ENGINE HEALTH

Carburetor 101

By Bill Hancock, Assistant Editor

For most of us in the antique boating world, carburetors are a way of life. For the most part, we all grew up around them and until the late 90's they came on everything that called itself a gasoline engine. Today, they have been replaced with digital fuel injection in the new cars which we drive. Let's take a look at the basic carburetor and explore how it works. First, a bit of basic engine theory is in order.

Our engines work on the principle of turning a chemical reaction into work. We burn a mixture of air and fuel in a tight container known as the combustion chamber which causes the mixture to heat up and expand. This expansion causes the pressure in the cylinder to rise which forces the piston down the bore. The piston is connected to the crankshaft by, of all things, a connecting rod. The crankshaft converts reciprocating motion into rotary

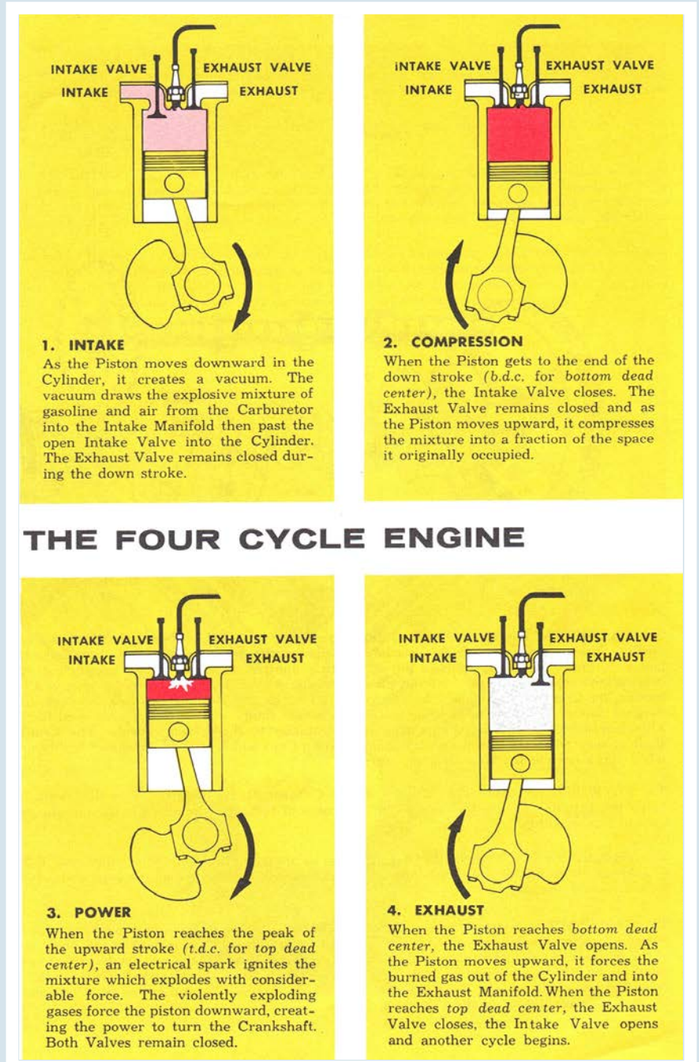

Fig 1 – The four strokes of a gasoline engine. Notice how they reference an explosion occurring. – *Courtesy Revell,Inc.*

motion, which turns our propeller and converts rotary motion into linear thrust. First, let's briefly look at the engine to see how it works. Follow the drawings in Fig. 1 and you will see the 4 strokes, or cycles, of a typical antique 4-stroke gasoline engine.

The carburetor mixes air with fuel in a very specific ratio to ensure complete burning. This ratio, called the Stoichiometric ratio, is typically around 14.7 parts of air by weight, mixed with I part of fuel by weight for the gasoline we use to create our combustible mixture, called a charge. The engine inhales the charge on the intake stroke. Think of the charge at this point in the process as a soup can filled with mostly air and a few drops of gasoline. Next, compression stroke compresses the charge anywhere from 1/6 to 1/13 of its original volume, depending on the compression ratio of the engine. As the piston nears the top of the cylinder on the compression stroke, the compressed charge is now the size of a can of tuna fish. Up to a point, the more a charge is compressed, the greater the resulting output.

As the piston is nearing the top of the cylinder, a spark is created in the combustion chamber, which begins to ignite the compressed mixture, and the burn begins. At this point, we must stop to dispel a rumor.

99% of the folks out there firmly believe that what happens next is called an explosion, and the force from these explosions is what powers our engines. Nothing could be further from the truth! **There is no explosion**! There is a rapid burn, but no explosion despite what the accompanying popular description in figure 1 says.

An explosion is an uncontrolled chemical reaction in which the speed of the flame travel approaches the speed of sound. An engine burns the mixture, albeit at a fast rate, but nowhere near the flame speed of an explosion. The noise which people hear and mistakenly call an explosion is simply the sound the hot, high pressure burned exhaust gas makes when the exhaust valve is rapidly opened during blowdown which occurs near the end of the power stroke when the hot high-pressure gas is expelled into our low pressure atmosphere.

Our engines rely on the closely controlled burn rate where the carefully timed spark initiates the burn and through flame propagation consumes the entire mixture in a well-controlled process. At this point, if the burn proceeds too rapidly, before the piston reaches Top Dead Center, the rising pressure inside the cylinder will cause further expansion and the flame speed will surpass sonic. At this point the engine will encounter detonation. Meanwhile the crankshaft and rod is still forcing the piston up the bore, which only makes matters worse. In the end, the piston usually cracks or becomes so hot it melts and the engine is severely damaged. The piston becomes caught between two opposing forces.

Detonation occurs when the flame speed exceeds the speed of sound. Left untended, detonation can very quickly ruin an engine. Because of the extremely high cylinder pressure, head gaskets will fail, and the cylinder temperatures will exceed the melting point of aluminum, which results in either a cracked or melted piston.

Several things can cause detonation. Old, or low octane fuel can cause detonation. Having the spark too far advanced will also cause detonation. Engine cylinder temperatures which are too high or improper air/fuel quality or mixtures will also cause the problem.

The octane rating of gasoline defines how fast the flame travels during the burn. The concept of octane rating becomes somewhat counterintuitive since the high-octane fuels are more resistant to rapid flame propagation. The higher the octane number, the slower the burn rate. For those reasons, always be sure to have fresh fuel in your tank with the recommended octane rating for your engine.

In our case, be especially careful of fuel which you buy on the water. Typically, marinas do not have a very high fuel usage rate. In order to get fuel delivered from the supplier, the fuel distributor will require at least a 5000 gallon tank to justify the discounted dealer pricing and to make their delivery trip worthwhile. 5000 gallons might last some small, low volume marinas for a full season, and into the next. If you happen to be the person who buys fuel early in the following season, you may be getting fuel that is well over a year old. In contrast a typical busy highway gas

station will routinely pump 30,000 gallons a week!

Enough background, let's talk about carburetors. In the beginning, carburetors had two functions: they mixed the air and the fuel and then controlled the amount of the mixture which entered the engine. By controlling the amount of air, they regulated the output. A flat round plate attached to a shaft and called a butterfly valve is placed in the bottom of the carburetor. If the driver wanted more power, he simply opened the throttle valve which allowed more of the mixture to enter the engine.

Now let's take a break and define load. To better understand load, think of two scenarios. In both cases the boat is doing 25 mph. In the first one, the boat has two people out for a joy ride skimming across the lake. The throttle is open about 50%, and the RPM is 2600. The engine is running at relatively medium load and producing good fuel economy. In the second scenario, the same boat now has three people in it and is pulling two water skiers. It is also going 25 mph and the engine is also turning 2600 RPM, but in this case, the throttle is open about 85%, or almost full throttle.

The load is the difference. So, what must happen? First, in order to maintain the given speed, the engine now has to make more power. However, if we are still turning 2600 RPM, our airflow will be the same. So how do we make more power? We monitor manifold air pressure (MAP), or as some people call it, manifold vacuum. MAP is closely proportional to load, so it makes a good reference point on which to base our fuel requirements. By monitoring the MAP, the carburetor can now sense load. While this is going on, we also want to change the spark timing, so we also tie the ignition system into the MAP.

If we relied simply on the air flow at a given RPM, we would be limited to the amount of power we could make at any given RPM. By using the basic air flow to supply the bulk of the fuel demand and augmenting it with an additional source, we can add additional power during high load periods. A vacuum controlled valve, appropriately called the power valve, opens as it senses increasing load in order to supply additional fuel flow. Now the air/fuel ratio has dropped from 16:1 down to 12.5 : 1 so the engine can make more power, which will require more fuel to do so.

One of the keys to good performance is to have a homogeneous mixture of air and fuel. If the charge is dripping wet in one corner and the air is completely dry in the opposite corner, the resulting burn will not be very effective. What we strive for is a well-mixed charge filled with tiny gasoline particles, evenly distributed throughout the charge. This initial mixing task falls on the carburetor, which utilizes a round, narrow passage called a venturi. When the air passes through the venturi, it causes a pressure drop. In just the right place, there is a small hole which allows the low pressure to siphon the fuel from the fuel bowl and mix it with the rushing airstream as it enters the engine. We control the amount of fuel going to the engine by small restrictors called jets which are carefully calibrated to allow precise flow. These can be changed to compensate for differences between various systems.

Now we have our engine running, so next we need to be able to idle.

Idle

One of the most overlooked performance features of a boat engine is its ability to idle. If the engine cannot idle well, it will guarantee a poor boating experience. The engine must be able to stay running during docking and long no-wake zones. It must not die when put into gear, or suddenly surge during a critical docking maneuver. So, when tuning your engine, above all, have a good reliable idle, then worry about how fast it will run. It's no fun to try to dock with a poorly performing engine. Boats don't have a brake pedal!

The idle circuit is its own separate entity. Think of the idle circuit as a tiny carburetor within a carburetor. It has its own fuel adjustment to keep the mixture perfect, called an idle screw. The idle mixture screw is a needle valve which controls the minute volume of fuel needed to keep the engine running properly during idle conditions, since the main jets and power valve don't function at idle.

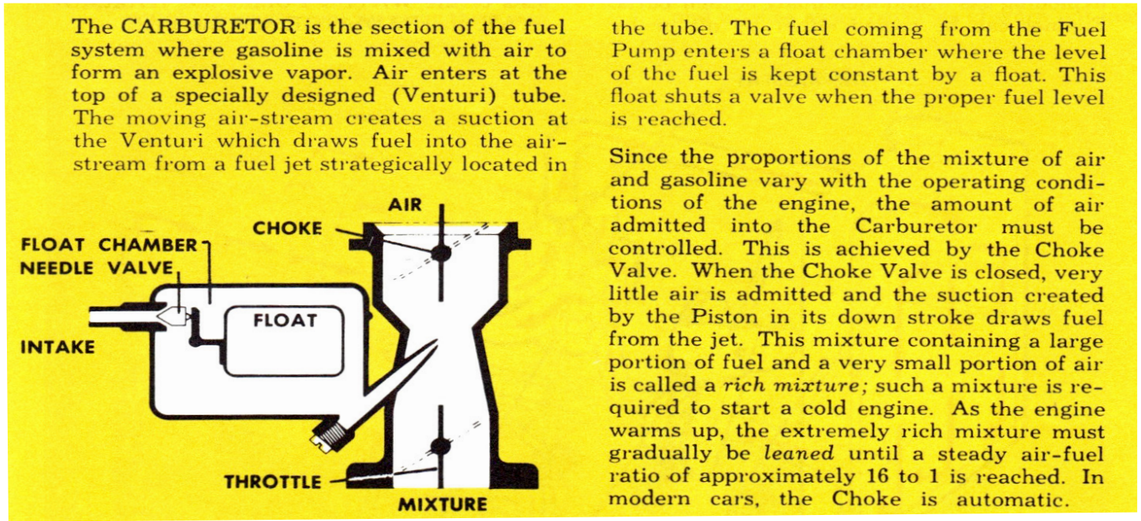

Fig 2 – The simple carburetor – *Courtesy Revell,Inc.*

The idle stop which prevents the throttle from fully closing during idle is adjusted by turning a screw which holds the throttle open a small amount. This screw is purely a mechanical adjustment and does not change the fuel mixture composition like the idle mixture screws do.

Look at Fig. 2 to familiarize yourself with the basic carburetor concept. You will notice the clever float arrangement which allows the float bowl to remain constantly full, as long as a supply of fuel exists. The float level is critical because it determines the amount and depth of fuel in the float bowl, which accounts for the pressure pushing the gas up the tube into the airstream.

Once we leave the dock and move from idle to half-throttle, we open the throttle rapidly. Now the carburetor must transition from the idle mixture to the full throttle mixture. In order to accomplish this change, the engine must accelerate. To do that, it needs some immediate help. A small mechanical pump provides an extra dose of gasoline squirted directly into the airstream. This shot of gasoline coupled with the extra air that is starting to rush in now that the throttle is opened wider allows the engine to start accelerating and gaining RPM. The shot of fuel comes from the accelerator pump. Think of it as a hypodermic needle full of gasoline that rests next to the carburetor so when a little boost of fuel is needed, it can be ready to provide it. Were it not for the accelerator pump, the engine would stumble and hiccup when the throttle was opened suddenly. By grossly enriching the mixture for a brief interval, the carburetor is able to provide the extra energy to accelerate the engine to the next RPM range. Once the acceleration is complete, the hypodermic needle refills itself automatically in order to be ready for the next acceleration.

Starting

In order to start a cold engine, it helps to induce a grossly rich mixture into the cylinders which will allow the engine to start firing and pickup speed. As the engine warms up, the mixture is gradually returned to around 12.5:1 Air-Fuel, where it will run best. The carburetor is fitted with a device which is like a secondary throttle plate called a choke and mounted above the primary throttle valve. By closing the choke, the engine draws in a relatively large amount of raw fuel when it first begins to rotate. This raw mixture is easily ignited and allows the engine to start and continue to run until it warms up. Once it warms up, the choke can be opened allowing the primary fuel metering system to take over and provide the correct air fuel ratio. It should be noted that the choke literally closes to shut off the incoming airflow, but typical operator's manuals refer to the action as opening the choke, and closing it when the engine warms up.

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If you choke the engine too long before it starts, it will "flood" the cylinders with excess fuel which will not ignite. The solution is to close the choke (in operator's parlance) and hold the throttle wide open and crank the engine. This will allow excess air to enter the cylinders and eventually dry out the excess fuel. Hopefully this occurs before you have discharged your battery. The other option is to close the choke and hold the throttle open and go have a coffee and let the fuel evaporate.

And now for a few the simple secrets to making a boat carburetor perform well. Carburetors, with a few noteworthy exceptions have, since the dawn of time, all been designed to have their base mounted level with the earth. It always amazes me as I walk down the docks and see the gleaming engines in the pristine hulls with carburetors which are not level. I am not talking a few degrees here, I have seen 20 degrees or more. I have given up arguing with people who will retort that "That's the way it came from the factory, so it has to be right". That may be, but it does not make it right. The knowledgeable people have installed leveling spacers under their carburetors so that the carburetor is relatively level as they go down the lake. Once you understand the reasoning behind the concept, it becomes obvious. The engines run much better and they are so much easier to tune when the carburetor is level.

The second secret is to make sure there are no vacuum leaks in your system. Vacuum leaks occur due to a number of things: leaky carburetor base gaskets, leaky intake manifold gaskets, broken vacuum hoses, missing plugs or work rings and valve guides. The carburetor relies on a strong vacuum signal to determine the air/fuel ratio. If you weaken the signal, the mixture calibration will suffer, and so will the power.

The third secret is to make sure you have adequate fuel delivery. If your fuel pump does not supply the fuel, the fire won't get too hot, and the power will be minimal. Clogged fuel filters, broken or cracked fittings, and worn fuel pumps are just a few of the problems which cause poor fuel delivery.

Old gasoline and water in the gasoline are often the culprits resulting in poor performance. Because we do not use our boats very often, they sit on the hoist or in the back yard or in the garage, where they constantly heat and cool every day as the ambient temperature changes. This heating and cooling cause the fuel tank to breathe in and out. At night, the tank temperature drops and the tank inhales a small amount of the damp night air. Once inside the tank, the water falls out of suspension, and in the morning the dry air in the top of the tank is expelled into the atmosphere as the tank warms up. Over time, the water in the tank adds up, and eventually becomes a problem. Make it a point to add a few cans of "Dry Gas" each season which will absorb the accumulated water so it can be burned along with the gasoline.

Now you know how a simple carburetor works. Having said that, there are no really simple carburetors that were built past the 30's. As time passed, more elaborate solutions were employed to attempt to match the complex demands of the engine. In the early 70's emissions, followed by fuel economy, became the driving forces and drove carburetor development to an unheard of state of complexity. Finally, as computers became main stream, they were linked with fuel injector technology to become the only way to meet the increasing demands of emissions and fuel economy goals. Today, there are aftermarket digital fuel injection controllers available that allows the average engine enthusiast to retrofit their engine with a fairly sophisticated engine management system. Properly matched, installed, and tuned, these systems will produce amazing results. You will never want to see another carburetor again. Digital Fuel Injection and engine controllers have become the microwave oven or personal computer of the engine world.

I will add one warning here however. These aftermarket fuel injection systems were developed, by and large, for automobiles which are land based. When utilizing these systems around water and especially salt water, be constantly aware of the connections and grounding requirements. Unlike the engine starter which requires hundreds of amps to function, the injection systems work on milliamp currents, hence any small bit of corrosion will inhibit their function. Use only high-quality connectors, surrounded by conductive grease.

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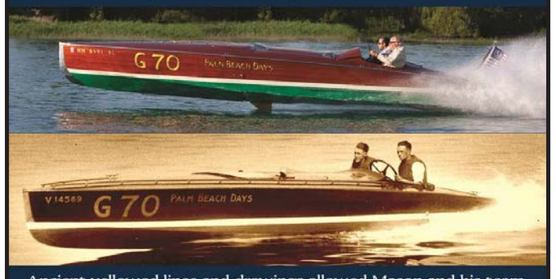

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