore you'll not see it until the line breaks under pressure. When servicing EFI power equipment engines, be sure to adhere to the appropriate service manual to avoid damaging the fuel lines.



# *Fuel Pressure Regulators*

The fuel pressure regulator maintains correct fuel pressure and keeps it above the pressure of the intake manifold. Excessive pressure is returned to the fuel tank by a separate return hose (Figure 40).

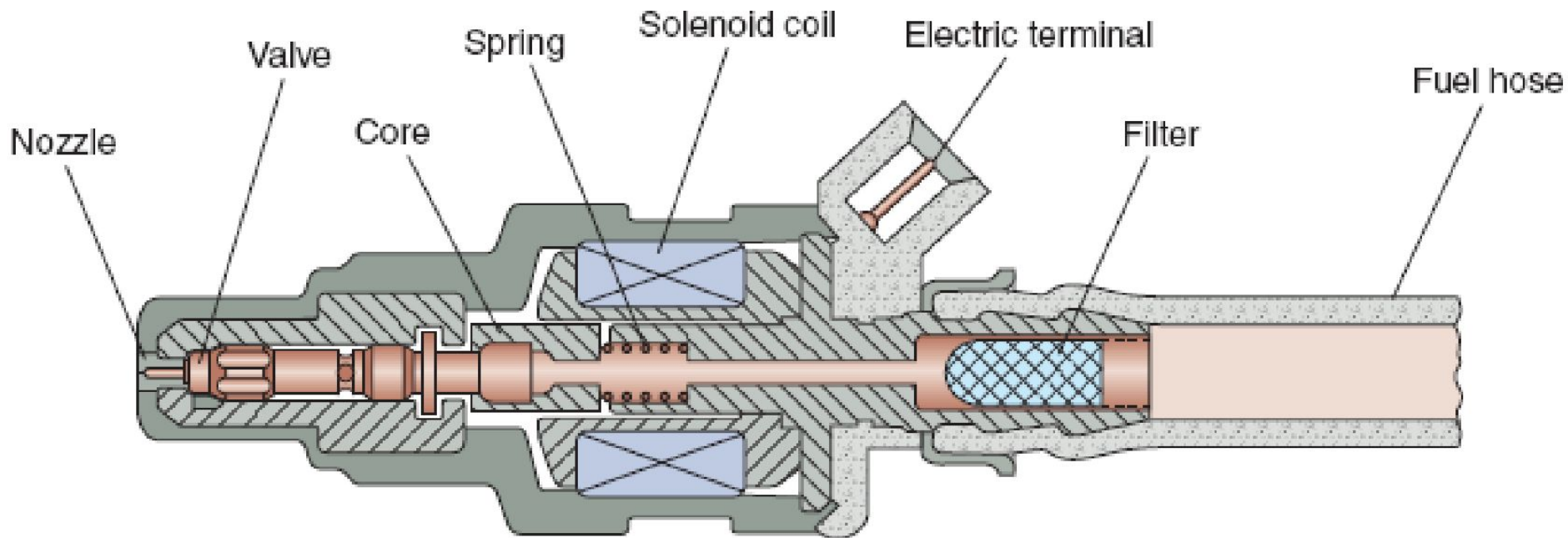


**Figure 40** A fuel pressure regulator is used to maintain correct fuel pressure and keep it above the pressure of the intake manifold.

# Fuel Injectors

The **fuel injector** is an electronically operated solenoid that turns fuel on and off (Figure 41).

Inside the injector, there's a spring-loaded plunger that closes against a valve seat. Once seated, the flow of fuel is blocked. When the solenoid coil within the injector assembly lifts the plunger, the pressurized fuel sprays into the cylinder. A battery supplies the power for the solenoid coil.



**Figure 41** The fuel injector is a solenoid that is either on (fuel flows) or off (fuel does not flow).



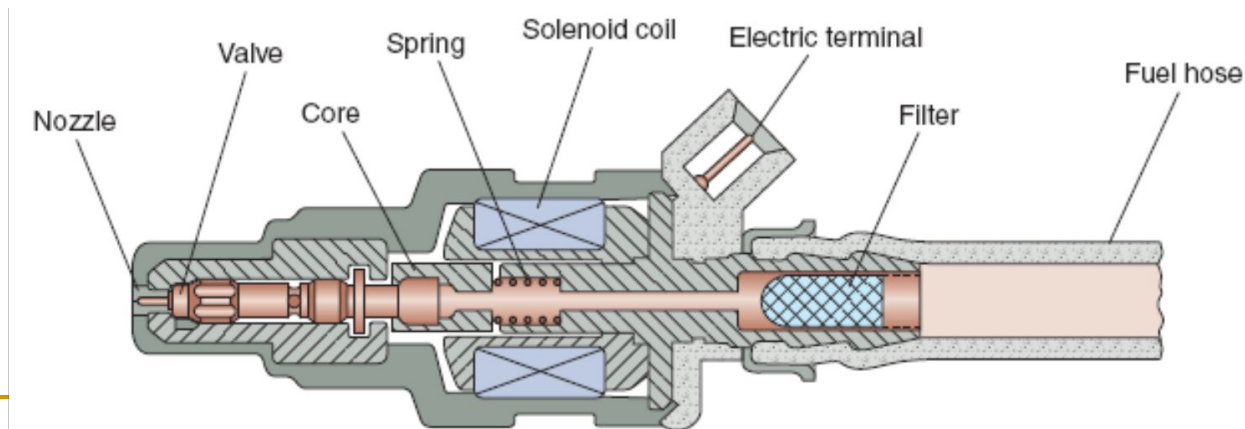
The fuel injectors generally closed and are either fully closed or fully open. The ECM “tells” the fuel injector when to turn on and off. The control unit also determines how long the injector must stay on, therefore telling the injector how much fuel has been injected into the engine.

This is known as **injector discharge duration**. The length of time for which the fuel injector is turned on is known as **discharge duration**.

The ECM controls the ground side of the injector, therefore making the injectors “switch to ground circuits.” Each injector is controlled by the ECM, and fuel is delivered to the cylinder only as it’s needed. This is known as **sequential fuel injection**.

Three factors influence fuel atomization in an EFI system:

- the shape of the injector,
- fuel pressure, and
- turbulence in the air intake tract.



**Figure 41** The fuel injector is a solenoid that is either on (fuel flows) or off (fuel does not flow).

Fuel injector tip openings are designed to provide a spray pattern that atomizes the fuel to help it mix with the incoming air. There are different types of fuel injector tips, the most common having a single outlet, although some engines use multiple outlets (Figure 42). These outlet designs are used to vary the spray pattern to the manufacturer's design needs for different performance requirements as well as manufacturing costs.



**Figure 42** Various types of tips can be found on a fuel injector. Decisions on the type of injector to be used can be based on intended use as well as cost.

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# *ECM*

The heart of all fuel injection systems is the ECM. The ECM receives signals from all the EFI system sensors, processes them, and transmits programmed electrical pulses to the fuel injectors. Both incoming and outgoing signals are sent through a wiring harness and a multiple-pin connector. The ECM uses a microcomputer to process data and control the operation of the fuel injectors, ignition spark and timing, and the fuel pump. The ECM receives information from basic input sensors and determines what, when, why, and how long the various operation steps need to be controlled.

Depending on the manufacturer, an ECM can also be called an electronic control unit (ECU).

# ECM Inputs and Outputs

The ECM has three types of inputs (Figure 43):

- Basic
- Correction
- Control

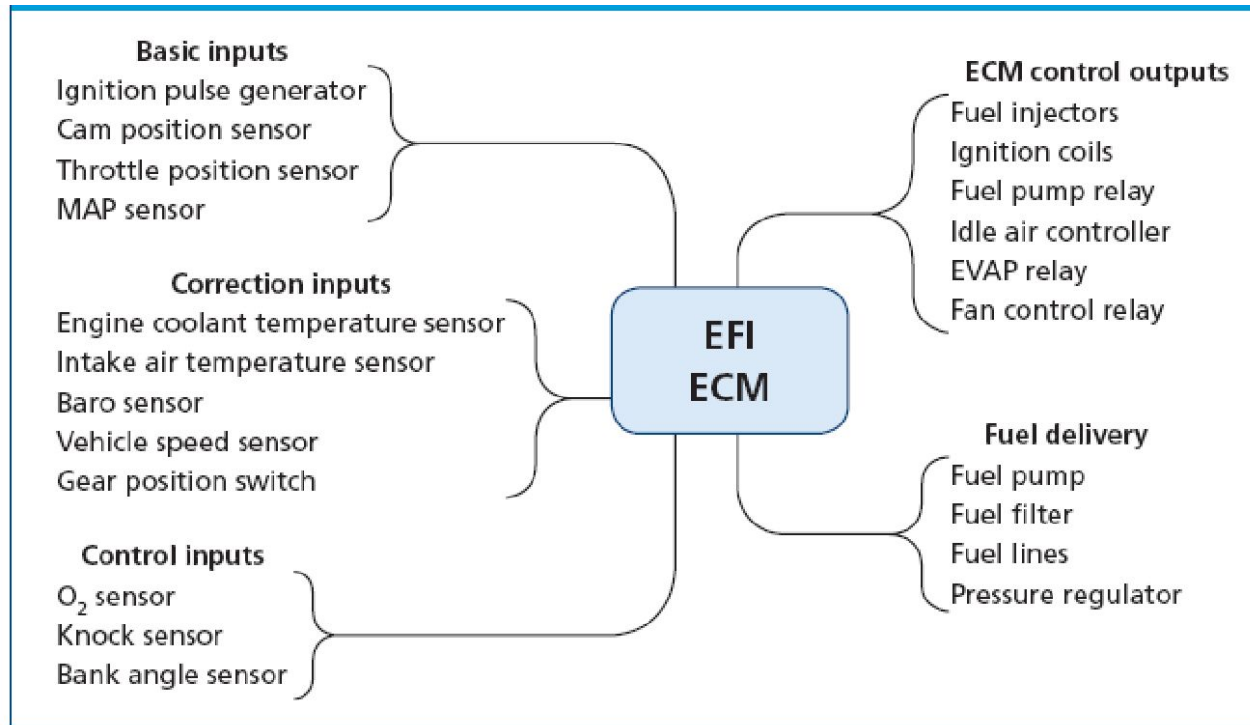


Figure 43. Typical inputs for an electronic fuel injection

# ECM Inputs and Outputs

The basic inputs provide information that the ECM needs to select a particular mixture control map (most EFI systems have at least two maps). The ECM then selects the basic fuel discharge duration from the chosen map. Basic inputs include ignition pulse, camshaft position sensor, throttle position sensor, and the vacuum pressure in the intake manifold [manifold absolute pressure (MAP) sensor].

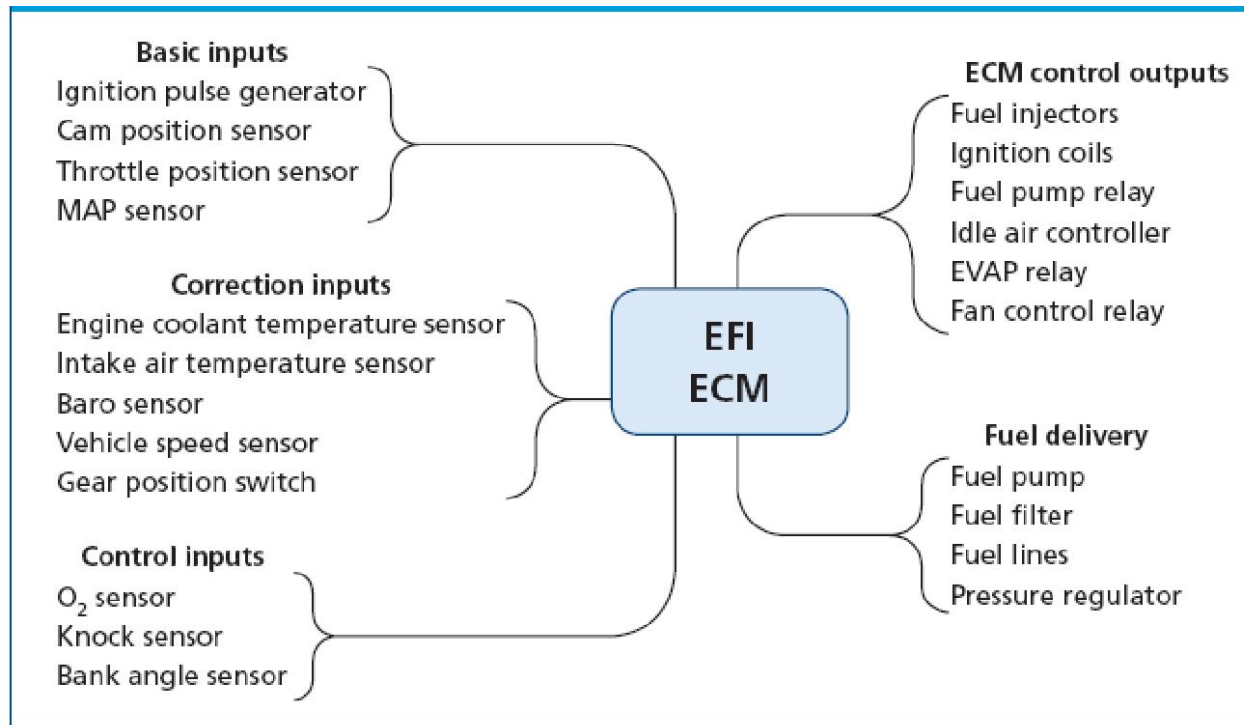


Figure 43. Typical inputs for an electronic fuel injection

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The correction inputs provide the information that the ECM needs to adjust the basic fuel discharge duration. Typical correction inputs would include engine temperature, intake air temperature, barometric pressure (BARO), and vehicle speed.

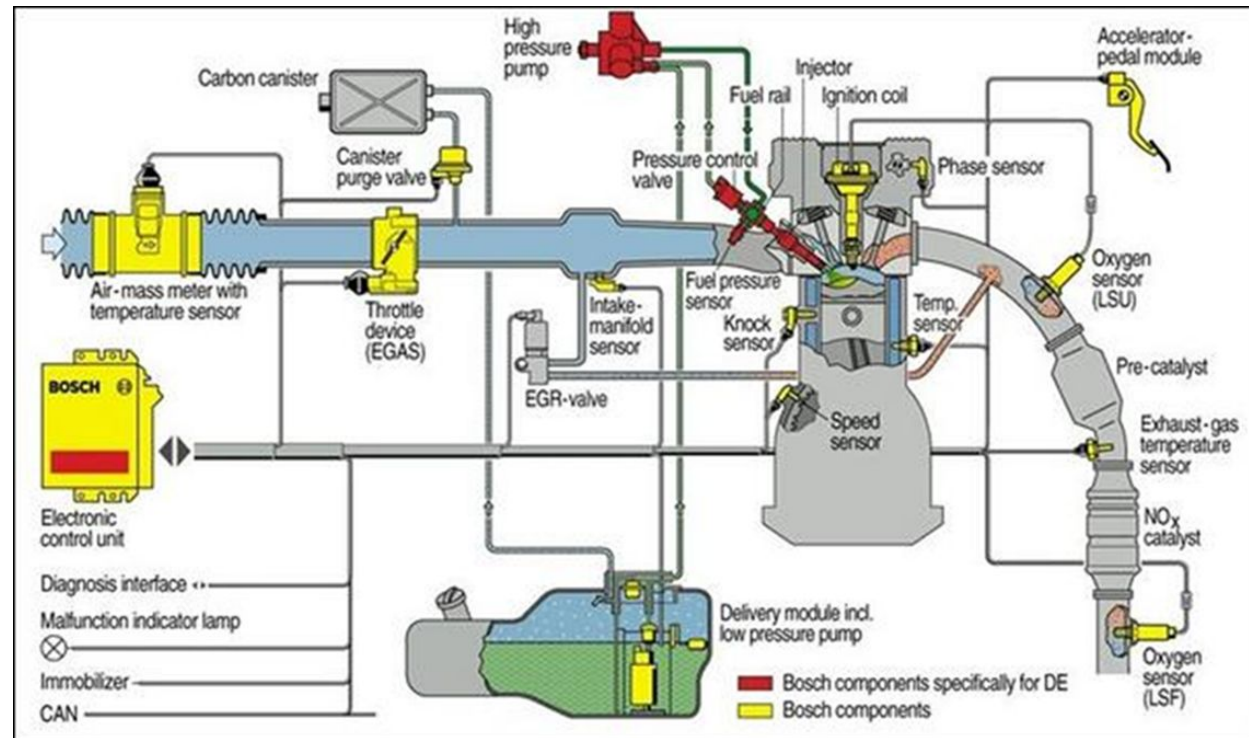
The control inputs provide the information that the ECM needs to adjust engine operation. These inputs would be the oxygen sensor and knock sensor. A bank angle sensor is used often in power equipment engines to cut off electrical power to the ECM in the case of the machine tipping over. Bank angle sensors are designed to stop the engine.

ECM outputs include the fuel injection, ignition spark as well as the operation of the fuel pump and cooling fan in liquid-cooled machines.

# Sensors

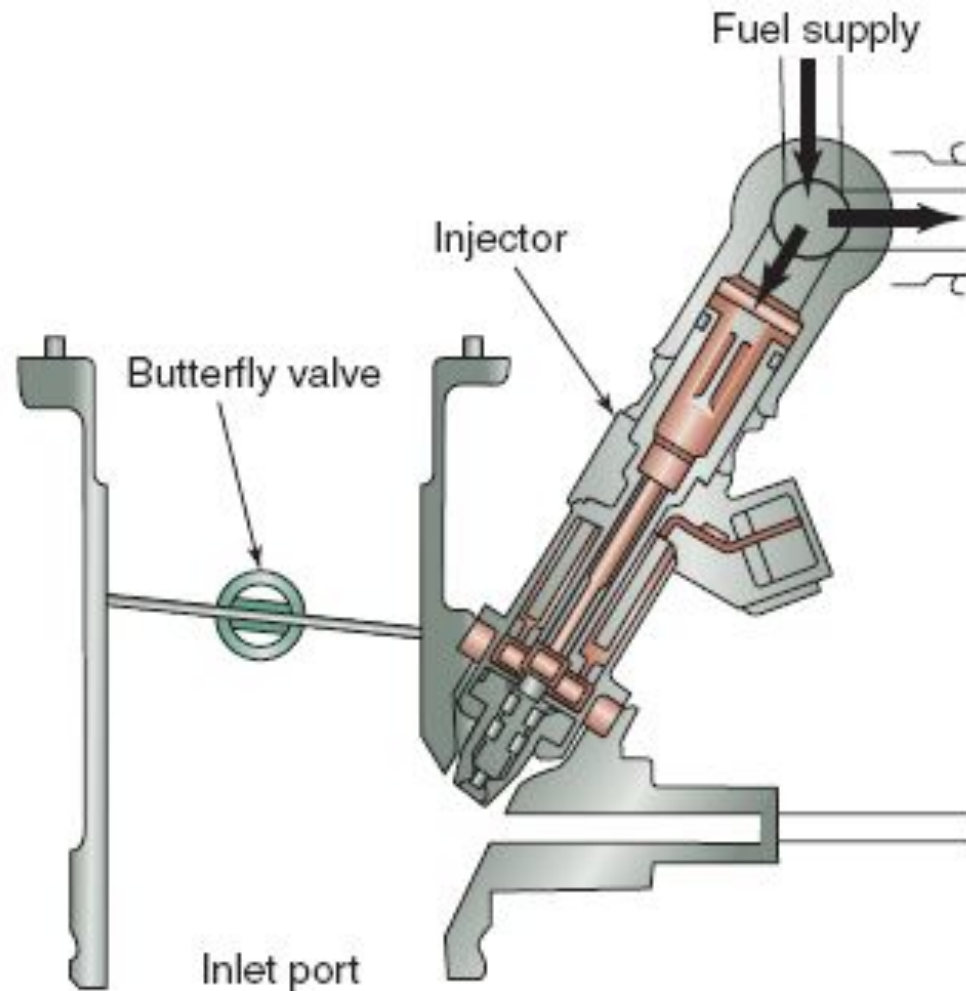
Various sensors monitor the engine and atmospheric conditions such as throttle position, engine revolutions per minute (rpm), engine and intake air temperature, vehicle speed and MAP (which is calculated into air density), coolant temperature, and piston position.

These sensors assist in all aspects of EFI and send information to the ECM to allow the engine to run as efficiently as possible.



# *Throttle Body*

Engines with EFI may have one throttle valve for each cylinder. The throttle body contains the injector as well as a butterfly valve (Figure 44). Power equipment engines with EFI don't need to depend on the Venturi effect because of the fuel injector delivery of a precise amount of fuel at any given time, unlike a carbureted power equipment engine that will receive the same amount of fuel at all throttle openings.



**Figure 44** A throttle body for an electronic fuel injection (EFI) system along with an illustration of a fuel injector and the inlet port of the throttle body.



# EFI Self-Diagnostics

Most modern power equipment engines that use EFI have a self-diagnostic system incorporated to assist technicians when problems arise. Various components on EFI are monitored continuously by the self-diagnosis function and if the ECM notices a fault, a light comes on within the dashboard of the machine. This light is sometimes called the “check engine” light or the “FI” light. Some manufacturers call this light by the term officially used in the automotive industry, which is the *malfunction indicator lamp* (MIL) (Figure 45), and depending on the severity of the fault, may give a warning to the user.

In other cases, the engine may go into a fail-safe operation mode, which allows the engine to continue to run but at a reduced performance level or stop completely, depending on the severity of the fault, such as when an electrical-related problem is detected by the system sensors. The MIL is used to detect and assist in diagnosing any EFI-related, electrical failure.



**Figure 45** The malfunction indicator light (MIL) will let a user know if a failure is detected in the EFI system. <sup>97</sup>

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# Basic Operation of the Fuel Injection System

In a typical EFI system, the ECM must “know” the amount of air entering the engine so that it can supply the stoichiometric air–fuel ratio.

Most EFI systems have a MAP sensor to allow the computer to calculate the amount of air entering the engine from the MAP and engine rpm input signals. The MAP sensor sends a signal relating to the pressure inside the intake manifold to the ECM.

The ignition pickup or crankshaft position sensor supplies an rpm signal to the computer.

The computer must have accurate signals from these inputs to maintain the stoichiometric air–fuel ratio.

Other inputs are used by the computer to fine-tune the air–fuel ratio through electronic feedback.

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# Electronic feedback and closed loop

**Electronic feedback** means the system is self-regulating and the ECM is controlling the injectors on the basis of operating conditions rather than on preprogrammed instructions.

As an example of a feedback loop used in many EFI systems, the ECM reads signals from an oxygen sensor, varies the pulse width of the injectors, and again reads the signals from the oxygen sensor. This cycle is repeated until the injectors are pulsed for just the amount of time needed to get the proper amount of oxygen into the exhaust stream.

While this interaction is occurring, the system is operating in a **closed loop**. During the closed-loop mode, sensor inputs are sent to the ECM; the ECM compares the values with those in its programs and then reacts to the information to adjust the air–fuel ratio and other engine systems.

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# Control loops and catalytic converters

When conditions such as starting or wideopen throttle demand that the signals from the oxygen sensor be ignored, the system operates in an **open loop**. During open loop, injector pulse length is controlled by set parameters contained in the ECM's memory. Systems with oxygen sensors may also go into the open-loop mode while idling or at any other time that the oxygen sensor cools off enough to stop sending a good signal, and at wide-open throttle.

The basic purpose of these control loops is to create an ideal air–fuel ratio, which allows engines using **catalytic converters** to operate at maximum efficiency while giving the best fuel mileage and performance possible.

A catalytic converter is a device used to reduce the toxicity of emissions from an engine.

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# Summary

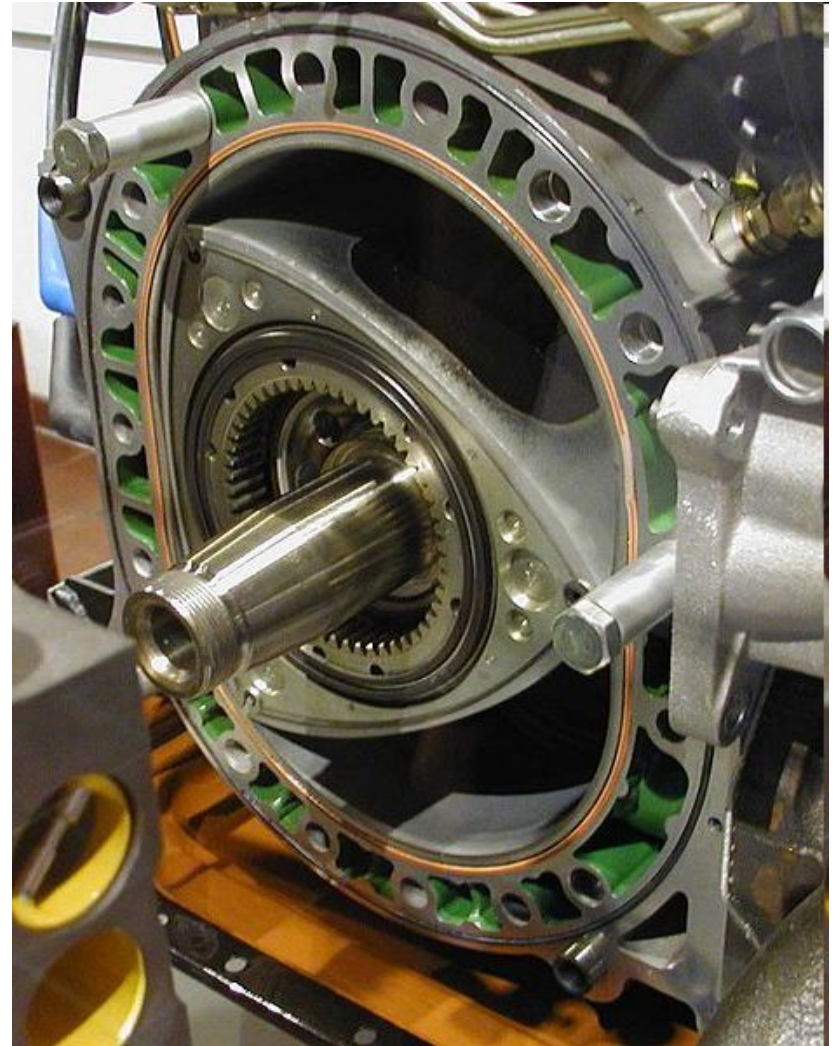
- The primary principles of carburetor operation are atomization, the process of combining air and fuel to create a mixture of liquid droplets suspended in air, and the Venturi principle, which states that a gas or liquid that's flowing through a narrowed-down section of a passage will increase in speed and decrease in pressure compared with its speed and pressure in wider sections of the passageway.
- Each type of carburetor has different components that function similarly.
- The purpose of fuel injection is to allow an extremely precise metering of air–fuel mixture ratios at any given engine and atmospheric condition.

# Wankel engine

The Wankel engine is a type of internal combustion engine using an eccentric rotary design to convert pressure into a rotating motion instead of using reciprocating pistons.

Its four-stroke cycle takes place in a space between the inside of an oval-like epitrochoid-shaped housing and a rotor that is similar in shape to a Reuleaux triangle but with sides that are somewhat flatter.

The very compact Wankel engine delivers smooth high-rpm power. It is commonly called a rotary engine, though this name applies also to other completely different designs.



*A cut-away of a Wankel engine shown at the Deutsches Museum in Munich, Germany*

# Wankel engine

The engine was invented by German engineer Felix Wankel. He received his first patent for the engine in 1929, began development in the early 1950s at NSU, completing a working prototype in 1957. NSU then licensed the concept to companies around the world, which have continued to improve the design.

Thanks to their compact design, Wankel rotary engines have been installed in a variety of vehicles and devices including automobiles, motorcycles, racers, aircraft, go-karts, jet skis, snowmobiles, chain saws, and auxiliary power units.



*The Mazda RX-8, a sports car powered by a Wankel engine*

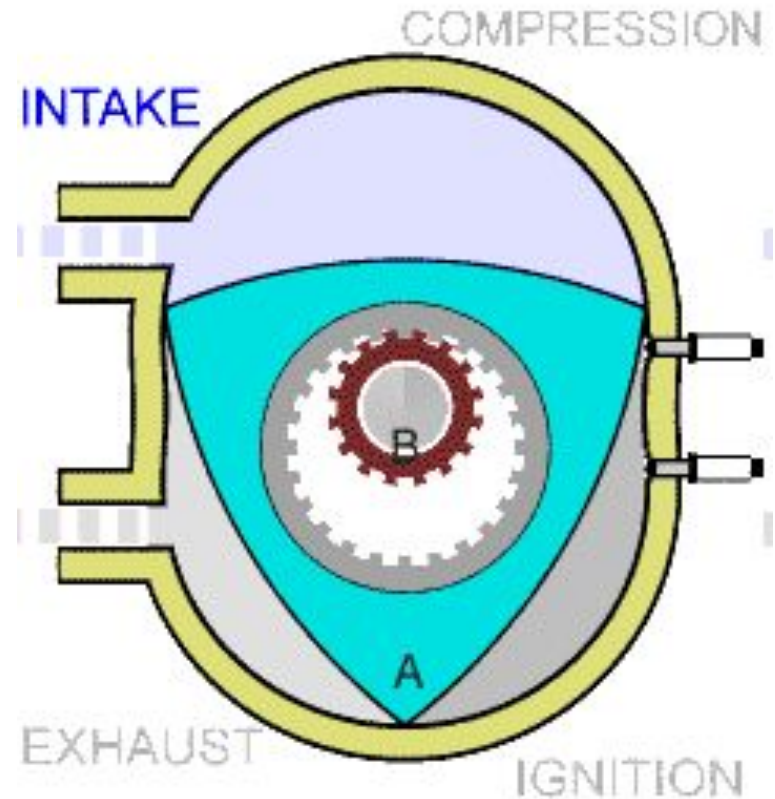


*Norton Classic air-cooled twin-rotor motorcycle*

# Design

In the Wankel engine, the four strokes of a typical Otto cycle occur in the space between a three-sided symmetric rotor and the inside of a housing. In the basic single-rotor Wankel engine, the oval-like epitrochoid-shaped housing surrounds a rotor which is triangular with bow-shaped flanks.

The theoretical shape of the rotor between the fixed corners is the result of a minimization of the volume of the geometric combustion chamber and a maximization of the compression ratio, respectively. The symmetric curve connecting two arbitrary apexes of the rotor is maximized in the direction of the inner housing shape with the constraint that it not touch the housing at any angle of rotation.



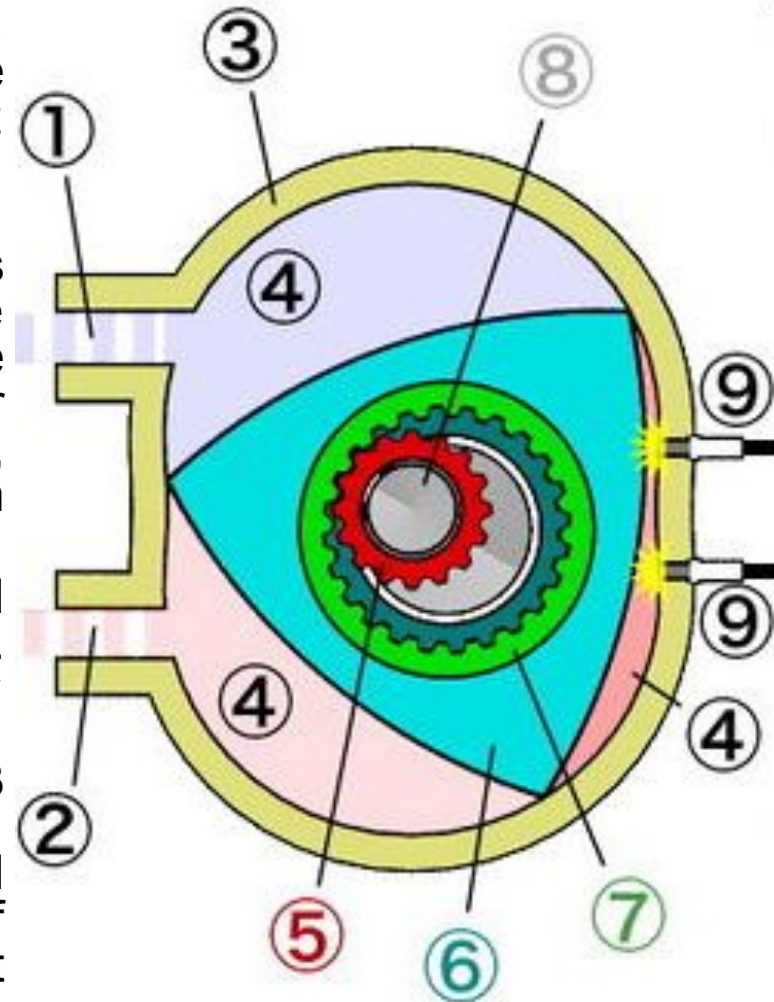


# Design

The central drive shaft **8**, called the eccentric shaft or E-shaft, passes through the center of the rotor **6** and is supported by fixed bearings (not shown).

The rotor **6** ride on eccentrics (analogous to crank) integral to the eccentric shaft (analogous to a crankshaft). The rotor both rotate around the eccentric and make orbital revolutions around the eccentric shaft. Seals at the corners of the rotor seal against the periphery of the housing, dividing it into three moving combustion chambers **4**.

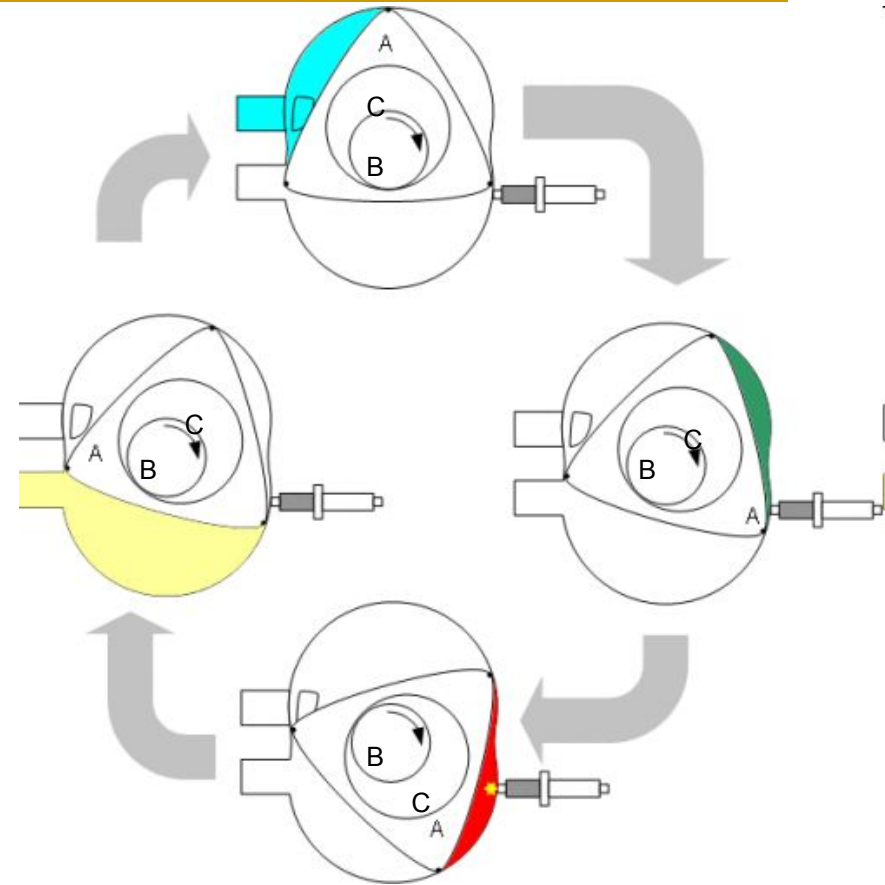
The rotation of rotor on it own axis is caused and controlled by a pair of synchronizing gears. A fixed gear **5** mounted on one side of the rotor housing engages a ring gear **7** attached to the rotor and ensures the rotor moves exactly 1/3 turn for each turn of the eccentric shaft **8**. The power output of the engine is not transmitted through the synchronizing gears. The force of gas pressure on the rotor (to a first approximation) goes directly to the center of the eccentric part of the output shaft.



# The action of the engine

The best way to visualize the action of the engine is to look not at the rotor itself, but the cavity created between it and the housing.

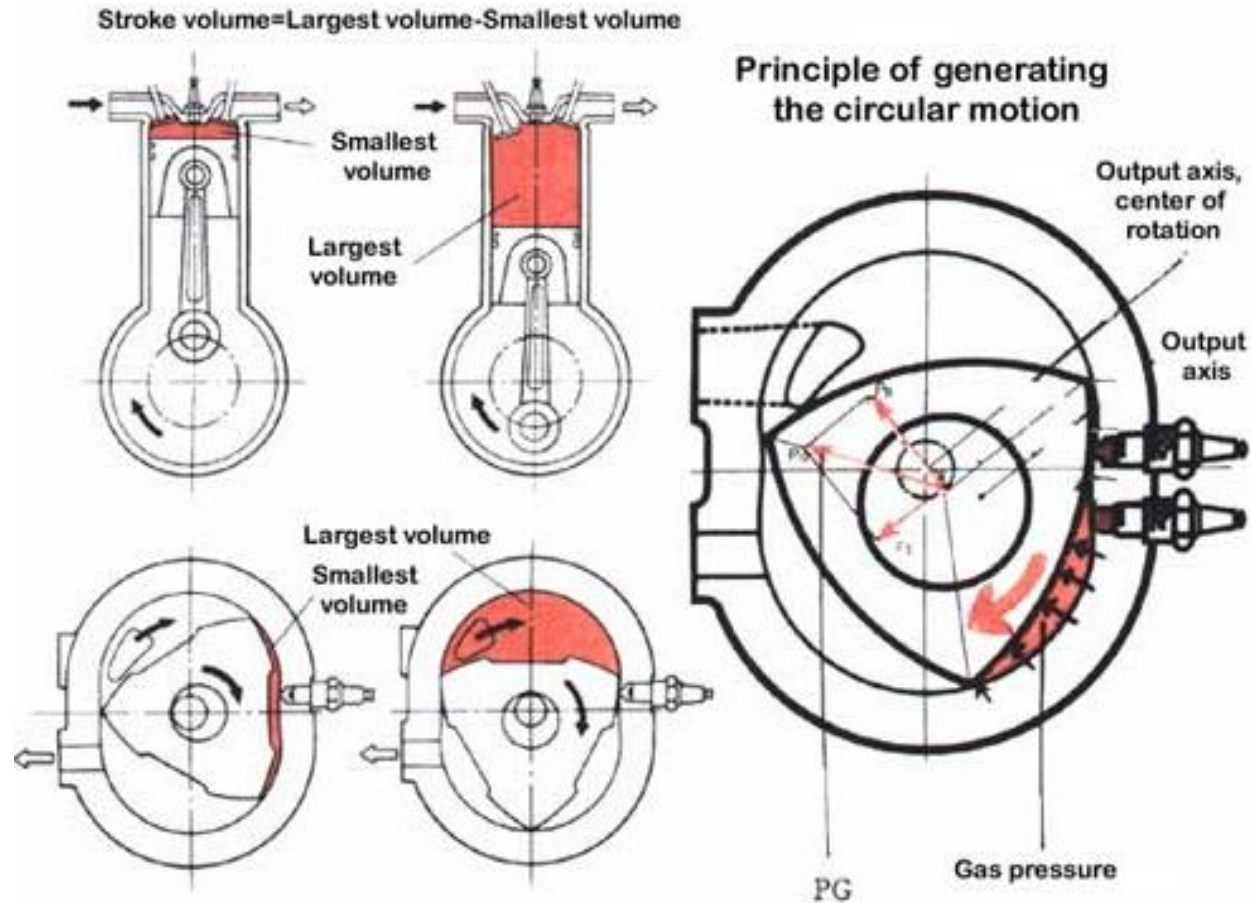
The Wankel engine is actually a variable-volume progressing-cavity system. Thus there are 3 cavities per housing, all repeating the same cycle. Note as well that points A and B on the rotor and e-shaft turn at different speeds—Point B circles 3 times as often as point A does, so that one full orbit of the rotor equates to 3 turns of the e-shaft.



*The Wankel motorcycle: The "A" marks one of the three apices of the rotor. The "B" marks the eccentric shaft and the "C" marks is the lobe of the eccentric shaft. The shaft turns 3 times for each rotation of the rotor around the lobe and once for each orbital revolution around the eccentric shaft.*

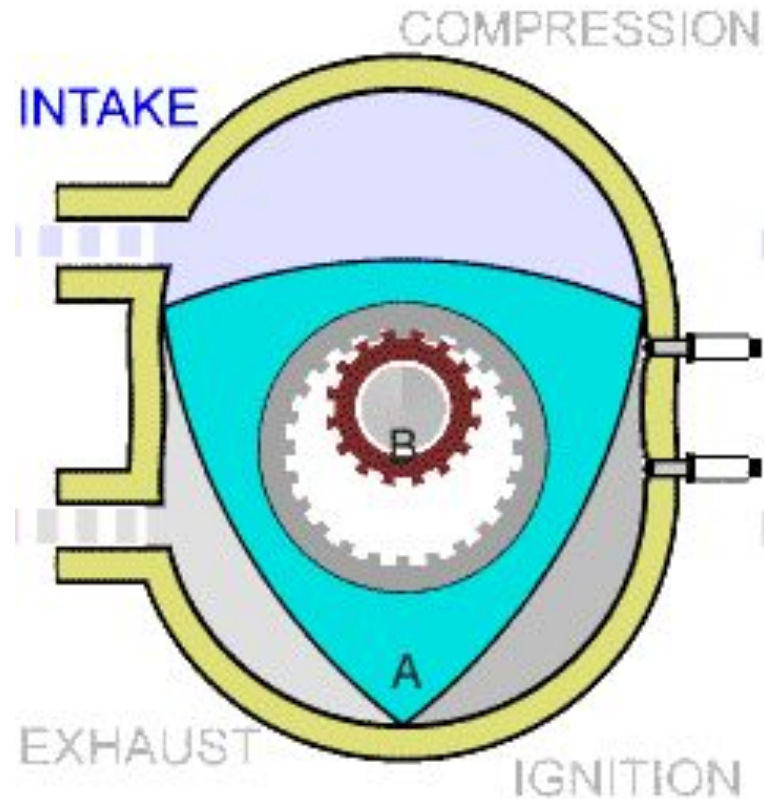
# The action of the engine

As the rotor rotates and orbitally revolves, each side of the rotor is brought closer to and then away from the wall of the housing, compressing and expanding the combustion chamber like the strokes of a piston in a reciprocating engine.



# The action of the engine

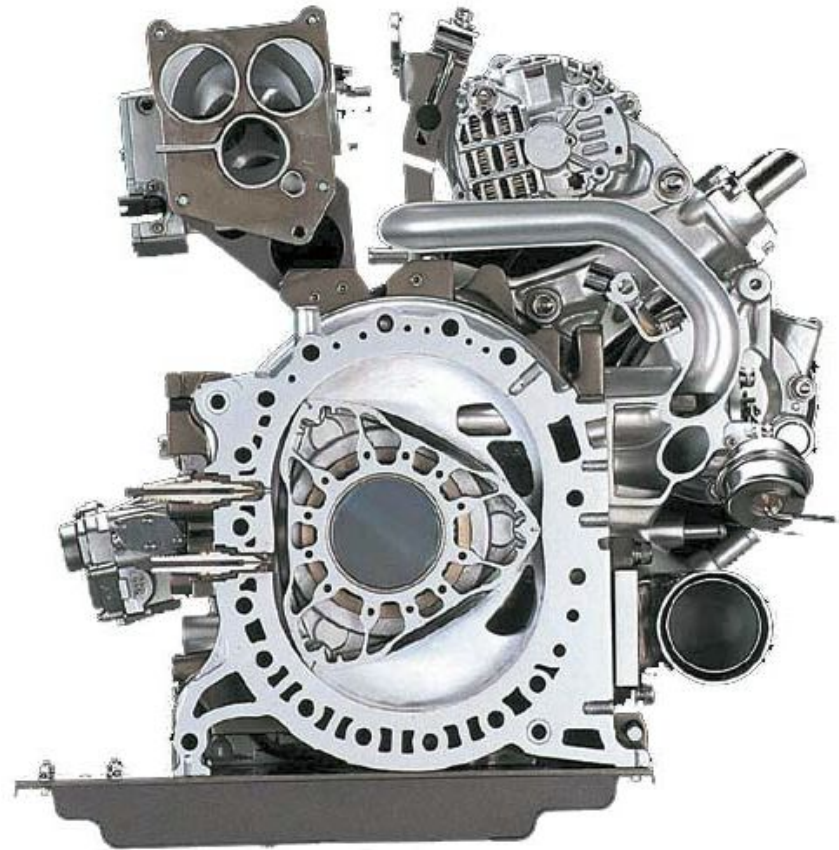
While a four-stroke piston engine makes one combustion stroke per cylinder for every two rotations of the crankshaft (that is, one-half power stroke per crankshaft rotation per cylinder), each combustion chamber in the Wankel generates one combustion stroke per driveshaft rotation, that is one power stroke per rotor orbital revolution and three power strokes per rotor rotation. Thus, power output of a Wankel engine is generally higher than that of a four-stroke piston engine of similar engine displacement in a similar state of tune; and higher than that of a four-stroke piston engine of similar physical dimensions and weight.



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Wankel engines also generally have a much higher redline than a reciprocating engine of similar power output. This is in part because the smoothness inherent in circular motion, but especially because they do not have highly stressed parts such as a crankshaft or connecting rods. Eccentric shafts do not have the stress-raising internal corners of crankshafts. The redline of a rotary engine is limited by wear of the synchronizing gears. Hardened steel gears are used for extended operation above 7000 or 8000 rpm. Mazda Wankel engines in auto racing are operated above 10,000 rpm. In aircraft they are used conservatively, up to 6500 or 7500 rpm.

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National agencies that tax automobiles according to displacement and regulatory bodies in automobile racing variously consider the Wankel engine to be equivalent to a four-stroke engine of 1.5 to 2 times the displacement; some racing series ban it altogether.

