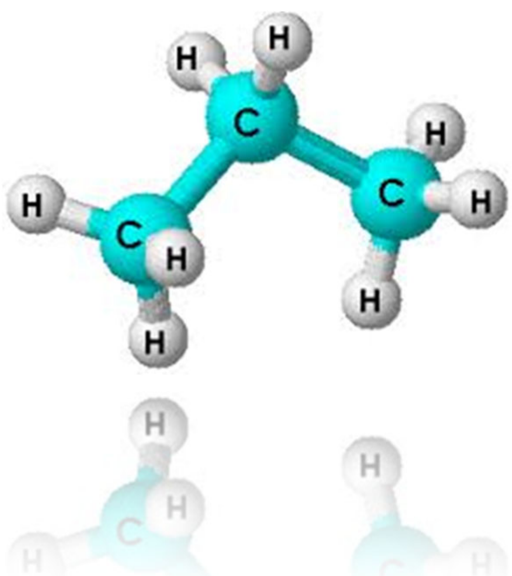
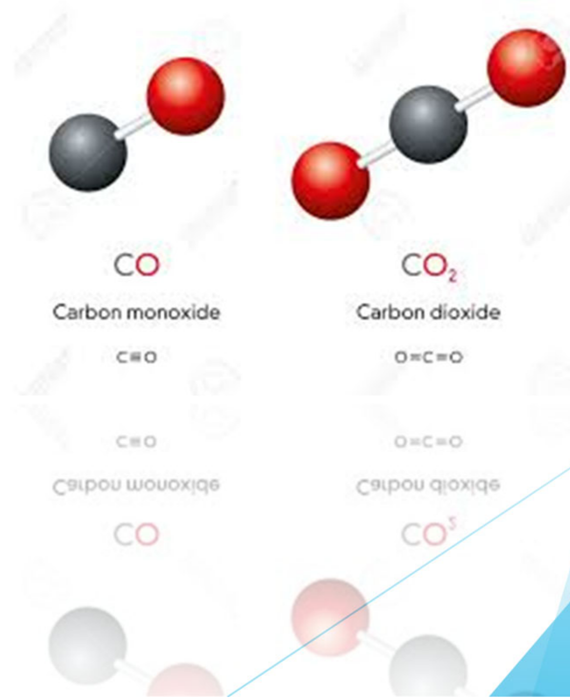
Science of Vehicle Emissions And Exhaust Emission Analysis

Hydrocarbon





Objectives

- Explain the chemical change that occurs to fuel and air during combustion.
- Understand the causes of various smog test tailpipe emission failures.
- Understand how to use tailpipe emission results as a diagnostic tool.

Perfect Combustion

- In theory, if combustion were perfect the components in the exhaust would be:
  - Oxygen (O2)
  - Carbon Dioxide (CO2)
  - Nitrogen (N)
  - Water (H2O)

Fuels include hundreds of different hydrocarbons that burn in different ways and at different rates; therefore, perfect combustion is not possible.

Why Perfect Combustion isn't Possible!

- Fuels consist of hundreds of differently structured hydrocarbons that burn in different ways, at different rates and at different temperatures.
- Also, not all engines are equally efficient.
- Exhaust gasses always contain fuel that didn't burn
- The air fuel ratio is never 100% spot on.
  - Result; carbon monoxide and hydrocarbons in the exhaust
- The hydrocarbons react with the nitrogen atoms to form Oxides of Nitrogen which causes photochemical smog.

By-products of Gasoline Combustion

- Oxygen (O_2)
- Carbon Dioxide (CO_2)
- Nitrogen (N)
- Water (H_2O)
- Hydrocarbons (HC)
- Carbon monoxide (CO)
- Oxides of Nitrogen (NO_x)
- **<u>All are affected by the air fuel ratio</u>**

Exhaust Gases

- HC- Hydrocarbons
  - Gasoline and oil are HC. Any HCs not burnt in the engine exit the tailpipe.
- CO- Carbon Monoxide
  - An odorless, colorless gas, deadly even in very small concentrations.
- NOx- Oxides of Nitrogen
  - odorless, colorless gas until it leaves the engine and mixes with oxygen in the atmosphere and becomes NOx
- CO2- Carbon Dioxide
  - This forms from the burning of fuel. Generally harmless but it is a greenhouse gas and has become a concern for the environment
- O2- Oxygen
  - About 21% of our air is oxygen. It is the basis of all combustion and is needed to release the energy from the fuel.

Additional Non-toxic Exhaust Gases

- These 2 gases are also present, but not part of smog testing
  - N2-Nitrogen
    - 78% of our atmosphere is nitrogen. N2 is mostly unchanged by going through an engine
  - H2O-Water vapor
    - This a big part of the exhaust stream. Hydrogen is the major source of energy in fuel and it combines with the oxygen to form water vapor.
    - Harmless besides the potential for rusting the exhaust system

Components of Diesel Combustion

- The same as gasoline engines plus:
- Higher levels of Oxides of Nitrogen (NOx)
- Particulate Matter (PM)
  - Black soot from partially burned diesel fuel

Exhaust Gas Analysis

When the tailpipe emissions are high what kind of problems can be the cause?

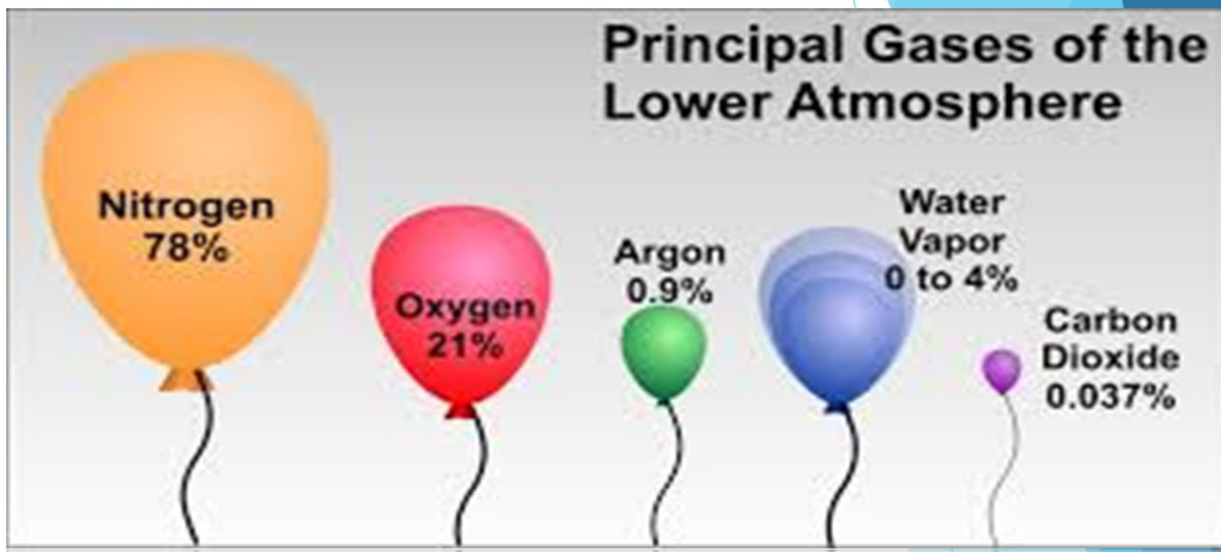
In simplest terms:

- **HC**: Result of misfire or poor combustion efficiency
- **CO and HC:** Result of rich conditions, lack of oxygen
- **NOx:** Excessively high combustion temperatures

We will discuss these gases in more detail and look at problems that would causes each of them to be out of the normal range.

The Air We Breath

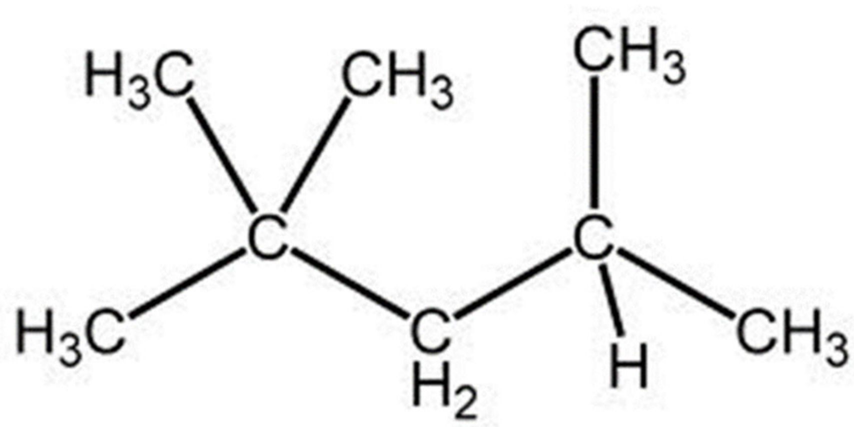
- Is composed of:
  - 21% Oxygen Molecules
  - 78% Nitrogen Molecules
  - 1% Argon
  - 0-4% H_2O
  - .037% CO_2



The amounts of Argon, water and carbon dioxide found it the air are insignificant and do not affect vehicle emissions.

Hydrocarbons (HC)

- The main components of gasoline and diesel fuel.
- A Hydrocarbon molecule is made up of Hydrogen atoms and Carbon atoms.
- These atoms are held together by covalent bonds (chemical bond).



Combustion Process

- During combustion, the bonds that hold the hydrocarbon molecule together are broken, freeing the atoms of hydrogen and carbon.
- The oxygen and nitrogen in the intake air are also broken, freeing the oxygen atoms and the nitrogen atoms as well.
- This allows all these molecules to recombine into new harmful compounds

Hydrocarbons in the Exhaust

- This is unburnt fuel (or oil) that remains in the exhaust stream
- When tail pipe testing it will be measured in **PPM (parts per million)**
- Normal levels are 30 ppm or less, often far less in newer vehicle
- Total misfire will cause very high levels, 100s or 1000s of PPM
  - Low compression, excessively lean mixtures, ignition system faults, plugs, cables, coils, timing
- Partial misfire will cause moderate high levels, perhaps 100 PPM
  - Rich mixtures added by the engine management system in response to some fault
  - Low engine temperature
- A worn engine letting oil into the combustion chamber can raise HC emissions.

Causes of Increases in HC Emissions

Unburned fuel in the exhaust.

- Increase when combustion is in incomplete.
- Common causes:
  - Misfire
  - Overly advanced ignition timing
  - Mechanical condition that would affect combustion
  - Extreme rich mixture (Also increases CO)
  - Extreme lean mixture (Lean misfire)
  - Emission control device not working properly:
    - EGR, secondary air system, catalytic convertor

Misfire

- Results in unburned fuel exits through the exhaust valve resulting in high HC tailpipe emissions.
- Raw fuel goes in and raw fuel goes out, pure HCs.
- Can be as high as 2000 ppm.
- Misfire can come from a variety of ignition problems:
  - open or grounded spark plug wires
  - worn spark plugs
  - weak coils

Ignition Timing Advance

- Too much advance will cause high HC.
- Why?
- The spark occurs before the air/fuel mixture was compressed enough for best vaporization, so it doesn’t burn as completely.
- Too small spark plug gap can also increase HCs because not enough gas molecules are ignited to start the flame, and the mixture is not completely burned.

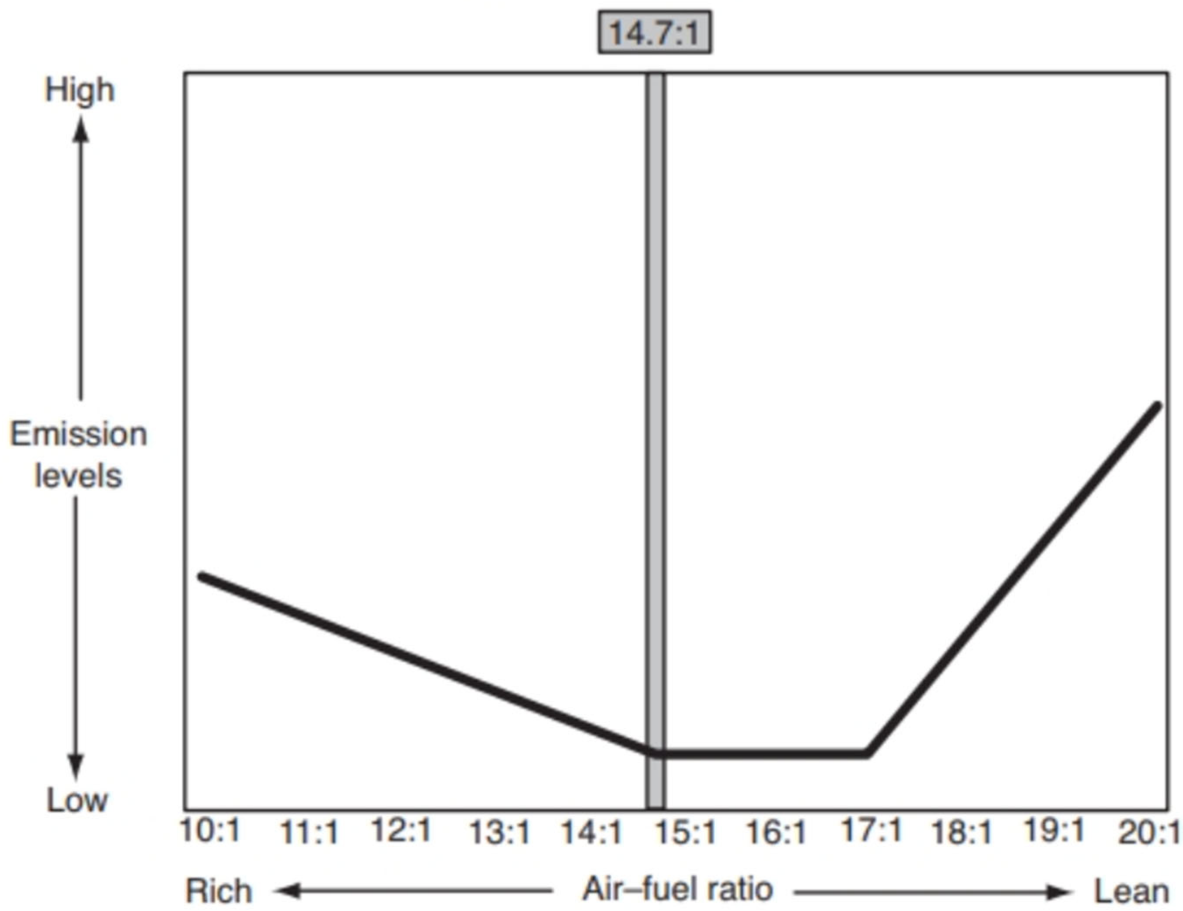
Increased HCs from Mechanical Problems

- Low compression condition will increase the HC's, especially at low RPMs.
- Worn piston rings reduce cylinder pressure and temperature, so good vaporization of the fuel doesn't occur.
- Valve sealing problems also lower compression and can let raw fuel out into the exhaust on the compression stroke.
- A burnt intake valve may cause a disruption of the airflow into other cylinders as pressures during compression and power strokes push back into the intake

Increased HCs from Incorrect Air/Fuel Mixture Ratios

- When the mixture is too rich, there is not enough air to burn all the fuel, so unburned fuel leaves the cylinder with the exhaust, increasing HCs.
- Rich mixture will also increase CO.
- If the mixture is too lean, the fuel particles are too far apart for good combustion. The flame front dies out before all the fuel is burned, leaving HCs in the exhaust

Effect of A/F ratio on HC

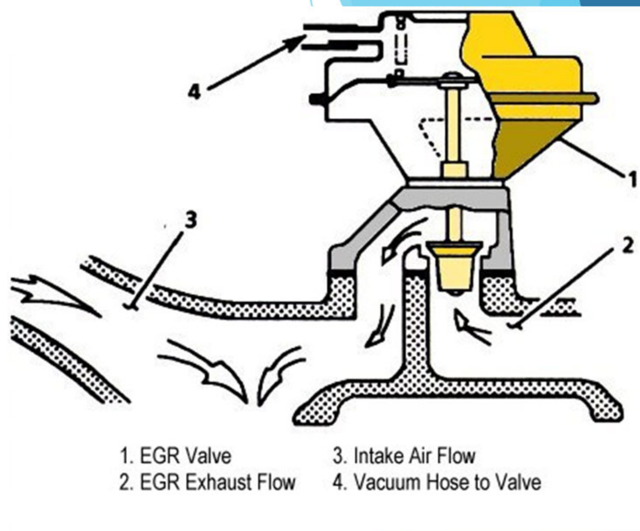


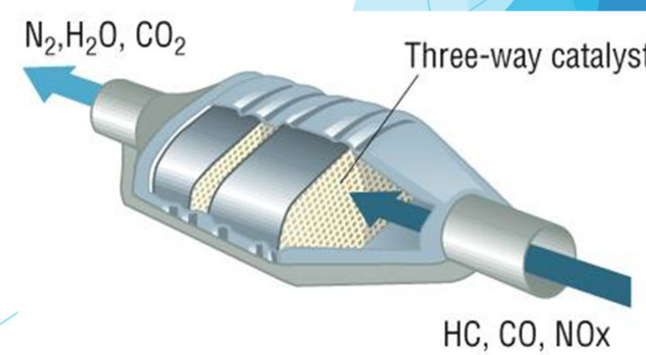
Increased HCs from faulty Emission Control Devices

- An EGR valve stuck open at idle will allow exhaust gas into the combustion chamber causing a misfire. EGR shouldn't work at idle.

- If air injection isn't working, there may not be enough extra O2 to complete the burning of the HC's in the exhaust manifold or cat.

- A worn or contaminated catalytic converter isn't efficient at oxidizing the HCs.



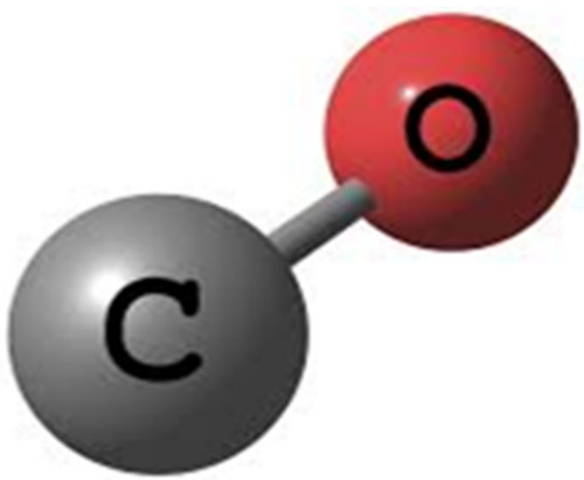


Carbon Monoxide (CO)

- Colorless and odorless, and highly toxic gas.
- Consists of one carbon atom and one oxygen atom.
- Formed during combustion.
  - Combustion causes the chemical bonds between the hydrogen and carbon atoms that form HC to break, releasing free carbon atoms.
  - These carbon atoms combines with free oxygen atoms to produce CO.
- No combustion / No CO

Carbon Monoxide (CO)

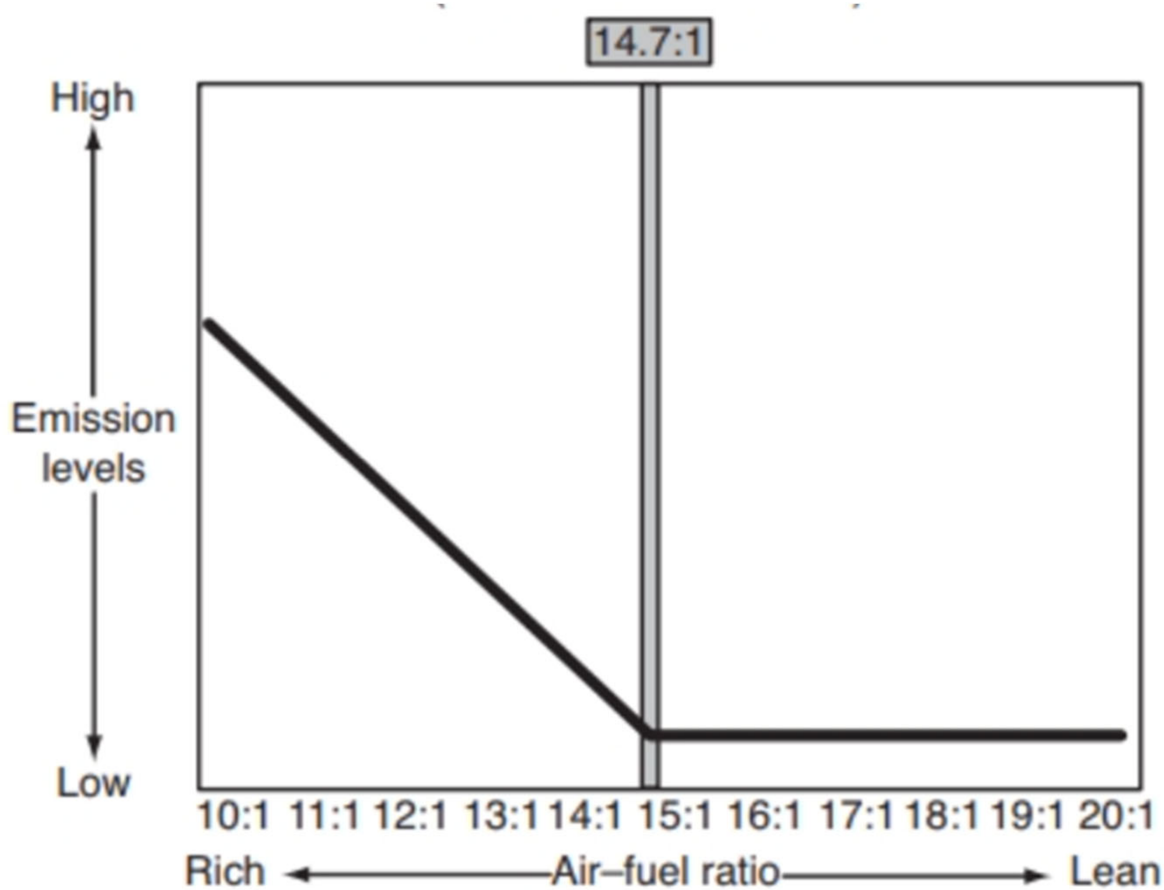
- Created when HCs are split during combustion
- When tailpipe testing it will be measured in **% (percent)**
- Normal levels are .3% or less, often far less in newer vehicles
- Always a product of combustion. No combustion means no CO



Causes of High CO readings

- High CO Indicates a rich fuel mixture
- High levels come from a **shortage of oxygen**, so are A/F ratio related
- Misfires do not raise CO, so ignition system faults will not be a cause for high CO.
- Look for factors causing a rich mixture:
  - High fuel pressure, leaking injectors, incorrect O2, ECT sensor signals, MAP sensor errors

Effect of A/F ratio on CO



Causes of High CO readings

- Indicates a rich fuel mixture
- Increases when there is a decrease in air or an increase in fuel
- Forms when there is not enough oxygen to produce CO_2.
- Measured as a percentage of the exhaust
- Usually CO is 0.5% or less in most vehicles; 0.00% on a vehicle with a good catalytic converter.

Causes of High CO

- Restricted air filter
- High fuel pressure
- Carburetor or fuel injector malfunction
- Sensor malfunction

CO Exhaust Gas Analysis

- Too much fuel will cause a rich mixture
- This could be caused by any of the following:
  - High fuel pressure.
  - Sensor malfunction (O2 Sensor biased lean).
  - Injector malfunction (leaking).
  - Faulty input to the PCM indicating a richer fuel mixture is needed.

Carbon Dioxide (CO_2)

- No direct harm to health.
- Exists in the atmosphere and is used by plants during photosynthesis
- Composed of two oxygen atoms covalently bonded to a carbon atom.
- Formed by combustion. No Combustion = No CO2.
- Measured as a percentage of exhaust.

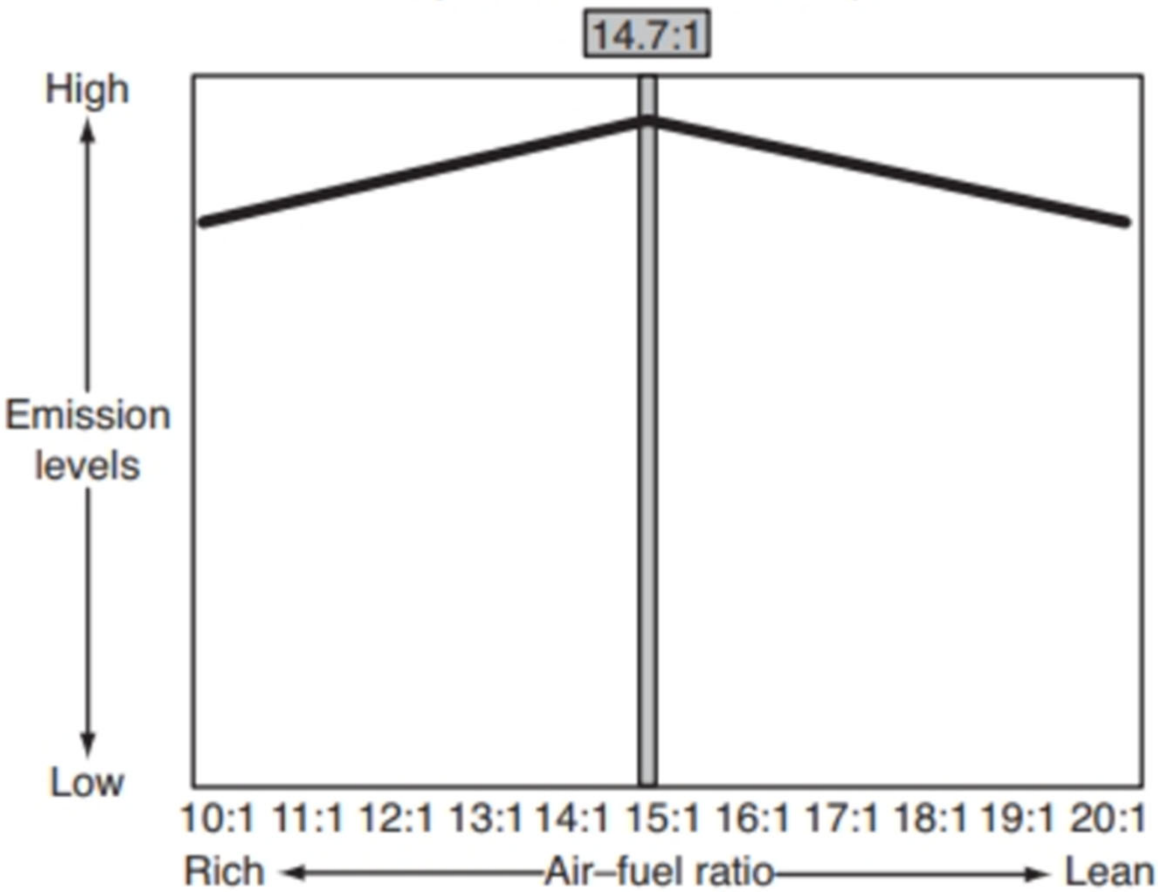
Carbon Dioxide (CO_2)

- CO_2 is formed when the oxygen in the intake air combines with the carbon in the fuel
- When tailpipe testing it will be measured in **% (percent)**
- Normal tailpipe levels are 12% to 15%

CO_2 Levels and Efficiency

- CO_2 is a product of engine combustion; and a smaller amount from the catalytic converter operation.
- CO_2 levels are highest when the engine is running at its highest efficiency
- Anything that reduces efficiency will reduce CO_2 levels
- Too rich, too lean, misfire, mechanical faults will all lower the engine efficiency and CO_2 will decrease.
- Tailpipe readings are usually 12 - 15%, sometimes higher.
  - Less than 12% can be an indication of a weak cat if everything else is normal.

Effect of A/F ratio on CO_2



Carbon Dioxide CO_2

- Used a measure of combustion efficiency.
- In complete combustion the carbon atoms from the fuel combines with two atoms of oxygen forming CO_2 instead of the CO.
- The higher the CO_2 the better the combustion efficiency.

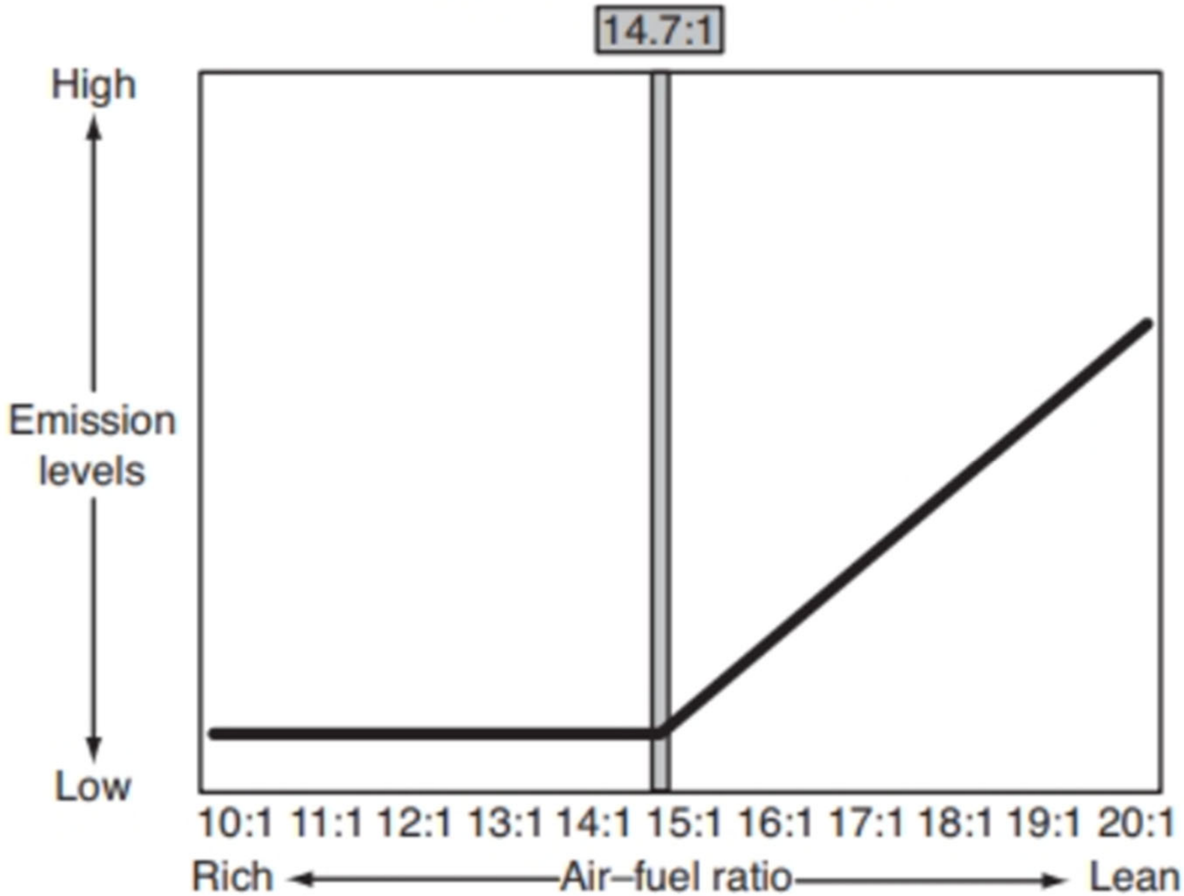
Oxygen (O_2)

- Also a diagnostic tool.
- Measures how rich or lean the AFR is.
- Measured as a percent of the exhaust.
- Nominal O2 readings are 1.5 % or less.
- Free Oxygen atoms will also combine with free hydrogen atoms to form water in the exhaust (H_2O).

Oxygen (O2)

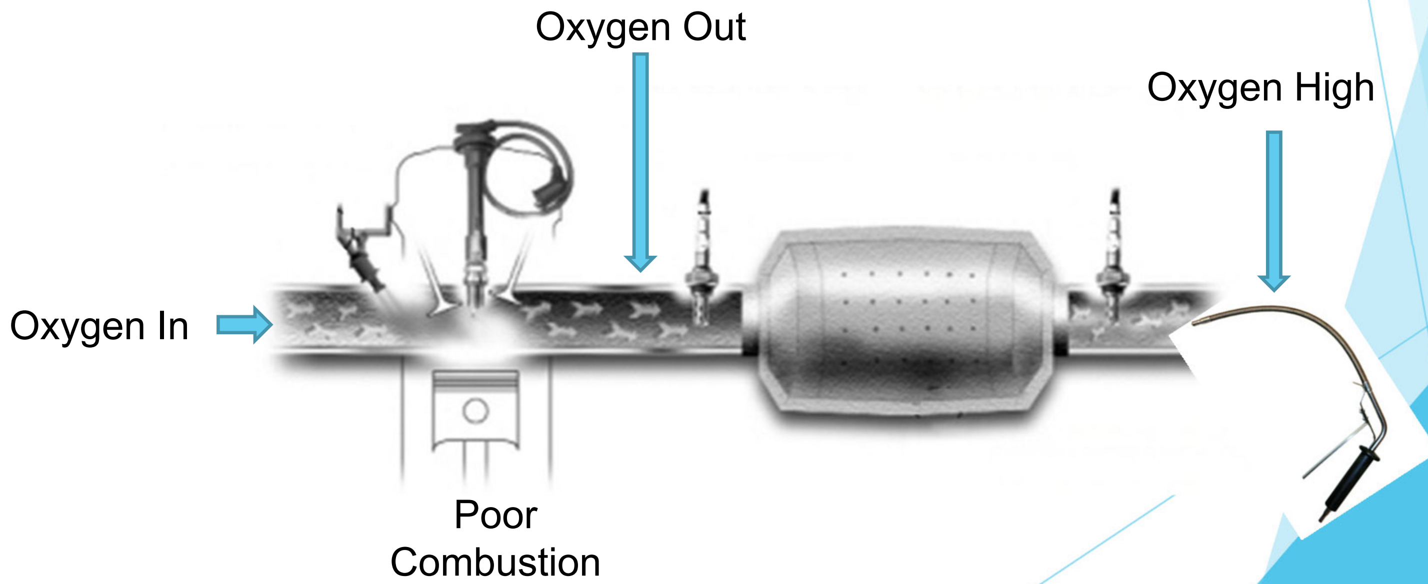
- Good combustion will use up most of the oxygen drawn into the engine
- When tailpipe testing it will be measured in **% (percent)**
- Normal levels are around 0% to 2%
- Oxygenated or high alcohol fuels will raise levels
- Poor sealing of the exhaust system may allow air to enter and raise levels at tailpipe
- Misfire can result in higher levels due to O2 not being burnt
- Lean mixtures result in high “left over” O2 levels

Effect of A/F ratio on O2



O_2 and Misfires

- Misfire will increase O2 readings because all the oxygen brought into the cylinder goes out the exhaust

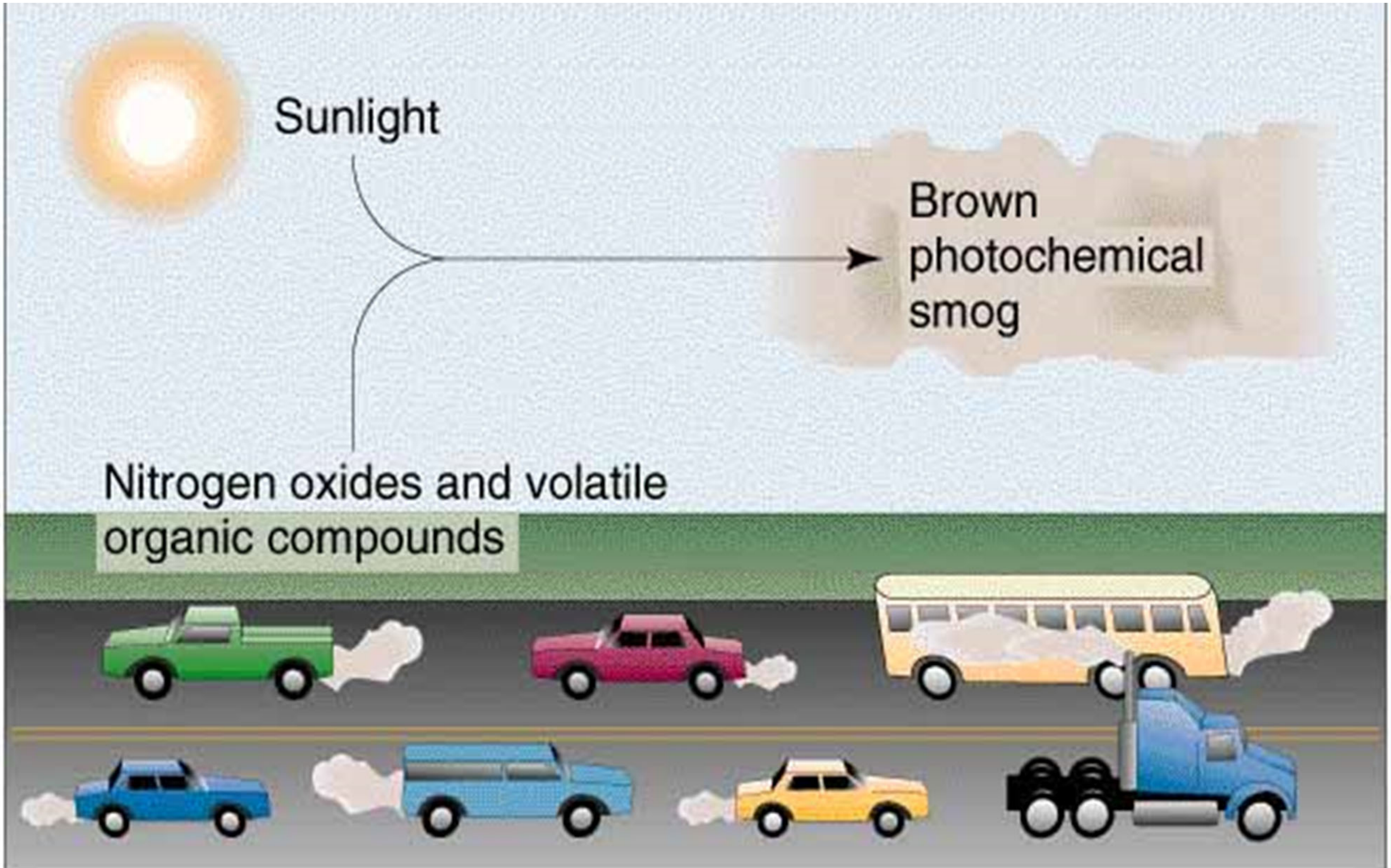


Secondary Air Systems and Oxygen (O2) Levels

- Many vehicles have systems to pump or introduce air into the exhaust manifold or catalytic convertor
- An air pump or pulse air injection system can raise the O2 reading by 3% - 8% during normal cold engine operation
- Improper operation of these systems during hot engine operation can affect O2 readings and influence O2 sensor operation
- High O2 levels in exhaust can also be an indicator of exhaust leaks.

Oxides of Nitrogen (NO_x)

- Includes nitrogen dioxide, nitric oxide, nitrogen oxide and nitrogen monoxide.
- Formed during combustion combined with high heat
- Formed when combustion chamber temperatures exceed 2500°F
  - The nitrogen combines with the oxygen to form NOx.
  - Requires engine load to reach these temperatures.
  - Measured on a dynameter Test only (ASM).
- **NOx + Sunlight = Photochemical Smog**
- Measured in ppm.



(b) Photochemical smog

Oxides of Nitrogen (NOx)

- This group includes nitrogen dioxide, nitric oxide, nitrogen oxide and nitrogen monoxide.
- Levels of NOx rise when combustion chamber temperatures reach 2500 degrees or more under load
- EGR and/or cam overlap is used to control combustion chamber temperatures
- **NOx + Sunlight = Photochemical Smog**

Oxides of Nitrogen (NOx)

- Only measured during dynamometer testing (ASM)
- When tailpipe testing it will be measured in **PPM (parts per million)**
- Normal levels are less than 100 ppm at idle, less than 1000 ppm at WOT

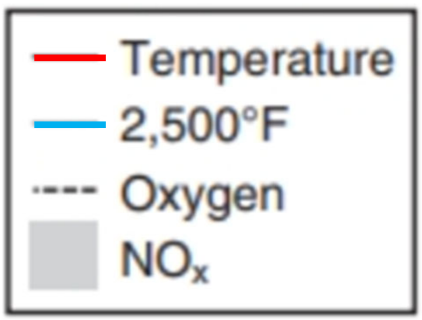
Causes of Excessive Oxides of Nitrogen (NOx) Levels

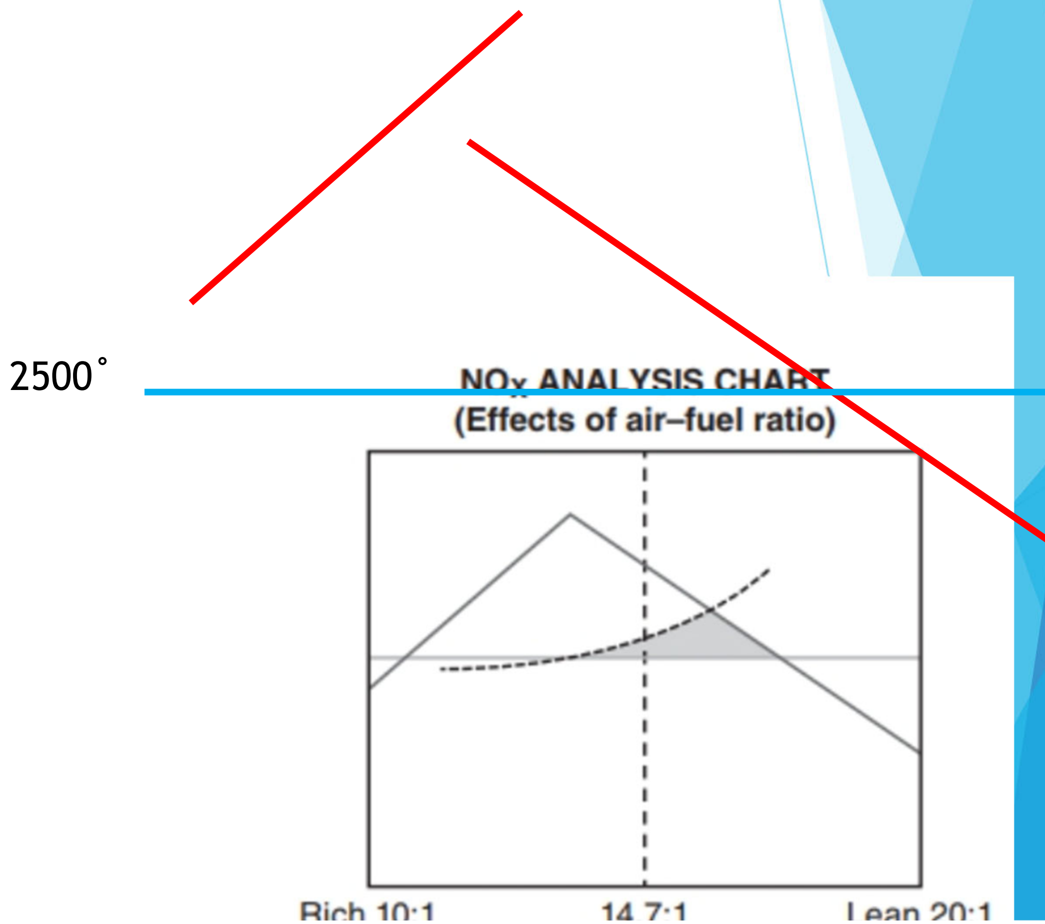
- Lean mixtures
- Spark knock, incorrect ignition timing
- Carbon deposits raising compression
- Incorrect control of turbo or superchargers pressures
- High engine temperature
- EGR system failures
- VVT system failure

Effect of A/F Ratio on NOx

Combustion temperatures are highest around 14:1, slightly rich, but that rich mixture leaves little left over O2 for the formation of NOx

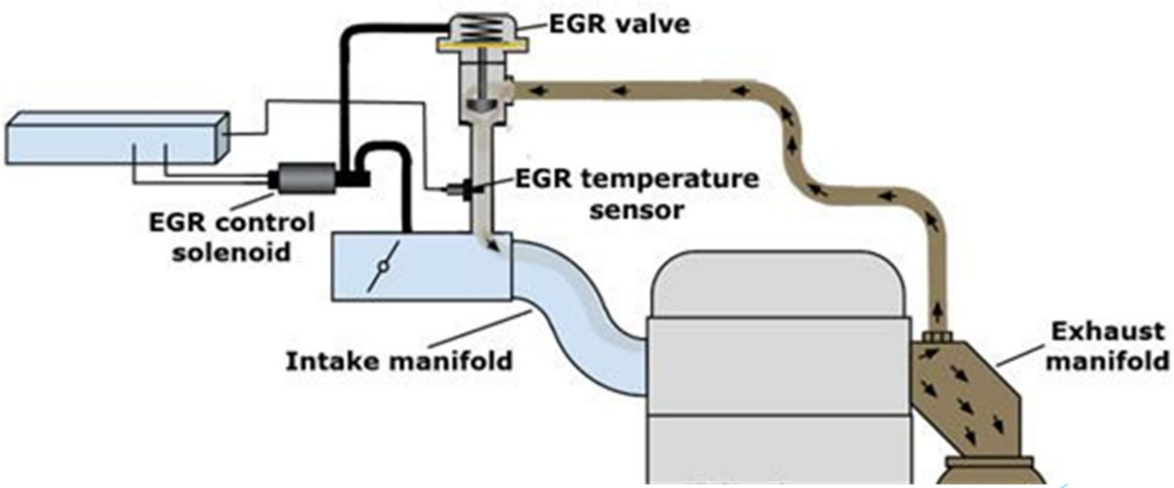
Also, the NOx reducing part of the catalytic convertor is less effective when lean mixtures are present





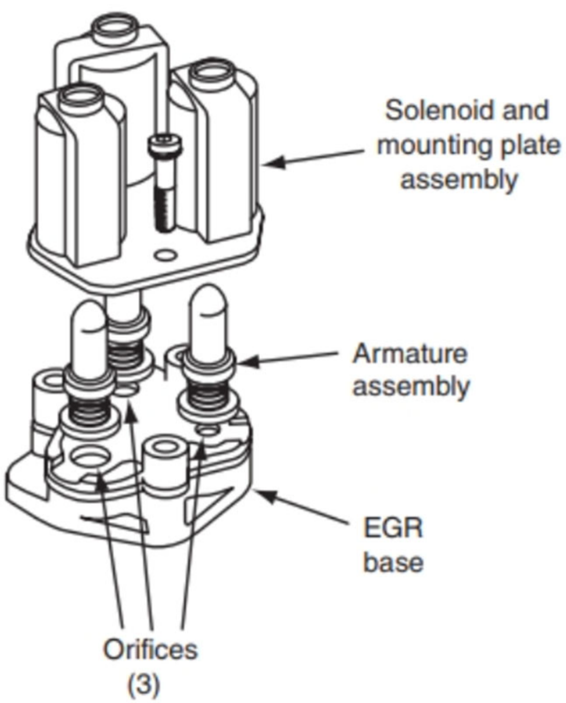
NOx Control using EGR

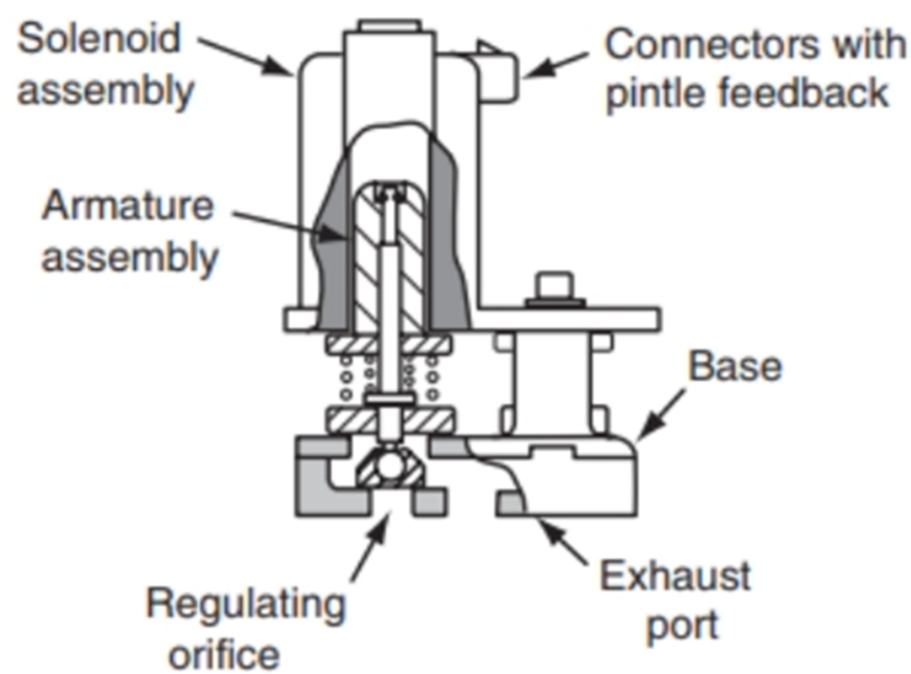
- Many vehicle use an EGR valve to add exhaust gas into the combustion chamber during the intake stroke
- Exhaust gas displaces oxygen and fuel, resulting in lower temperatures
- An EGR valve routes some exhaust gas back into the intake manifold
- EGR valves also allow higher compression and more spark advance to be used
- EGR valves do not operate at idle or WOT



NOx Control using EGR

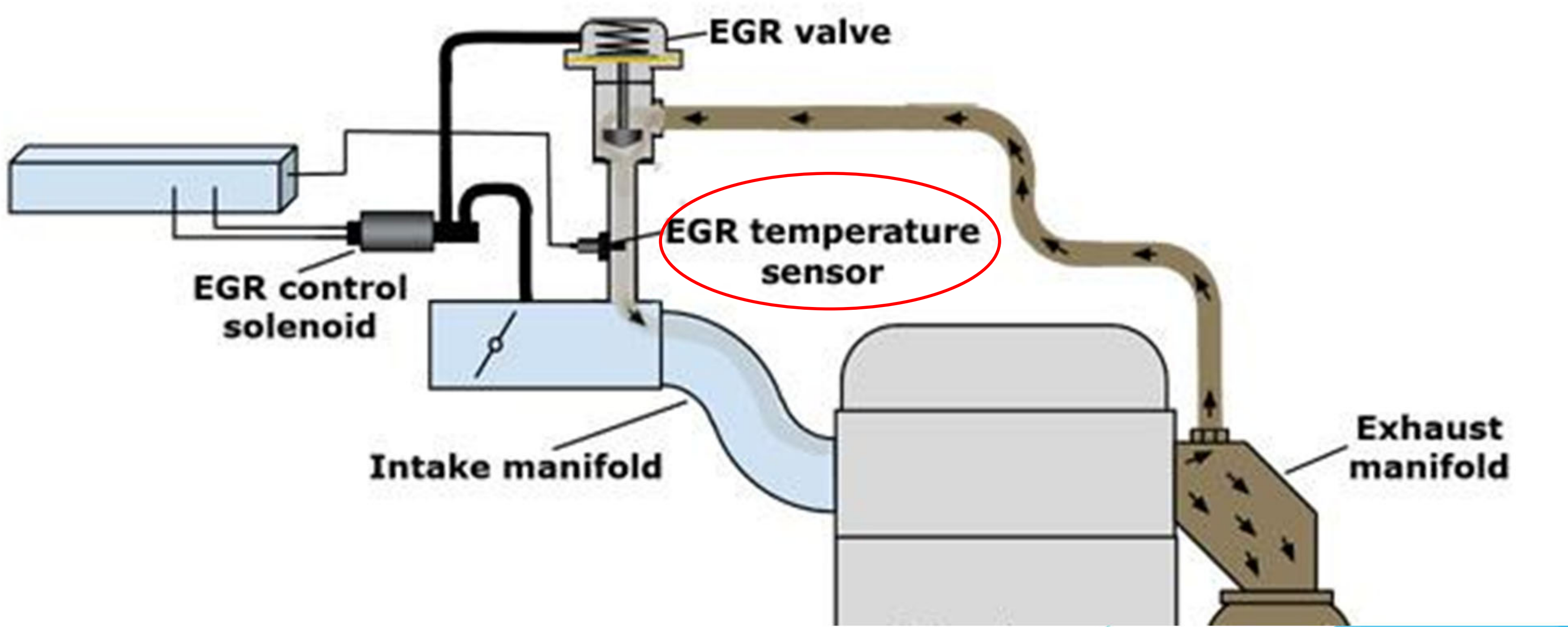
- Some EGR valves use electric solenoids controlled by the PCM





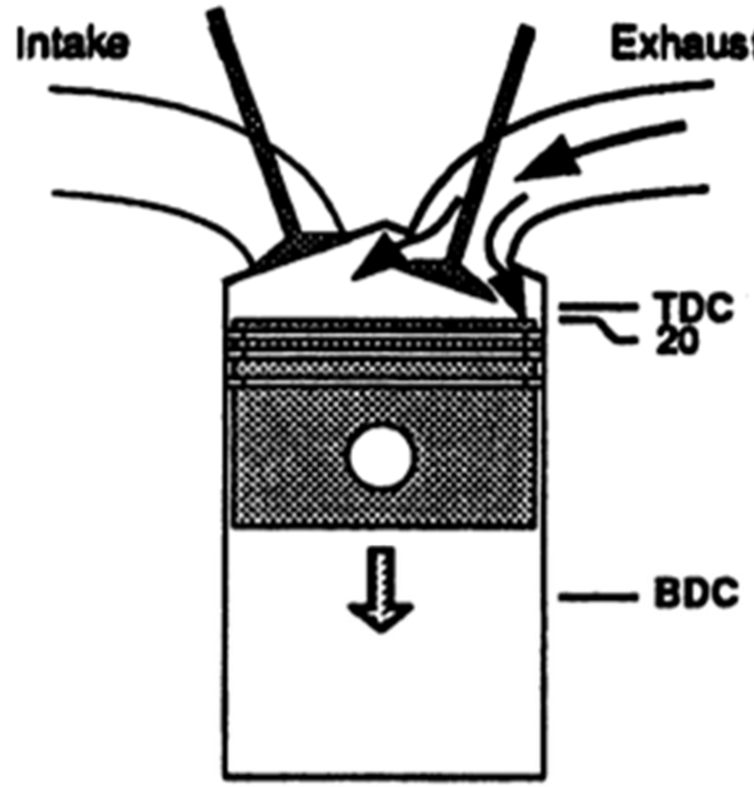
EGR Valve Feedback

- A sensor to measure temperature of exhaust gas in the passage, or a sensor to measure the opening of the valve provides feedback to the PCM that the EGR valve has opened as commanded



EGR through Valve Timing

- Variable valve timing can be used to close the exhaust valve late, pulling some exhaust gas back into the cylinder during the intake stroke
- Or close the exhaust valve early and leave some exhaust in the cylinder
- This has the same effect as the EGR valve function



Exhaust gas is drawn back into the cylinder at exhaust pressure:
- NOx is reduced (internal EGR)

Remember the basics:

- HC: Misfire or poor combustion
- CO: Too rich of a fuel mixture
- CO2: Measures combustion efficiency
- O2: Too lean or too rich AFR, misfire
- NOx: Combustion temps too high or too lean

Understanding the relationship each has to the other is critical in deciphering the emission readings from a tailpipe.

Here are some more basic rules to remember:

Remember the basics:

- When a misfire occurs due to no spark or a lean fuel mixture, HCs will be high along with higher O_2 and low CO_2
- No Spark = No Burn; No Burn = No Combustion; No Combustion = Raw Fuel + Air exits engine
- Poor Combustion = Low CO_2

- Lean Fuel Mixture = Too little Fuel; Too little Fuel = Poor Combustion; Poor Combustion = Misfire; Misfire = Raw Fuel+ Air
- Poor Combustion = Low CO_2)

Remember the basics:

- High HC with low CO = possible misfire.
- Too rich a fuel mixture causes high CO, and HC increase.
- Poor Burn = High HC = Poor combustion = Low CO_2.

Remember the basics:

- Combustion temperatures above 2500º increases NOx.
- Overheating engine = High Combustion Temp = High NOx
- Lean Fuel Mixture = High Combustion Temp = High NOx
- Faulty EGR system=High Combustion temp= High Nox
- Carbon in Combustion Chamber = Increased Compression = High Combustion Temp = High NOx

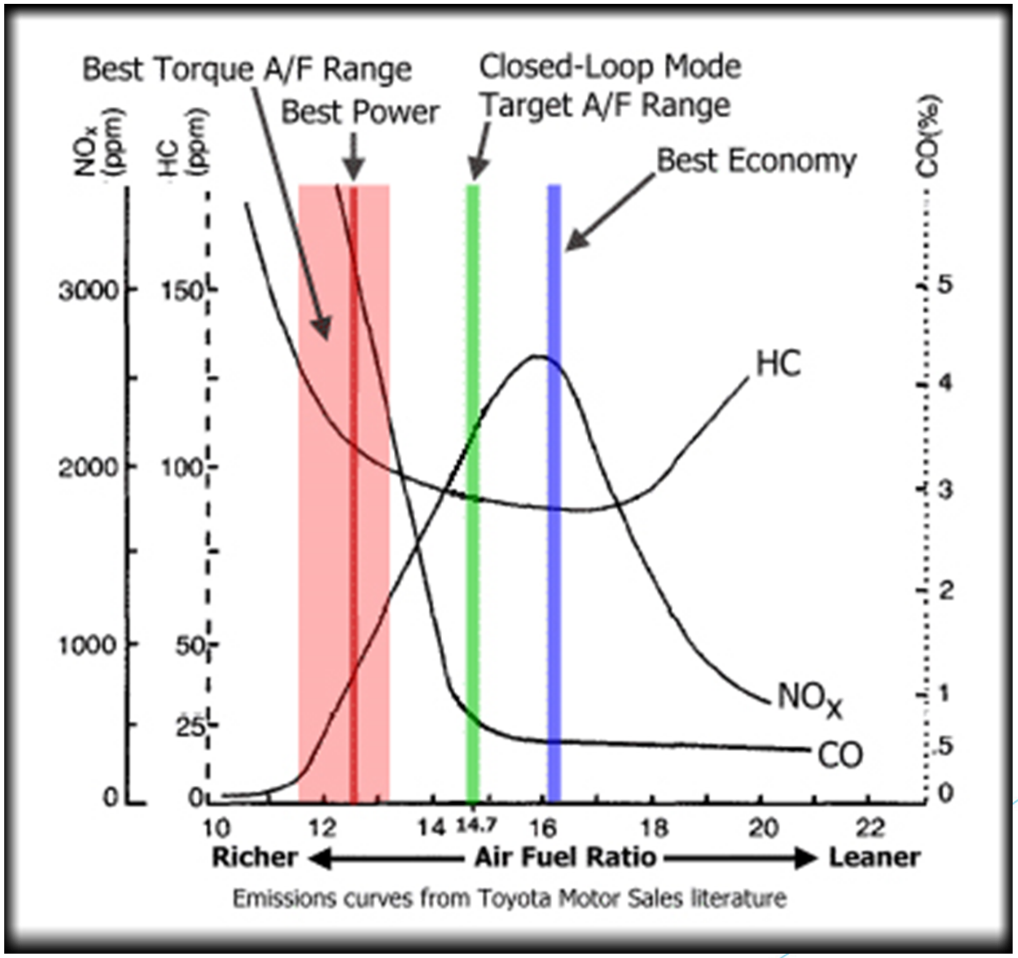
Air Fuel Ratio

- Proportion by weight of air and fuel needed for combustion
- Too much fuel = a rich condition
  - High HC and CO
- Too little fuel = a lean condition
  - High HC, low CO

Stoichiometric

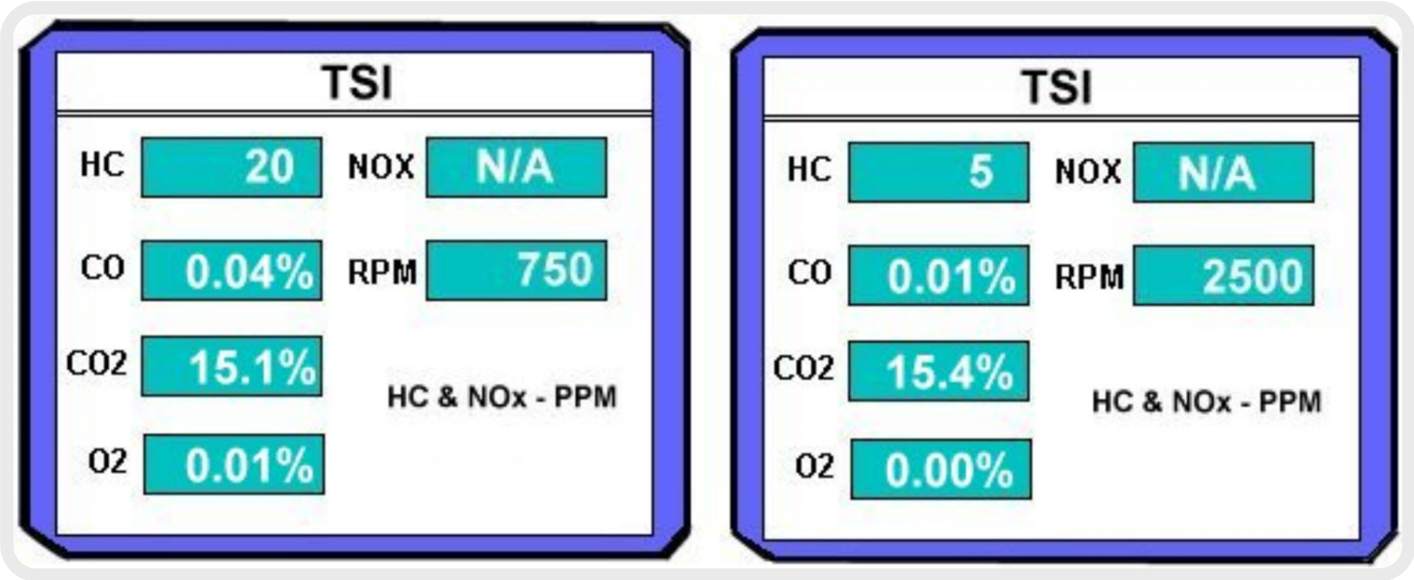
- An "ideal" fuel/air mixture in which both the fuel and the oxygen in the air are completely consumed
- 14.7 parts air to 1 part of fuel by weight
- Mixture ratio area where catalytic converter operates most efficiently

Stoichiometric Chart



Exhaust Gas Analysis

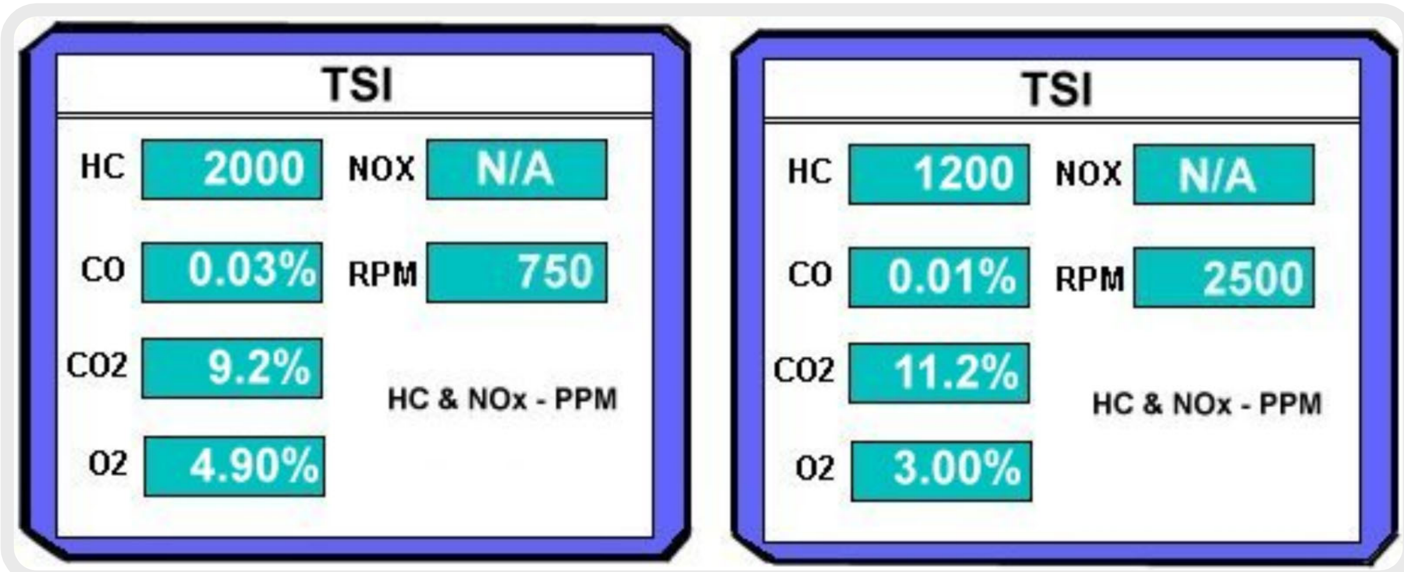
Normal, good tailpipe readings at idle and 2500 rpm



High CO2 and low O2. HC and CO both at low levels.
This vehicle is in fuel control, no misfires, and no exhaust leaks or sample dilution.

Exhaust Gas Analysis

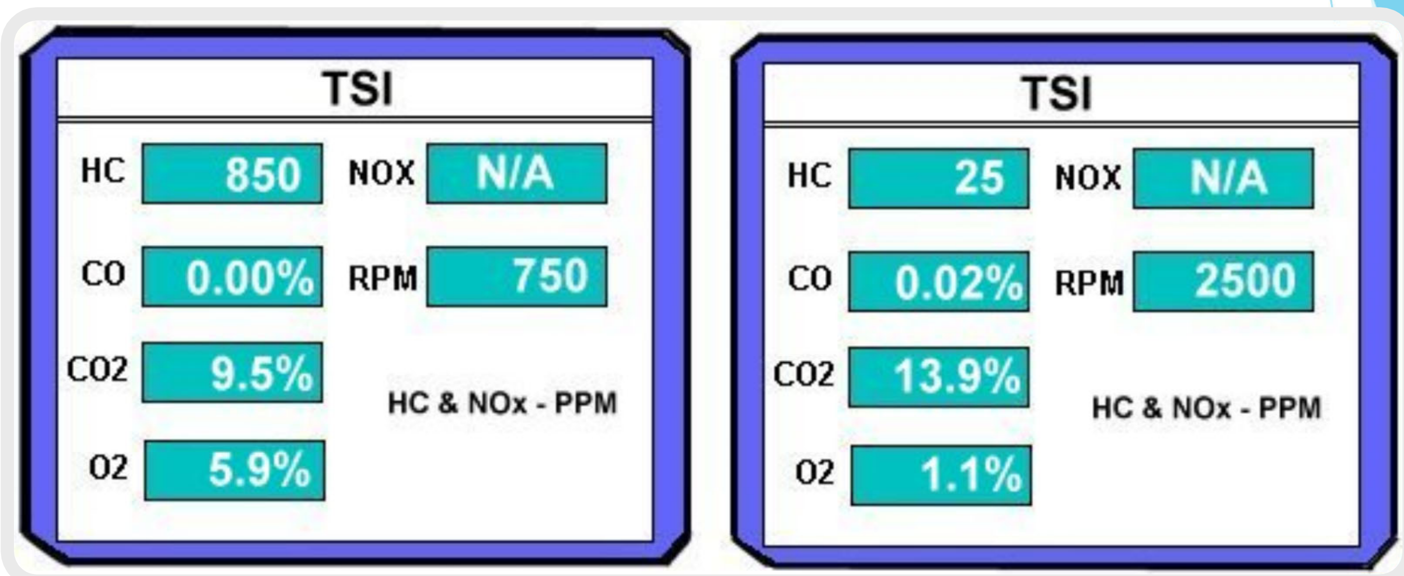
Diagnose these readings:



A) Rich Fuel Mixture
B) Bad CAT
C) Lean Fuel Mixture
D) Ignition Misfire

Exhaust Gas Analysis

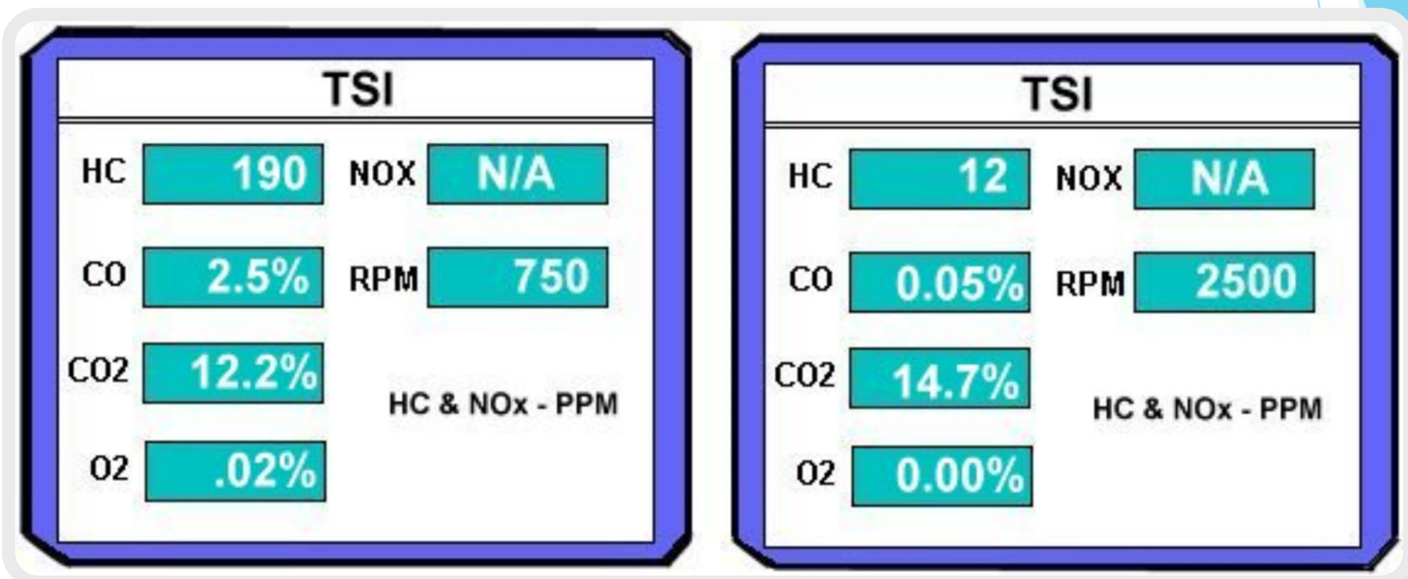
Diagnose these readings:



A) Fouled Spark Plug
B) Vacuum Leak
C) Retarded Ignition Timing
D) Bad CAT

Exhaust Gas Analysis

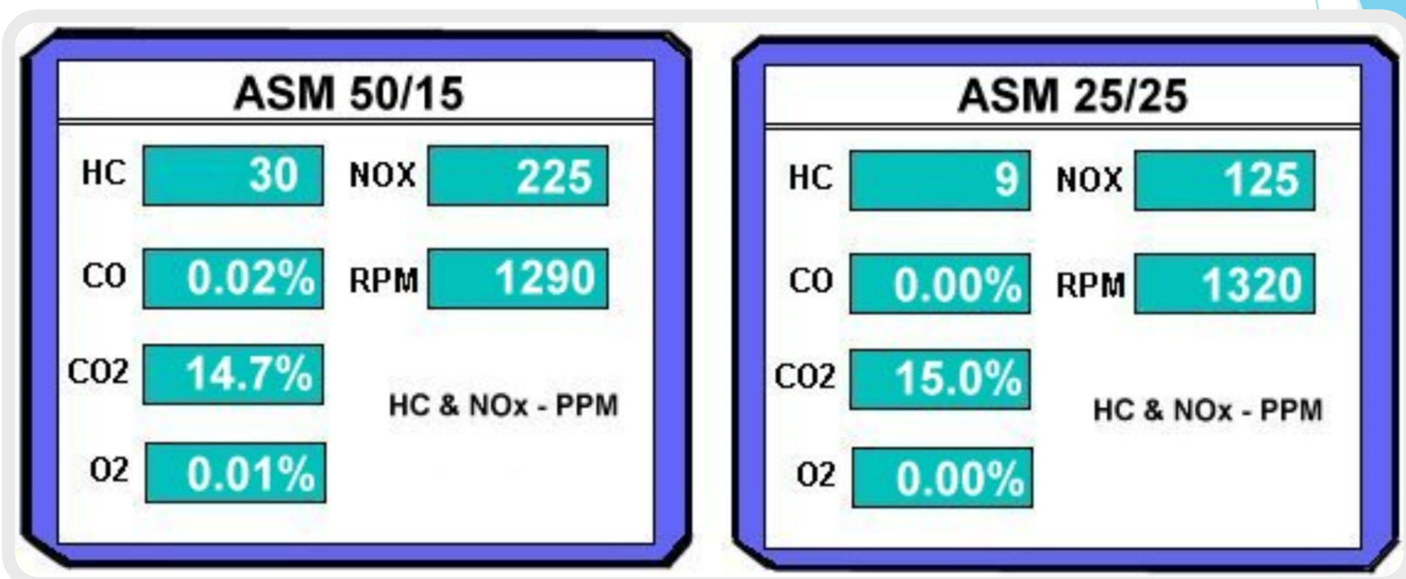
Diagnose these readings:



A) Rich Mixture @ Idle
B) Advanced Ignition Timing
C) Bad CAT
D) Vacuum Leak @ Idle

ASM Exhaust Gas Analysis

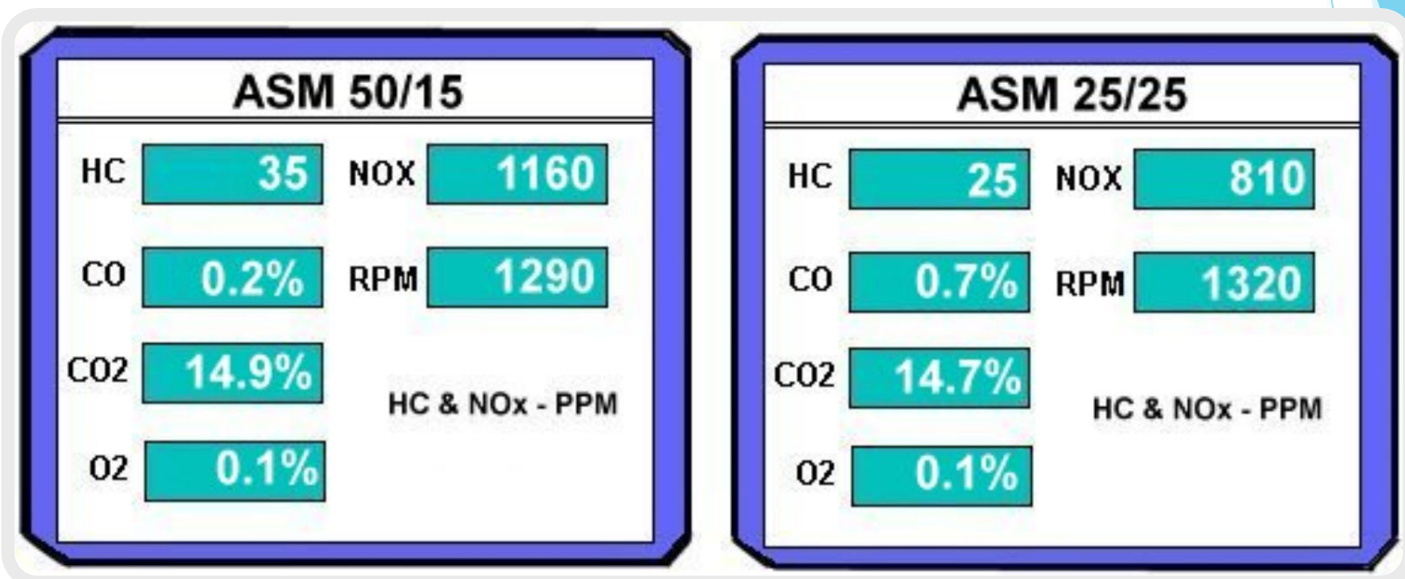
Diagnose these readings:



A) High NOx
B) Advanced Ignition Timing
C) Normal Emission Readings
D) Too Much CO2

Exhaust Gas Analysis

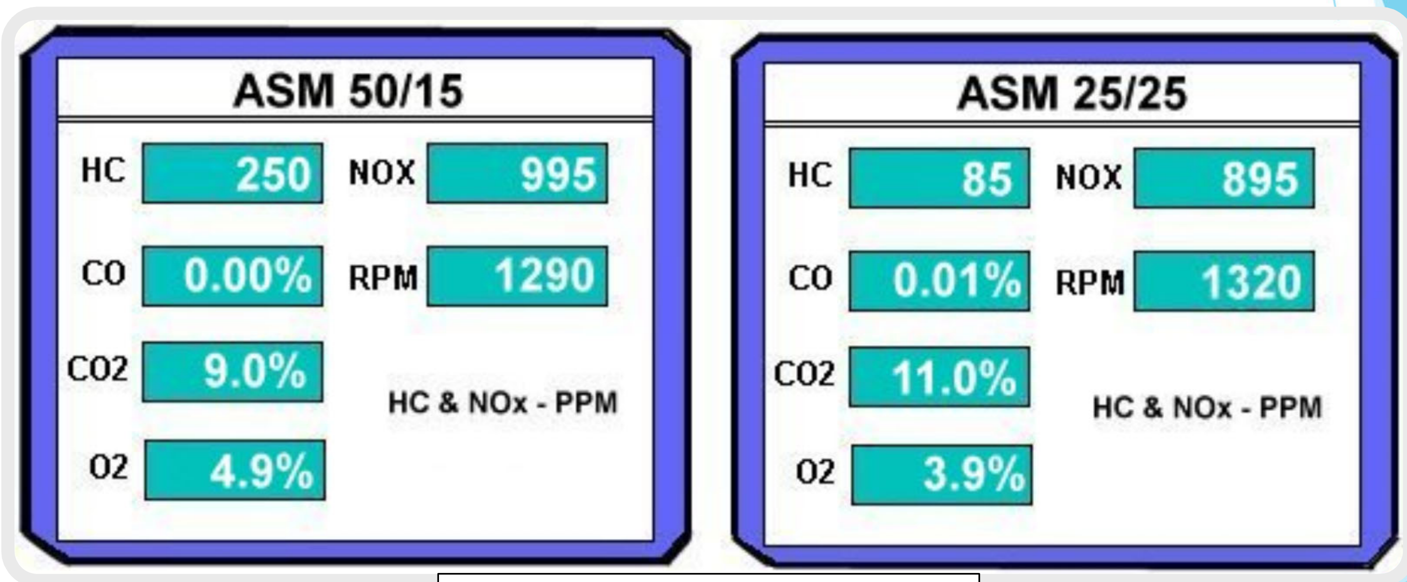
Diagnose these readings:



A) Restricted EGR Passage
B) Advanced Ignition Timing
C) Too Little CO2
D) Engine Misfire

Exhaust Gas Analysis

Diagnose these readings:



A) Not Enough EGR
B) Retarded Ignition Timing
C) Vacuum Leak
D) Engine Misfire