ENHANCING FUEL FOR BETTER

> If you look carefully, you can see that the spray patterns from these dirty injectors aren't uniform.

The spray pattern has two major functions: to both atomize and evenly distribute the fuel to a specific point in each cylinder's intake tract. The engineer who designed the fuel system will have selected the injector spray pattern that will work best for each particular engine. Robert Bosch alone produces in excess of 1,000 different injector part numbers with different spray patterns and flow rates, and that company is by no means the only fuel injector manufacturer in the market.

Improving the performance of an EFI engine isn't always as simple as adding a set of headers or a high-performance camshaft because whenever you increase airflow, you also need to increase the amount of gasoline delivered. You may need to reprogram the engine management computer and/or replace the fuel injectors with higher flow units.

Any injector is built to a specific flow rate of "X" lbs. of fuel per hour at a given fuel pressure. You can slightly increase the flow by upping the fuel pressure, but if you go too far you can cause the injectors to lock closed. Whenever you modify an engine's air pumping ability, the flow rate of the injectors must match the engine's new air/fuel mixture needs. The fuel supply system (fuel pump, filter & fuel line size) and the fuel tank vent system (fuel vapor canister — EVAP) must be designed so the injectors will have adequate fuel volume and fuel pressure.

In theory, each cylinder of a fuel-injected engine should have the same ideal air/fuel mixture for every driving condition, but in the real world this is not always true. The injectors of a production engine are not always perfectly flow-matched. Most new OEM (original equipment manufacture) fuel injectors are held to a + or - 2% flow variance. Ideally, each would flow exactly the same amount, but holding a production line to that standard would raise the cost of the injectors substantially. In some cases, the replacement aftermarket units that you buy at your local jobber or auto parts store are not built to the same flow standards as the OEM injectors are held to. Also, due to part number consolidation, both the OEM replacement fuel injectors from the car dealer and many of the injectors available from the aftermarket will not have the same fuel flow rate as the originals had. The variation can be as much as 25% when compared to the OEM injectors that the computer was programmed for. So, if you replace just one bad injector with a new one that doesn't flow the same volume of fuel as the rest, performance will suffer.

Remember, the oxygen sensor is an averaging device. If the flow rate and spray pattern are not exactly the same from each injector, the air/fuel mixture delivered to each cylinder will vary. When the air/fuel mixture varies by more that 6-8 % from cylinder to cylinder, some cylinders will be running too rich and others will be running too lean, and the engine's power output, drivability and fuel mileage potential will suffer. In our opinion, the injectors should always be replaced as a set unless you have the capability of confirming that the flow volume and spray pattern are the same for all by testing them on a flow bench.

> In the first place, the injectors must receive adequate pressure and volume, which can be assured by means of a high-performance pump.

> With this variation in fuel delivery volume combined with the way an oxygen sensor provides only an average reading, some cylinders are going to be lean, and others rich. That's not the recipe for maximum performance and driveability.

Many of the aftermarket high-performance fuel injectors we have tested have had more flow variance than we would like to see. For example, one set had four injectors that flowed at one rate, three that flowed 10% more, and one that flowed the same as the first four at 35 lbs. of fuel pressure. but at 42 lbs. jumped up to same rate as the higher-flowing three injectors. A set such as this would have been a tuning nightmare if we had not caught the problem on the flow bench.

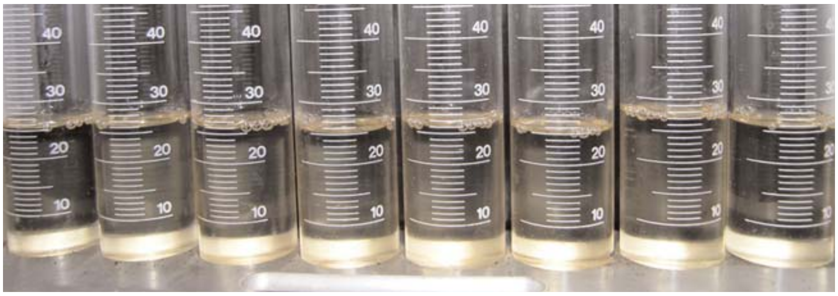
PERFORMANCE TUNING

Many of the race teams that are building and tuning fuel injected engines for professional competition are using a wide-band oxygen sensor system to monitor the air/fuel mixture each cylinder gets from the fuel injection system. To do this, a sensor is mounted in the header tube of *each* cylinder, which allows the tuner to read the air/fuel mixture of individual cylinders at any engine operating condition on the dyno, or at the track. The data thus obtained, plus the flow bench data of each fuel injector are used to fine-tune the air/fuel mixture for each cylinder. We have done performance-tuning work using a wide-band oxygen-based air/fuel meter system from Innovate Motorsports, which included mounting a wide-band O2 sensor in each cylinder's header tube. The data we got allowed us to actually see the air/fuel mixture each cylinder was getting. Then, by matching the flow from the fuel injector to each cylinder's needs, we were able to increase power and fuel efficiency while lowering the exhaust emissions.

In the days before wide-band O2 sensors were in common use, one of the race teams we do fuel injector flow testing work for was dominating most of the races they entered because we flowed the injectors and marked the flow of each right on the injector. They then used this data to match the flow of each injector to the cylinder that needed more or less fuel, which was determined by looking at each cylinder's exhaust gas temperature (EGT) reading. This allowed them a tuning advantage over the other teams. Now that the sanctioning body has started allowing the use of a computer that gives the tuner the capability of adjusting the "on time" or "pulse width" of each individual injector, this team no longer has that same tuning advantage.

Ideally, each cylinder of a engine would need the same fuel injector flow, but compromises in the intake and exhaust system design required to allow the engine to fit into the engine compartment result in different cylinders having different fill rates due to restrictions in intake flow or exhaust system back pressure. The Society of Automotive Engineers (www.sae.org) has an excellent technical paper #1999-01-1170 titled, "The Determination of Air/Fuel Ratio Differences Between Cylinders in a Production Engine Using Exhaust Gas Oxygen Sensors." Good reading for those of you who want a more in-depth discussion of this concept.

> A thorough cleaning of these injectors was all it took to achieve this degree of uniformity. That's not always the case, however.



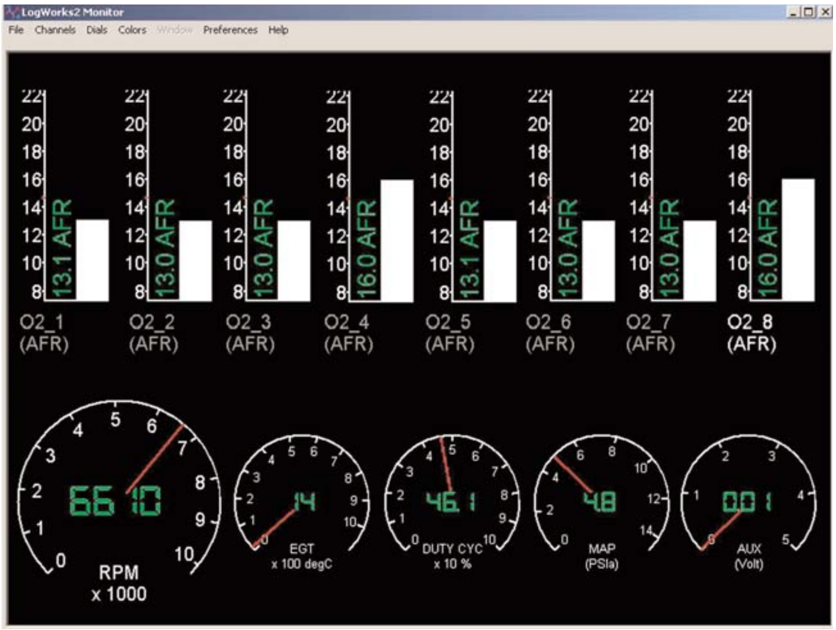
> Even this brand-new set of high-performance injectors has an 8% variation in volume.

> With a wide-band oxygen sensor for each header tube, this meter system allows the tuner to read the air/fuel ratio of each individual cylinder.

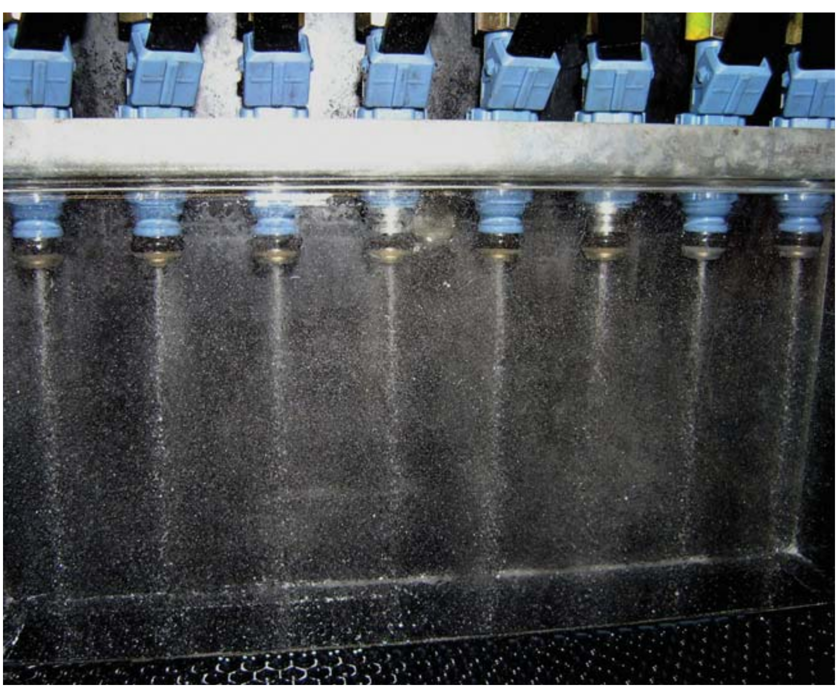
CHECKING INJECTOR FLOW

The fuel injector flow bench we use is from ACE/ANSU. This tool allows us to check the actual flow from the fuel injectors at any fuel injector on-time, rpm or fuel pressure we choose to simulate. We've had customers bring injectors to us for flow testing after an engine failure due to a lean condition. One example was an engine with an aftermarket supercharger. The instructions directed the installer to increase the fuel pressure so the engine would get the extra fuel it needed for the extra air it would be ingesting. The problem we found was that as we increased the fuel pressure on the bench, the injectors actually began to stop flowing one at a time. The increased pressure was actually causing the injectors to lock closed. The fix for this problem was to install fuel injectors that were designed to flow more pounds of fuel per hour. The flow bench also allows the user to observe the injector spray patterns and actually measure the fuel flow from each fuel injector so the user can actually see if the injectors are truly flow matched.

A common problem we have seen with the GM Multec fuel injectors that were used in "Tuned Port" fuel injected engines produced from 1985 through the early 1990s is that the insulation on the injector coil windings deteriorates, allowing the injector coil to short circuit. Apparently, gasoline causes the insulation to break down. The problems you may experience from this can vary from an occasional one-cylinder miss (caused by an intermittent short in the injector coil) to a totally dead cylinder (a fuel injector with a coil that is shorted to the point where it no longer supplies any fuel to the cylinder). An ohmmeter can only read the fuel injector coil in an unloaded condition, so you may not be able to find an injector that has an intermittent short. The ACE/ASNU flow bench has a function that allows the user to check the resistance of the fuel injector's coil while it's in a loaded condition. The only other way we know of to test a fuel injector coil for an intermittent short is to use the OTC/SPX #3397 Fuel Injection Tester (it checks the coil while it flows current through it). If one or more fuel injectors have failed due to shorted coils, we would suggest replacing the whole set because the coils in the other fuel injectors will most likely short/fail in the near future.



> LogWorks software displays the data the Innovate meter is capturing. Note how lean #4 and #8 are.



> On the test bench, you can clearly see the variation in fuel delivery volume.

> This fuel injector tester will let you know if the actuating coil is shorted.

DIAGNOSING THE FUEL SYSTEM

The use of an automotive scan tool is the best way to diagnose the fuel system on a production fuel injection system. The long-term fuel trim data can be used to read how much the computer is adjusting the fuel injector pulse width so the engine has the correct air/fuel mixture. The misfire data for each cylinder that can be seen with a scan tool can also be used to determine if any one cylinder has a higher misfire rate than the others. The computer can only adjust the average air/fuel mixture it "sees" through the data it receives from the oxygen sensor. If one injector is flowing less than the others, all the computer can do is to command all the fuel injectors to supply more fuel.

If flow becomes restricted as the injectors get dirty, the computer will attempt to increase the flow by opening the injectors longer through the use of its long-term fuel trim (LFT) function. Injectors that are low-flow will need more pulse width than those that are flowing the correct volume. If the injectors are leaking fuel, the computer will subtract fuel. The engine will perform its best when the computer does not continually have to correct for fuel injectors that are not supplying the proper volume of fuel.

Port fuel injectors are located in a very hot area of the engine, so are subject to deposit build-up problems created by the effect of high temperatures on gasoline. The high under-hood temperatures that occur after you shut off your engine will also cause deposits to build up in the injectors as the fuel boils. These deposits will both distort the spray pattern and restrict the injector's ability to supply the engine with the correct volume of fuel.

PREVENTING DIRTY FUEL INJECTORS

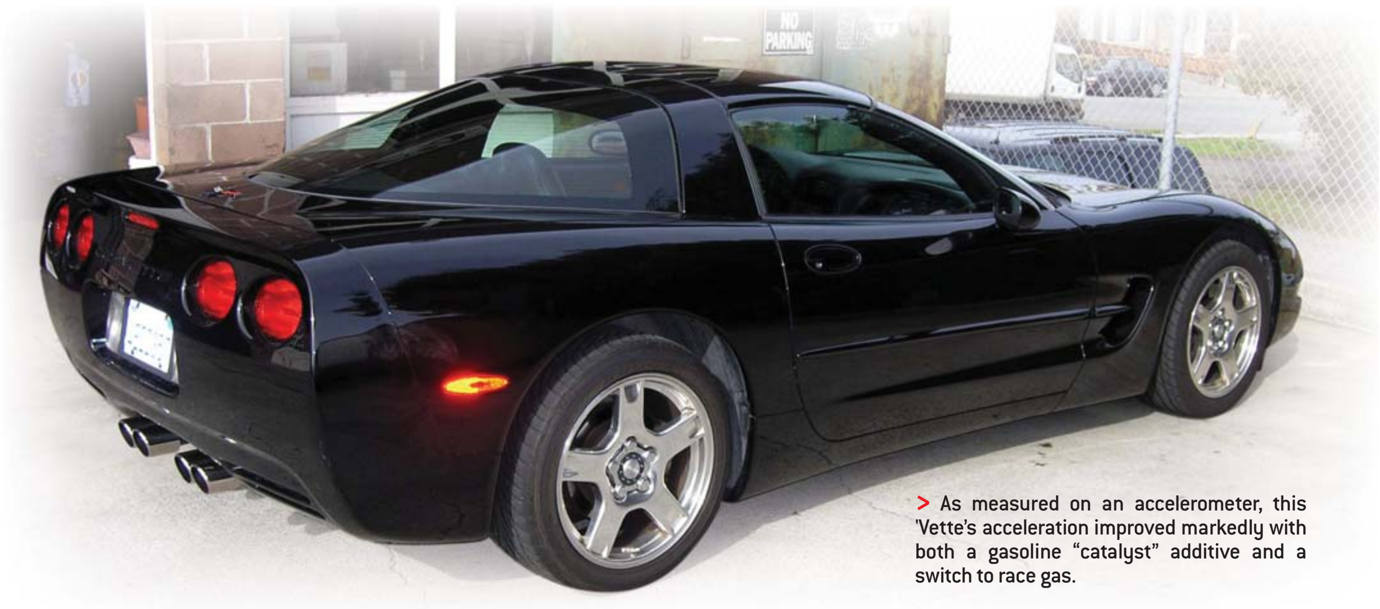
The best medicine to help prevent fuel flow restriction is the use of a gasoline that contains a good detergent. Many car manufactures recommend the use of a gasoline that conforms to the new "Top Tier" gasoline standards to help keep the fuel injectors clean. Many of the major brands of gasoline are now being blended to "Top Tier" standards. The level of detergents in "Top Tier" gasoline, however, is not always high enough to keep your injectors clean, so from time to time you may need to add some extra cleaning power to your gasoline. The subject of cleaning fuel injectors and the intake tract is something we will address in depth in a future article.

ADDING PERFORMANCE TO GASOLINE

During many years of racing and performance tuning, we've done experiments with fuel additives that claim to add performance to gasoline. Very few have lived up to their advertisements, but some have produced surprisingly good results. For example, we have recently been working with a new fuel catalyst from Chevron called PurEscape, and it actually did increase the power and drivability in each car we tried it in. The active ingredient in PurEscape is from a family of chemicals known as fatty acid polyols (the exact formula is a patented trade secret). When PurEscape is added to today's reformulated gasoline, both engine performance and drivability showed

> A scan tool lets you look into what the computer is doing to adjust fuel trim. Combined that with misfire data and you can often identify a problem cylinder.

> Not only will deposits such as these restrict flow, they'll also disrupt the carefully-engineered spray pattern.



> As measured on an accelerometer, this 'Vette's acceleration improved markedly with both a gasoline "catalyst" additive and a switch to race gas.

noticeable improvements. It's normal for a spark-ignited engine to have a certain amount of variance in combustion efficiency. PurEscape improves the gasoline's combustion properties and makes it easier for the spark plug to ignite the air/fuel charge in the combustion chamber every time, thus allowing the combustion process to become more consistent. When PurEscape is added to gasoline, it helps release the gasoline's energy faster during the combustion process resulting in higher average cylinder combustion peak pressures.

One of the people we turn to when we have a question or need advice on performance fuel-related issues is Tim Wusz of Rockett Brand Race Fuel (formally Union Oil Race Fuel). When we were discussing the results we were seeing with PurEscape, he said it would be an interesting experiment to compare the performance of an engine with premium unleaded fuel from our corner gas station, the same gasoline with PurEscape mixed in, and 100 octane unleaded race fuel. The performance improvement results did prove to be quite interesting. NOTE: *We cleaned the fuel injectors before we did any of our performance tests so any performance improvements would be from the fuel blend, not from any improvement in fuel flow or spray pattern.*

TESTING FOR PERFORMANCE IMPROVEMENT

The test vehicle we will reference here is a 1997 Corvette with the LS-1 engine and automatic transmission, but the results were just as good on a fuel-injected four-cylinder Toyota. The driver of the Toyota said the PurEscape made her car feel like it was on steroids, and it also got more miles to the gallon of gasoline each time she used it in a tank full of gasoline.

We used the accelerometer function of a data logging system to measure the G-force that was created as we accelerated from a dead stop to 60 mph so we could compare the gains we experienced as we tried the different fuel blends. We started with a major brand of premium-unleaded gasoline straight, then we added the PurEscape to that same fuel. We next removed that blend from the tank and replaced it with Rockett brand 100 octane racing unleaded gasoline. As a final test, we added the PurEscape to the race gas.

The first acceleration tests were used to establish a performance baseline with the premium-unleaded gasoline in the Corvette's gas tank. We performed three wide-open throttle acceleration runs on a level road from zero to 60 mph with the traction control system engaged. The accelerometer logged peak G-force readings of 0.62, 0.60 and 0.63 during the three acceleration test runs.

Repeating the tests on the same day and at the same location with the premium-unleaded gasoline and PurEscape mixed in gave us peak G-force readings of 0.69, 0.70 and 0.69. There was also a noticeable improvement in drivability and a seat-of-the pants power gain.

The 100-octane Rockett race fuel gave us 0.72, 0.73 and 0.73. Again, we could definitely feel the difference.

As a final test, we added PurEscape to the 100-octane race fuel and repeated the acceleration tests. This time, we couldn't feel any difference, and the G-meter recorded runs of 0.73, 0.74 and 0.72.

We've always known that race fuel could allow a engine to produce more power than pump gasoline, but we never thought a fuel catalyst like PurEscape added to pump gasoline would provide the performance gains we recorded. Apparently, improved gasoline chemistry can allow an engine to produce more power without having to make any expensive engine modifications. **HRP**

SOURCES:

www.toptiergas.com

CHEVRON
www.techronconcentrate.com, www.chevronpurescape.com

ACE/ASNU ACE
800/325-3888, www.asnu.com

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