UNDERSTANDING 5 GAS DIAGNOSIS

AND EMISSIONS Gas Diagnostic Steps This procedure will help in your efforts to figure out what the five-gas reading are telling you. In order for five gas analyses to be conclusive five gas readings should be taken before the catalytic converter. Look at the hydrocarbon levels first. HC readings will tell you quickly if it is rich, lean or if it has a misfire. Then look at the CO2. These will confirm the HC readings. Use the CO2 to verify if it has incomplete combustion. The vehicle cannot have a misfire or be too rich or too lean if the CO2 is good. There must be a problem with the catalytic converter or air injection system. Look at the CO. if it has high CO it is rich; if CO is low it could be lean. O2 is a good lean indicator. If it has high O2, it could be lean.

COMPONENTS OF EMISSIONS

Hydrocarbons (HC) Raw gasoline or gasoline that has not burned. Associated with incomplete combustion. Combines with NOx and sunlight to form photochemical smog.

Carbon Monoxide (CO) Partially burned fuel known as a rich indicator. CO is a highly toxic gas it displaces oxygen in the blood stream.

Oxides of nitrogen (NOX) Unnatural combination of oxygen and nitrogen. Occurs during high temperature and high pressures. Reacts with HC and sunlight to form photochemical smog.

Carbon dioxide (CO2) A measurement of combustion efficiency. Occurs during combustion of HC and O2 to produce H2O and CO2

Oxygen (O2) Supports combustion, also known as a good lean indicator

CAUSES OF EMISSIONS
In order for the internal combustion engine to obtain the lowest level of emissions all elements of combustion have to be in place. Spark timing, air, fuel, and compression. If any of these elements are out of place the combustion process will suffer and HC will increase. The amount HC increase depends on the severity of the problem. For example an engine with an ignition misfire will produce the highest level of HC. The air/fuel enters the cylinder then gets compressed but not burned. In this example none of the fuel will burn and enters the exhaust stream in its natural state as HC. The HC levels from the exhaust wouldn't be much different than sampling the fuel tank filler neck, its raw fuel untouched by combustion. This is what occurs during a total loss of combustion usually associated with ignition misfires. Anything that would stop the burning process sooner than we would like will increase HC readings in the exhaust. There is only one type of misfire that won't result in a HC increase. This would be an injector circuit problem no fuel equals no HC increase.

**Electrical misfires:** if the spark plug does not fire the fuel will not burn. This will create the highest level of HC emissions from the tail pipe.

**Advanced ignition timing:** spark occurs before the air fuel mixture is properly compressed. This creates incomplete combustion. When ignitions occurs to early the expansion of the gasses put downward pressure on the top of the piston as it is moving up in the compression stoke. This will create a loss of power, also these expanding gasses are being compressed this raises the pressure in the cylinder which then causes excessive NOX emissions and detonation.

**Lean air fuel mixtures:** HC molecules are separated by too much air, the flame cannot jump gaps for the entire air/fuel charge to burn. This is a (lean misfire). In the case of a lean misfire combustion occurs intermittently so the severity if the HC increase is not as much as total ignition loss. Remember during a lean misfire there is no combustion. There is some fuel mixed in with the large amount of air the small amount of fuel doesn’t burn the result is an increase in HC. Note hydrocarbons normally will not increase during a slightly lean condition. When slightly lean combustion still occurs.

**Rich running condition:** To much fuel for the amount oxygen. The O2 is used up before all the fuel has burned. The flame goes out and HC levels increase. In a slightly rich condition the flame may reach all the fuel but only partially burn it producing high levels of CO this may not result in a HC increase. Remember HC is fuel that has not burned. Any fuel that gets burned or partially burned will come out of the tail pipe as CO or CO2. CO is created when fuel is only partially burned this occurs when only 1 oxygen atom has attached to 1 carbon atom. CO2 is created when fuel is compactly burned this occurs when 2 oxygen atoms has attached to 1 carbon atom (CO2).
**EGR valve open at idle:** oxygen is replaced by inert exhaust gas that does not support combustion and fuel will not burn. This increases HC levels at idle. An engine at idle does not run as efficiently as an engine under a load. The reason for this is volumetric efficiency. An idling engine can only get as much air as the throttle plate will allow into the intake manifold. When the EGR valve is open at idle it crowds out air that would normally be used for combustion instead the fuel doesn’t burn and HC emissions increase. When the engine is under load the throttle plate is open and there is very little restriction to airflow into the intake manifold. This means there is enough oxygen to complete the combustion process even when the EGR valve is open. An EGR valve that is open under load becomes insignificant because of volumetric efficiency; HC levels drop because the combustion process is more compete. Volumetric efficiency is the amount of air that fills the cylinder when the intake valve opens.

**Idle speeds too low:** This is usually due to insufficient airflow past the throttle plate. This lowers the pressure in the cylinder reducing combustion efficiency therefor HC levels increase. This problem creates low volumetric efficiency. Anything that restricts the intake airflow to the cylinder will result in low cylinder pressures and raise the HC levels.

**Leaking piston rings:** The air/fuel mixture isn't compressed properly causing low combustion efficiency, therefore elevating the HC levels. The HC that escapes past the piston rings enters the crankcase. Over time this will saturate the engine oil with fuel. This fuel is drawn through the PCV valve causing a rich mixture (see above)

**Burnt intake or exhaust valves:** when a cylinder doesn’t seal on its compression stroke the pressures will be too low for complete combustion to occur and HC levels will be elevated. The HC will generally be higher at idle than under a load due to volumetric efficiency. An engine generally will run at half the efficiency at idle then it does under a load. This is evident when we perform a running compression test. The reading you get off the compression gauge on a cylinder while the engine is running is about half of what you see when checking compression while cranking. When cranking the throttle plate is all the way open and the engine is Turing slow this allows lots of air to enter intake manifold and since the intake valve is open for a long period of time there is plenty of time to fill the cylinder. With the car running the throttle plate is closed and the engine is spinning fast. The rpm of the engine and the positioning of the throttle plate is what determine the amount of air that can enter the cylinder. Therefore when the valves are burnt the problem is more prevalent at idle than under a load when the engine is more efficient.

**Some other causes:**

Malfunctioning air injection systems
Malfunctioning catalytic converter

There are many more causes of elevated HC emissions. It can be simplified to one simple phrase (anything that stops the combustion process too soon will cause elevated
HC with the exception of an injector circuit malfunction). Think of HC as a measure of poor efficiency. The higher the HC the worse the efficiency of the engine will be.

CO is partially burned fuel that occurs when the air/fuel mixture is rich. CO will increase only when there is not enough air to burn the fuel that enters the cylinder. During a rich running condition fuel will burn until the oxygen is gone allowing the flame to go out. This means the oxidizing process has been stopped by the lack of oxygen available in the cylinder, which caused incomplete combustion. CO is a byproduct of combustion and can only be made when burning takes place in a cylinder. Problems that create lower than normal combustion will usually result in lower than normal CO with the exception of a rich condition. This is why CO is a good rich indicator it will only be elevated when the fuel mixture is rich.

**Plugged PCV valve:** The engine can receive as much as 30% of its air intake from the PCV system. When the PCV system gets plugged it starves the engine of needed oxygen to complete the burning process therefore this will create a rich running condition and elevate the CO readings. The wrong size PCV valve, one that is too small, will have same results elevated CO emissions.

**Dirty air filter:** Carbureted engines are very susceptible to this condition. The carburetor works on differential pressures. When the air cleaner is plugged it creates a choke affect. It’s like shutting the choke plate thus creating vacuum in the throat of the carburetor and lowering the pressure at tip of the discharge nozzle. The pressure in the fuel bowl remains at the same and the pressure at the discharge nozzle drops lower than what s in the bowl. The pressure difference between the fuel bowl and the discharge nozzle allows the fuel to flow from the discharge nozzle. Fuel injected engines are less susceptible to this condition. They use Mass Airflow sensors and Vane Airflow meters for fuel metering. Their operation depends on the air pulled across it to register a load condition to the PCM, however the restricted air filter will limit flow across the sensor. This condition may cause lower than normal intake manifold vacuum this in turn may effect cars that use map sensor as a load sensing device. The PCM would read the signal from the map as a load condition and richten up the mixture.

**Fuel in the crankcase:** Fuel that enters the crankcase is drawn through the PCV system this fuel is not metered and will cause the fuel system to be rich. This fuel will be an addition to what the system is already receiving from its normal source.

**Saturated Evap canister:** The EVAP canisters job is to store fuel vapors from the fuel tank and carburetor float bowl while the vehicle is at rest. The computer will purge these vapors from the canister when the vehicle enters closed loop and is off idle. When the canister purge solenoid is activated it allows engine vacuum to pull the stored fuel vapors into the intake manifold to be burned. These vapors dissipate from the canister quickly and will make the fuel system rich momentarily. When the EVAP canister is
saturated the fuel in the canister will not dissipate and causes the air/fuel mixture to be continually rich. This problem will cause high CO conditions off idle.

**Note:** Most canister purge systems will not begin purging until the engines computer system has entered closed loop and the throttle is off idle.

**Some other causes:**

- Malfunctioning air injection system
- Malfunctioning catalytic converter
- Malfunctioning in computer controls
- High fuel pressure
- Sunken float
- Leaking injectors

Remember that CO is a rich indicator it will be elevated when the fuel system is rich. CO can only be present in the exhaust when combustion occurs; therefore it is a byproduct of combustion.

---

NOx is formed when combustion temperatures exceed 2500 degrees. Oxygen bonds to nitrogen to form the deadly gas NOx. This occurs under high temperature and pressure.

**Advanced timing:** spark occurs before the piston has reached the top of its compression stroke. When the air fuel mixture ignites the gasses expand the piston still moving up compresses the expanding gases creating abnormally high pressures and high temperature. NOx emissions will sky rocket with this type of problem. The high temperature in the cylinder will also create pinging and detonation.

**EGR valve malfunction:** the purpose of the EGR system is to dump a small amount of exhaust gas into the intake manifold therefore taking up space of real air and fuel. With less air/fuel entering the cylinder the bomb becomes smaller and peak combustion temperatures are lowered to below 2500 degrees. With the technology advancements in the internal combustion engine we are seeing EGR valves become obsolete. Automakers are able to keep peak combustion chamber temperature below 2500 degrees with computers and better-designed combustion chambers.

**High performance parts:** the purpose of high performance parts is to increase the size of the bomb that occurs within the cylinder. This is done by either getting more air and fuel into the cylinder or by shrinking the size of the combustion chamber therefore raising the cylinder pressure. Either way it’s done it all has the same results higher cylinder temperature and or pressures and elevated NOx production.
Cooling system problems: when the cooling system cannot adequately dissipate the temperature around the cylinders the results are elevated NOx.

Low octane fuel: fuel with low octane ratings will burn faster and ignite with lower temperatures. As air and fuel get compressed temperature within the cylinder rises if they raise to the flash point of the fuel the fuel will ignite this is known as pre-ignition. Once the fuel ignites the gasses begin to expand. The expanding gasses get compressed as the piston moves up in the compression stroke creating high temperature and high pressures within the cylinder. After the air/fuel pre-ignites the spark plug fires and creates another flame front. These two flame fronts collide which creates a shock wave within the cylinder giving us the knocking noise that is associated with pre-ignition.

Lean air fuel mixture: When oxygen is added to fire the fire gets hotter. Blacksmiths used bellows to add oxygen to fire so it would be hot enough to mold the metal horseshoes. If we add oxygen to fire within the cylinder it to gets hotter creating excessive temperature and elevating NOx production. Lean air fuel mixtures will burn slower allowing it more time to build up heat.

Carbon build up on pistons: Carbon on the top of the pistons shrinks the size of the combustion chamber allowing higher pressures therefore raising the temperature within the combustion chamber. When the air fuel mixture is compacted into a smaller compartment it creates a bigger bomb when ignited by the spark plug.

Carbon on intake valves: Carbon build up on the backside of the intake valves soaks up the fuel entering the cylinder creating a lean condition. This has been known to create elevated levels of NOx.

Inoperative knock sensor: A knock sensors job is to signal the PCM when pinging occurs this input allows the PCM to retard the timing. When pinging is occurring within a cylinder the temperature and pressures will be high therefore NOx will be elevated.

Turbo charger/super chargers: Add on parts such as these are designed to increase volumetric efficiency by pressurizing the intake manifold. When the intake valve opens pressurized air/fuel mixture flows into the cylinder, unlike naturally aspirated engines that rely on atmospheric pressure to fill the cylinder. These add on parts actually force the air/fuel mixture into the cylinder. When more air and fuel enter the cylinder the combustion within the cylinder becomes more intense. The outcome of these devices is increased horsepower and production of NOx.

Computer inputs: The PCM is responsible for controlling the air/fuel mixture and spark advance. It uses sensor inputs to achieve this goal. When a sensor is out of calibration the PCM will respond by changing timing and air/fuel mixture to whatever way the sensor is biased. For example, the O2 sensor is biased high this means the voltage output of the sensor is too high for the oxygen content in the exhaust. The PCM will
interpret this as a rich condition and will lean out the mixture in response to the O2 sensor signal. This lean mixture will in turn create a high NOx production.

**Cylinder head machining:** Often cylinder heads are shaved when performing valve jobs. This is done to create a flat surface for the head gasket to seal. It is not unheard of to take as much as 30 thousand off the cylinder head. When this is done it creates a smaller combustion chamber. This shrinkage of the combustion chamber increases the cylinder pressure and the outcome is NOx production. This problem can be corrected by using a thicker head gasket.

Carbon dioxide is the result of proper combustion of HC and O2. Any problems in the engine that affect the combustion process will lower the CO2 levels. You cannot have a misfire and expect to see high CO2 levels. The higher the CO2 level, the more efficient the engine is running. Optimum CO2 is 13% to 15%. CO2 can be used as an efficiency meter of the engines.

Combustion efficiency. When there is a problem that affects the combustion process the CO2 will be low. CO2 can help you determine if a high HC problem is engine related or catalytic converter. For example high HC followed by high CO2 would indicate a problem in either the air injection system or catalytic converter. Or high HC followed by low CO2 would indicate the problem is affecting the combustion process so it's engine related. Keep in mind that a good catalytic converter can raise the CO2 level up 2% over that of what the engine can produce. So the question comes up is the CO2 high because the converter is good or is CO2 high because the engine is running good only an intrusive catalytic converter test will tell us the complete truth.

O2 readings that show up on your five gases analyzer is extra oxygen that was not converted during the combustion process this means that it is unused. This is why O2 is an excellent lean indicator. When the engine is running lean, O2 will increase proportionately with the air/fuel ratio. As the engine goes to the lean misfire conditions around 16.0 to 1 O2 will rise drastically. Good O2 reading at the tail pipe should be under 3%.
**Quick Reference Chart**

<table>
<thead>
<tr>
<th>Symptom</th>
<th>HC</th>
<th>CO</th>
<th>CO2</th>
<th>O2</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ignition misfire</strong></td>
<td>Large increase</td>
<td>Some decrease</td>
<td>Some Decrease</td>
<td>Some-large increase</td>
<td>Some-large decrease</td>
</tr>
<tr>
<td><strong>Compression loss</strong></td>
<td>Some-large Increase</td>
<td>Some decrease</td>
<td>Some Decrease</td>
<td>Some Large Decrease</td>
<td>Some-large decrease</td>
</tr>
<tr>
<td><strong>Rich Mixture</strong></td>
<td>Some-large Increase</td>
<td>Large increase</td>
<td>Some decrease</td>
<td>Some Decrease</td>
<td>Some-large decrease</td>
</tr>
<tr>
<td><strong>Lean mixture</strong></td>
<td>Some Increase</td>
<td>Large Decrease</td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>Some-large increase</td>
</tr>
<tr>
<td><strong>Very Lean Mixture</strong></td>
<td>Large Increase</td>
<td>Large Decrease</td>
<td>Some Decrease</td>
<td>Large Increase</td>
<td>Some-large decrease</td>
</tr>
<tr>
<td><strong>Slightly retarded timing</strong></td>
<td>Some decrease</td>
<td>No change or Some increase</td>
<td>No change</td>
<td>No change</td>
<td>Large Decrease</td>
</tr>
<tr>
<td><strong>Very retarded Timing</strong></td>
<td>Some Increase</td>
<td>No Change</td>
<td>Some Large Decrease</td>
<td>No Change</td>
<td>Large Decrease</td>
</tr>
<tr>
<td><strong>Advanced timing</strong></td>
<td>Some Increase</td>
<td>No change or Some decrease</td>
<td>No change</td>
<td>No Change</td>
<td>Large Increase</td>
</tr>
<tr>
<td><strong>EGR Operating</strong></td>
<td>No Change</td>
<td>No Change</td>
<td>Some Decrease</td>
<td>No Change</td>
<td>Large Decrease</td>
</tr>
<tr>
<td><strong>EGR Leaking</strong></td>
<td>Some Increase</td>
<td>No Change</td>
<td>No change or Some decrease</td>
<td>No Change</td>
<td>Some decrease or No change</td>
</tr>
<tr>
<td><strong>Air injection Operation</strong></td>
<td>Large Decrease</td>
<td>Large Decrease</td>
<td>Some Large Decrease</td>
<td>Large Increase</td>
<td>No Change</td>
</tr>
<tr>
<td><strong>Catalytic converter functional</strong></td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>Some Increase</td>
<td>Some Decrease</td>
<td>Some Decrease W/3-w cat</td>
</tr>
<tr>
<td><strong>Catalytic Converter Not functional</strong></td>
<td>Some-large Increase</td>
<td>Some-large increase</td>
<td>Some Decrease</td>
<td>Some Increase</td>
<td>Some Increased W/3-w cat</td>
</tr>
<tr>
<td><strong>Exhaust Leak</strong></td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>Some Increase</td>
<td>No change</td>
</tr>
<tr>
<td><strong>Worn Engine</strong></td>
<td>Some Increase</td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>No change or Slight decrease</td>
</tr>
<tr>
<td><strong>O2 sensor Biased low</strong></td>
<td>Some Increase</td>
<td>Some-large increase</td>
<td>Some Decrease</td>
<td>Some Decrease</td>
<td>Some Decrease</td>
</tr>
<tr>
<td><strong>O2 sensor Biased high</strong></td>
<td>Some Increase</td>
<td>Some decrease</td>
<td>Some Decrease</td>
<td>Some Increase</td>
<td>Some increase</td>
</tr>
<tr>
<td><strong>Flat Camshaft</strong></td>
<td>No change or Some decrease</td>
<td>Some Decrease</td>
<td>No change or Some decrease</td>
<td>No change or Some decrease</td>
<td>No change or Some decrease</td>
</tr>
</tbody>
</table>