Fuel & Fuel Systems

About Gasoline

Source: www.grapeaperacing.com

Octane Rating

Octane is a rating of a fuels resistance to ignite. The higher the octane, the harder it is to ignite. A higher octane may be necessary to prevent pre-ignition and detonation in a high performance engine.

A higher octane fuel will generally burn slightly slower than a lower octane fuel which could require a change in ignition timing. Using a higher octane fuel than you need will not help power, the slower burn rate can actually cause you to lose some power.

To get technical, octane is actually a hydrocarbon with 8 carbon atoms chained together. If your gasoline were made up of 100% octane, it would have an octane rating of 100. We use octane as the rating because it is the hydrocarbon in gasoline that resists detonation and pre-ignition the best.

On the other end of the scale, we have heptane, a hydrocarbon that has 7 carbon atoms chained together, which resists detonation and pre-ignition very poorly. It does not take much compression at all to get it to spontaneously ignite. A fuel made up of 100% heptane has an octane rating of 0. Gasoline with an octane rating of 87, means that it is made up of 87% octane and 13% heptane or a combination of fuels that give the same anti-knock characteristics.

So if pure octane yields a 100 octane rating, how can we get a higher octane than 100%? Well, we can't, but certain additives can make a fuel resist detonation and pre-ignition better than pure octane. A chemical called tetraethyl lead was very popular in the past to boost octane ratings. It has been banned for use in automotive gasoline due to pollution. Leaded fuels are not compatible with catalytic converters or oxygen sensors found on all cars today.

A common additive these days is MTBE (Methyl Tertiary Butyl Ether). This chemical boosts octane ratings and it is also an oxygenate. Being an oxygenate, it reduces the amount of unburned hydrocarbons and carbon monoxide in the exhaust.

It is not important to know exactly what the chemicals are that the boost octane rating of gasoline. What is important is that you understand that they increase the octane rating, and not actual octane.

Detonation

Normal combustion will take place at a pretty steady rate (for a given rpm and load). When a large amount of the charge burns extremely fast and uncontrollably, it is known as detonation. Detonation can destroy an engine in a matter of seconds.

It is common knowledge that heat causes detonation, but heat is not the only cause. Pressure plays a big role in it also. You can get detonation by running with too much ignition advance; if heat was the only cause, signs of detonation would around the exhaust valve, but this is not the case. Usually when detonation takes place from too much advance, the detonation occurs on the intake side of the chamber, which is the coolest side of the chamber. This happens because detonation did not occur until the pressure got excessive, which was after the spark. By the time that happened, the charge near the exhaust valve has already been burned. Most of the time, detonation will occur after normal combustion has started.

Apart for destroying pistons and spark plugs, light detonation can cause all sorts of other problems, like fatiguing cranks and rods quickly and pounding bearings to death, so avoid detonation at all costs.

Pre-Ignition

When the charge ignites before the spark, it's called pre-ignition. This can happen with or without detonation, but usually will cause detonation in a high performance engine. Hot spots in the combustion chamber are the usual cause of pre-ignition. A spark plug with a high heat range can cause a hot spot.

When pre-ignition occurs, the charge begins to burn, When the ignition system fires, the result is usually 2 separate flame fronts. What happens after that is very unpredictable, but it usually leads to detonation. It will act much like too much ignition timing, but it is not controllable or consistent.

Motor Octane Rating

The motor octane rating, referred to as MON (motor octane number), is the best rating to use when selecting fuel for your race or high compression engine. When testing MON, the fuel is heated to 300° F and the intake air is heated to 100° F. The test engine is a single cylinder 4-cycle engine that is run at 900 rpm. Ignition timing is varied with compression ratio. Engine load is varied during test.

Research Octane Number

Known as RON (research octane number). Tested at 600 rpm with a fixed timing of 13° BTDC. The fuel temp is not controlled at all and the intake air temp is varied with barometric pressure. This is done to covert everything to a SAE standard day, which is 60° F, 0% Humidity, and 29.92 inches barometric pressure. The RON should not be used when selecting fuel for a race or high performance engine. The RON will almost always be higher than the MON.

(R+M)/2 Method

This is what you get at the gas pumps. It is average of the RON and MON. It is ok to use this for lower compression street motors, but when you get much over 10:1, you should really pay attention to the MON. The closer the RON is to the MON, the more stable the fuel is. This can be very critical when running 7000+ rpm.

Specific Gravity

This is the weight of the fuel compared to water. If a race fuel has a .75 specific gravity, it is 3/4 of the weight of the same amount of water at the same temperature.

Checking your float bowl level in your carburetor is important when changing your fuels specific gravity. A float will sit further in a fuel with a lower specific gravity, which will raise the fuel level in the float bowl. A lower specific gravity also makes jetting more critical because the engine will run leaner (less dense fuel).

A fuel with a higher specific gravity will run cooler (if no jetting changes have been made to compensate), because a denser fuel will make a richer mixture. When running forced induction with high boost levels or large nitrous oxide systems, you want a high specific gravity fuel.

An air/fuel mixture is not measured in volume; it's measured in weight. For a 12:1 mixture, you have 12 lbs. of air to 1 lb. of fuel. When changing to a fuel with a different SG, jet changes are important to maintain your air/fuel ratio. As a general rule of thumb, every 0.01 difference in specific gravity requires a change of 1 jet size. When changing to a high specific gravity fuel, you will need smaller jets; when a lower specific gravity fuel is used, you will need larger jets. If your new fuel has a specific gravity that is 0.02 higher, you will need to drop your jet size by about 2 to keep the same air/fuel ratio.

Reid Vapor Pressure

Vapor pressure is the pressure exerted by the vapors released from any material at a given controlled temperature when enclosed in a laboratory vapor tight vessel.

Vapor pressure for normal street grade gasoline is anywhere 9.0 to 15.0 psi depending on the air temperature. The higher the average air temperature, the lower the Vapor Pressure needs to be. The lower the median temperature of an area, the higher the Vapor Pressure must be to properly atomize the fuel with air for good combustion.

If a racing grade gasoline's Vapor Pressure is too low (below about 5.5 psi) it can cause faltering acceleration during sudden wide-open throttle applications. If it is excessively high (above 8.0 psi), it may result in vapor lock or fuel percolation hindering fuel flow from the tank to the engine when high under-hood temperatures are encountered. This can lead to engine performance problems ranging from poor to erratic power output to engine overheating to full engine stall due to fuel starvation.

Aviation Gasoline

Many people seem to think that AV gas is a good way to go for a high compression engine. That is not true at all. It will not make any more power; it will actually hurt power when compared to similar racing gasolines. Aviation fuels were designed for aviation use, not automotive racing.

The popular choice is Avgas100LL, which stands for 100 octane low lead. It has 2 grams of lead per gallon, making it unsafe for car engines with oxygen sensors and catalytic converters. It also has a high level of aromatics, which generally cause poor throttle response.

The other choice is Avgas100/130, which has 4 grams of lead per gallon. It is better than Avgas100LL, but still not as good as racing gasoline. Gasoline designed for racing will have a specific gravity of about 0.75. The best you'll find in avgas will be about 0.70 if you're lucky.

If you want the most power from your racing engine, you'll need to use a fuel that was designed for that application. AV gas is not.

Source: www.grapeaperacing.com

Alcohol

Source: www.grapeaperacing.com

Types of Alcohol

The two most common types of alcohol used for racing fuel are Methanol and Ethanol. Both can be made from a variety of renewable resources, including waste products such as grass and tree trimmings, paper waste and more.

Today, ethanol is made primarily from corn and sugarcane. Methanol can be made from the same types of renewable resources, but today it is mostly made from natural gas.

Air-to-Alcohol Ratio

The correct ratio is anywhere from 7.1-9.1:1 depending on the type of alcohol and the additives in it. Gasoline on the other hand runs at 14.1-15.1 depending on the additives. Both situations require richer than the optimum ratio on hard throttle. It's common to run gasoline at 12-12.5:1 and alcohol around 6:1 at wide-open throttle. The point here is that if you switch to an alcohol fuel from gasoline, you will use at least twice the amount.

The caloric value (heat energy) of alcohol is about ½ the value of gasoline. So you'll need to burn twice as much to get the same power potential. This means you'll need a fuel system that can flow twice as much. Carburetor circuits or fuel injectors need to flow twice as much as well. This is not as easy as is sounds, simply jetting up may not be possible. Even the largest jets can be too small for an alcohol engine. This is why you'll see alcohol carburetors that are built just for alcohol. The special carburetors have larger passages through out. Needle valves flow more, and everything is compatible with alcohol, which is very corrosive.

Unlike gasoline, alcohol will continue to make additional power at mixtures that are much richer than the ratio that gives the highest BSFC. This is because alcohol is an oxygenated fuel, so by adding fuel, you are also adding oxygen. It is also a good safeguard to run rich on alcohol.

Alcohol has a much better cooling effect than gasoline. A rich mixture further increases alcohols ability to cool the intake charge, making a denser mixture. This added cooling effect allows a high compression ratio to be run. This is one the biggest advantages of running alcohol. An engine that could barely run 12:1 compression on gasoline without detonation could run over 14:1 on alcohol.

Cost

The cost of alcohol varies as much as gasoline, but in general, the cost is about ½ to slightly over ½ the cost of racing gasoline. This isn't as cheap as it may sound at first. Remember that you'll be using at least twice as much. In terms of over all cost, you'll pay more for alcohol for the same amount of run time.

Source: www.grapeaperacing.com

Race Fuel Specifications

Source: www.grapeaperacing.com

Racing Gasoline

Fuel Brand	Motor Octane	Research Octane	(R + M)/2	Specific Gravity	Lead Content *
ERC - 110	104	110	107	.745	3.23
Sunoco - 111	105	117	111	.725	N/A
Sunoco - 112	109	115	112	.715	N/A
Sunoco - 117	113	121	117	.700	N/A
Trick - 112	105	112	108.5	.730	4.0
Trick - 119	108	119	113.5	.740	4.0
Union76 - 110	106	114	110	.728	4.1
Union76 - 114	110	118	114	.728	N/A
Union76 - 118	114	120	117	.704	N/A
VP - Red	105	110	107.5	.742	4.23
VP - C 12	108	110	109	.710	4.23
VP - C14	114	116	115	.690	4.20
VP - C14+	115	117	116	.690	6.00
VP - C15	115	117	116	.713	4.20
VP - C16	117	118	117.5	.730	6.00
VP - C18	116	116	116	.696	4.23

*** Lead Content is measured in Grams Per Gallon**

The closer the motor and research octane ratings are to each other, the more stable the fuel is. What it tells you is that the octane rating is affected very little by heat (and race engines make plenty of heat). Notice how close all the VP racing fuels are, this makes VP an excellent choice for a high rpm, high compression racing engine.

Source: www.grapeaperacing.com

Fuel System Plumbing Recommendations

Source: www.grapeaperacing.com

Carbureted Gasoline Engines

Horsepower	Rigid Line Size	-AN Hose Size	Pump GPH at System Pressure	Pump GPH Free Flowing
200	5/16"	-04	17	46
350	3/8"	-06	29	81
550	1/2"	-08	46	127
800	5/8"	-10	67	184
1200	3/4"	-12	100	276

These figures are for gasoline engines and figured assuming a .05 BSFC (.5 lbs. of gasoline is needed make 1 hp for 1 hour). If you're in doubt, it's better to have more fuel flow then too little.

The formula to figure your fuel flow requirement is:

(max hp x .5 bsfc) / 6 = GPH

You divide by 6 because gasoline weighs 6 lbs. per gallon. For example:

(550 hp x .5) / 6 = 45.8 GPH rounded up to 46 GPH

The -AN (Army Navy) number of a hose simply stands for 16ths of an inch, so -08 = 8/16" which = 1/2"

Source: www.grapeaperacing.com

Fuel Injector Selection

Source: www.grapeaperacing.com

Brake Specific Fuel Consumption (BSFC)

In order to know what size injectors you need, you'll need to know how much fuel it takes to make the desired horsepower you want. The BSFC is simply how many pounds of fuel it takes to make 1 hp for 1 hour. BSFC will be about 0.45 for most street injection set-ups. This means that if you have a 400 hp engine with a BSFC of 0.45 you'll need 180 lbs of fuel per hour to maintain 400 hp. The formula for pounds of fuel per hour is:

BSFC × Peak HP = lbs/hr

If we used 400 hp, which would be 400 flywheel hp with no accessories, our example it would look like this:

0.45 × 400 = 180 lbs/hr

We would need all of our injectors to be able flow 180 lbs/hr to maintain 400 hp.

Injector Sizing

Now if it is an 8 cylinder engine, you can figure out that each injector must supply 22.5 lbs/hr. Injectors will work best if they don't exceed more than 85 duty cycle. An injector that flows 26.5 lbs/hr will be at an 85% duty cycle when flowing 22.5 lbs/hr, but you may not find an injector that flows exactly what you need. It is best to step up to the next size, for our example, we might need to step up to 30 lb/hr injectors. The formula for injector sizing is:

lbs/hr = (BHP × BSFC) ÷ (No. of Injectors × DC)

Where:
BHP = Peak Brake Horsepower
BSFC = Brake Specific Fuel Consumption
DC = Injector Duty Cycle

Lets say we have an engine with 300 hp, a 0.45 BSFC, 8 injectors (8 cylinder with 1 injector per cylinder) and we want an 80% duty cycle for the injectors. The formula would look like this:

lbs/hr = (300 × 0.45) ÷ (8 × 0.8) = 21.1 lbs/hr

We would the look for and injector for that size or the closest size larger. A 22 lb/hr injector would work great.

Fuel Pressure

Most injectors are rated at 43.5 psi (which is about 3 bar). By changing the pressure, you change the flow rate. If you need 25 lbs/hr, and there is an injector that will flow 24 lbs/hr at 85% duty cycle, it is possible to use more fuel pressure to make the injectors flow more. It is better to do this when the injectors are just a little too small, than to go to larger injectors. The chart below will show what adjusting fuel pressure can do. You can see from the chart that there are quite a few options to get very close to what you'll need.

Injector Flow Rates At Various Pressures

Rated Flow @ 43.5 psi	Fuel Pressure				
	40	45	50	55	60
19 lb/hr	18.21	19.32	20.37	21.36	22.31
22 lb/hr	21.09	22.37	23.58	24.73	25.83
24 lb/hr	23.01	24.41	25.73	26.98	28.18
30 lb/hr	28.76	30.51	32.16	33.73	35.23
36 lb/hr	34.52	36.61	38.59	40.47	42.27
55 lb/hr	52.74	55.94	58.96	61.84	64.59
83 lb/hr	79.59	84.41	88.98	93.32	97.47

Horsepower Support

You can figure how much hp your injectors can support with the following formula:

HP = (lbs/hr × No. of injectors × DC) ÷ BSFC

Using a 0.45 BSFC is good for normally aspirated engines, but if blower, turbo, or a dry nitrous system is being used, a 0.5 BSFC is better. Forced induction engines will usually run closer to a 0.5 BSFC. This is mostly due to forced induction engines running on the rich side for safety. Running richer helps raise the detonation threshold by cooling the charge. It reduces efficiency slightly, which is why BSFC numbers are higher.

Remember that if you change fuel pressure, you must change the lbs/hr rating according to the chart. Lets say we want to know how much hp a set of injectors will support for a 4 cylinder turbo engine running at 85% duty cycle. The injectors flow 22 lbs/hr. The formula will look like this:

HP = (22 × 4 × 0.85) ÷ 0.5 = 150 hp

If you think the engine will exceed 150 hp, more fuel pressure or larger injectors will be required.

Estimated Injector Size by Airflow

If you are using 1 injector per cylinder in a normally aspirated engine, you can used the following formula to estimate the size of the injector by air flow:

Lbs/hr = (CFM × 0.44298) ÷ # of Cylinders

Impedance

There are two basic types of injectors, saturated (high impedance) and peak and hold (low impedance). Saturated injectors are more common and draw less amperage form the ECU. Saturated injectors also create less heat because they draw less amperage. A saturated injector will have an impedance of about 12 ohms, this means that at 12 volts it take 1 amp to hold the injector open.

Peak and hold injectors will have impedance closer to 2 ohms and draw about 6 amps. They use high current to open the injector very quickly and precisely, and then they draw less to hold the injector open. For high horsepower and flow rates, the peak and hold injectors are much more precise, but they are more venerable because of the heat they make. They can also deal with higher fuel pressure than saturated injectors. If it is a street engine that will be daily driven, saturated injectors are more reliable for long-term use. Peak and hold are better for high horse power and competition use.

Most factory ECU's will consist of 4 injector drivers. These drivers can control up to 4 low impedance injectors, so if you're racing 4 cylinders, you have a wide range of ECU's to choose from. Us V8 guys are a little more limited. If our power levels can use high impedance injectors, then there is no problem. A factory ECU with 4 injectors drivers can easily run 8 high impedance injectors (2 injectors per driver), which is exactly how the factory sets them up on stock V8 engines.

If you plan on running more than 4 low impedance injectors, your choices are a little more limited. There are a few aftermarket injector controllers that can be added to the factory ECU. They simply use the outputs of the factory drivers to trigger 8 low impedance injectors. Some also give some tenability by allowing you to trim the pulse widths.

The other option, which is gaining popularity, is an aftermarket ECU with 8 low impedance injector drivers. These not only allow the use of 8 peak and hold injectors, they can also be custom tuned for any modifications and offer many other options that are desirable to serious enthusiasts.

Source: www.grapeaperacing.com