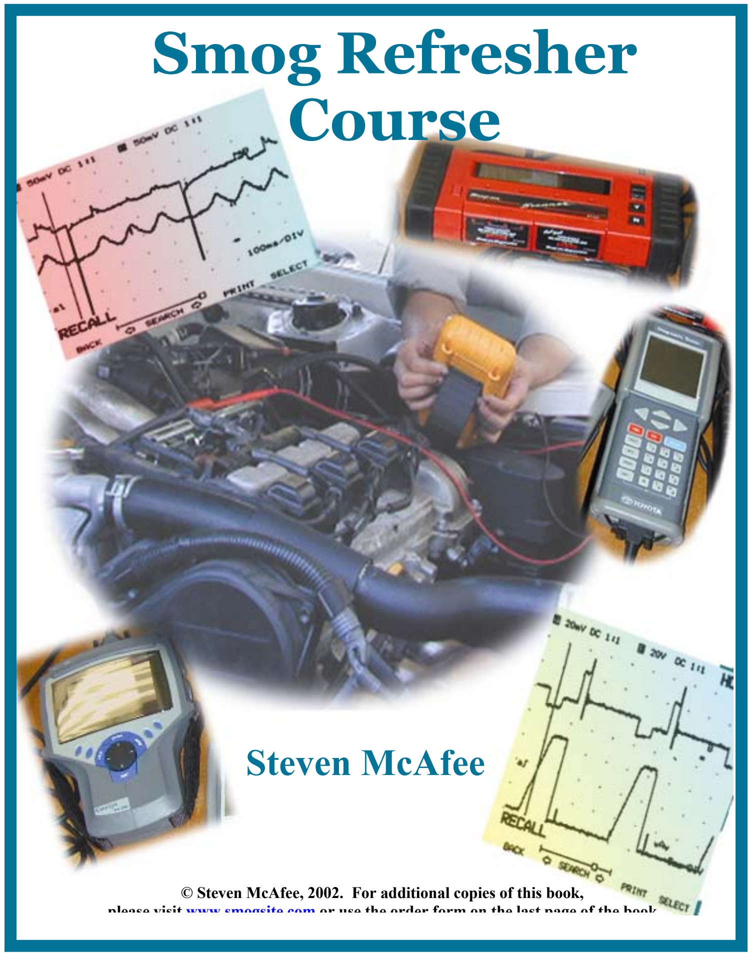
Excerpts from the book:



1. Excerpt from Exhaust Analysis Theory (pages 5, 6)

When we do exhaust analysis, we are being a **detective**. We look at what came out of the exhaust and figure out what could have happened before to create those emissions. What happened in the combustion chamber, or before the combustion chamber, to create these results?

We can use clues and patterns of exhaust readings to figure out if we have a problem in one of the following areas:

- Air/Fuel Ratio
- Combustion
- Ignition
- Emission Control Device

Then we know where to start our diagnosis with visual and functional tests.

Good Combustion:

Let's start by reviewing **good combustion**. The idea is to properly burn up all the gasoline and not have any "leftovers". Into the combustion chamber we put gasoline, symbolized by 'HC' for hydrocarbons. These are combinations of hydrogen and carbon atoms, organic matter from old dinosaurs maybe? We also add lots of air, which contains oxygen, symbolized by 'O2'. (Oxygen atoms feel more comfortable going around in pairs.) Normal air is about 20.7% oxygen, and if your shop smog machine doesn't show about this when reading the air inside your shop, you could have a bad oxygen sensor in your smog machine, or a serious problem with the air in your shop, or the planet has a problem... Back to combustion. The air we add to the combustion chamber is mainly nitrogen, about 78%. (No, that's not nitrous, but related.) This doesn't burn, it just goes along for the ride and expands with the heat, helping to push down the piston.

Coming out of the combustion chamber we have carbon dioxide, water and nitrogen. The carbon dioxide is symbolized CO2. (One carbon atom combined with two oxygen atoms) It's good, in that plants like it and it doesn't hurt us, but too much is blamed for global warming. The water is symbolized by H2O, two hydrogen atoms combined with one oxygen atom. Did you realize that for every gallon of gas we burn, the tailpipe puts out about a gallon of water? And then good combustion also puts out all the nitrogen that came in.

Good combustion is simply put this way: **HC + O2 + N2 = H2O + CO2 + N2**.

I leave out the numbers which show proportions. Most of you know we want an ideal mixture of 14.7 pounds of air to one pound of gasoline for the cleanest burning.

(Stoichiometric ratio, a term used in chemistry where the right amount of ingredients are present so everybody has a dance partner and nobody is left out.)

Bad Combustion:

Now for **Bad Combustion**. This is where the wrong things happen, and the byproducts of combustion produce gases which contribute to air pollution or other problems. One example is raw gasoline (HC) which goes in, then comes out, and isn't burnt up in the process. Another example is carbon monoxide (CO). It doesn't create smog, but it's deadly, so you don't want it around. A third example is NOx. It helps create out brown smog. These are all a problem, and we are soon going to talk about them in more detail. But first, look at what it takes to create photochemical smog:

> **HC + NO**x **+ Still air + Sunlight = Smog.** Get the idea? The HC and NOx are what it takes to create smog, so if we prevent them from coming out of the tailpipe, we cut down on the smog.

Smog Machine Measurements:

Next we need to know **what the Smog Machine measures**. These are the gases that the 4 or 5-gas smog machine sees:

- HC: Unburned Gasoline
- CO: Partially Burned Gasoline
- CO2: Completely Burned Gasoline
- O2: Oxygen, the Good Stuff
- NOx: Oxides of Nitrogen (This is only seen by a 5-gas smog machine)

When the tailpipe emissions are bad, what kind of problem do we look for? Here is a **summary** of what we are going to talk about:

- HC: misfire or bad burn
- CO: too rich
- CO2: engine efficiency
- O2: too lean or just air
- NOx: too hot or too lean

Now, let's talk about these gases in more detail, and see what causes each of them to be out of normal range.

2. Excerpt from Exhaust Gas Analysis Examples (pages 11,12)

This first set of examples shows **four gas readings** (HC, CO, CO2 and O2) during the two speed **idle test** commonly run on the BAR 90 machine in a basic smog test area. Some tests were only run at the low speed idle to save the catalytic converter. These are real readings from real cars.

	Idle	Cruise
HC	**1 ppm**	**5 ppm**
CO	**0.04 %**	**0.01 %**
CO2	**15.5 %**	**15.4 %**
O2	**0.1 %**	**0.1 %**

Normal clean emissions

This is a ‘91 Mitsubishi Galant, 2.0 fuel injected, with no air injection. These are the clean emissions of a good system and great catalytic converter.

	Idle	Cruise
HC	**28 ppm**	**30 ppm**
CO	**0.01 %**	**0.04 %**
CO2	**9.6 %**	**9.3 %**
O2	**7.4 %**	**7.8 %**

Clean emissions with air injection

This ‘81 Plymouth Reliant 2.2L has air injection. Notice the high O2 (7.4 - 7.8 %) but the CO2 is lower (9.6 - 9.4 %) The added air (which has lots of O2) has diluted the CO2.

	Idle
HC	**2000 ppm**
CO	**0.63 %**
CO2	**9.5 %**
O2	**7.4 %**

Lean Misfire

This ‘78 Volvo with fuel injection has a massive intake air leak. In this lean misfire HC is at the max. The lean air/fuel ratio makes it hard to burn all the fuel. There is far more oxygen than could be used, and the CO2 is showing low efficiency.

	Idle	Cruise
HC	**148 ppm**	**45 ppm**
CO	**5.67 %**	**0.07 %**
CO2	**11.3 %**	**13.4 %**
O2	**0.2 %**	**2.9 %**

Failed emissions - rich at idle
This '85 Mazda is rich at idle - the CO is way high, the CO2 is lower, and HC came up a bit. The idle mixture screws had been richened to make up for rough idle from retarded timing. At cruise it's clean, just not as efficient. It has pulse air, but at idle all the O2 was used up to clean up the CO as much as it could.

	Idle	Cruise
HC	**337 ppm**	**158 ppm**
CO	**1.64 %**	**2.57 %**
CO2	**14.8 %**	**13.6 %**
O2	**0.3 %**	**0.4 %**

Failed emissions - Bad O2 sensor
This '88 Honda 119 CID with feedback carburetor system has a dead O2 sensor. So the ECM can't adjust the air/fuel ratio, it leaves the carburetor slightly rich. The CO is a bit high. Being a carburetor, it also brought up the HC. A new O2 sensor fixed it.

3. Exhaust Gas Analysis Test (pages 15, 16)

Let's start out with some simple questions on **5-Gas Exhaust Analysis** for review, then we'll get into the more complex questions. Let's assume the catalytic converters on the cars in the test are not real good, maybe only 50% efficient. If we had really good cats, no matter what the problem the cat could clean it up for a while, and we wouldn't see any emission problems coming out the tail pipe. And please keep in mind that in real life these emission readings would vary a lot depending on the exact vehicle being tested. You may have seen one in the shop yesterday that was different. Just think about the general concept or theory involved in the test question.

1. A simple problem like a spark plug wire that fell off will likely cause lots of which pollutant to come out the tailpipe? Let's assume the engine is a non-feedback engine, or it stays in open loop.

A: NOx
B: CO2
C: CO
D: HC

2. If an EGR valve functioned properly and came open, but the passage was clogged with carbon, which pollutant would likely be high in a loaded mode test on a dyno?

A: CO
B: HC
C: NOx
D: CO_2

3. High numbers of NOx come out the tailpipe when Vehicle A had it's dyno smog test. Which of the following conditions could cause this?

A: An ignition misfire from a shorting spark plug wire
B: Too much carbon inside the combustion chamber
C: A bad thermostat that causes the engine to run hotter than normal
D: Both B and C

4. Let's say an engine puts out these readings at the tailpipe: HC 459 ppm, CO 4.7%, CO_2 10.3% and O_2 0.1%. What do you think is going wrong with this engine?

A: Air-fuel ratio too lean
B: Air-fuel ratio too rich
C: Normal, nothing wrong
D: Too much air

5. Which exhaust gases are measured in percentage (%)?

A: HC, CO, CO_2
B: CO, CO_2, O_2
C: CO, CO_2, NOx, O_2
D: HC, NOx

6. Let's say an engine puts out these tailpipe readings: HC 537 ppm, CO 0.05%, CO_2 9.7%, and O_2 4.5%. What do you guess is wrong with this engine, if anything? (Hint: there is no air injection.)

A: Air-fuel ratio too lean
B: Air-fuel ratio too rich
C: Normal, nothing wrong
D: Plugged exhaust

4. Exhaust Gas Analysis Answers and Explanations (page 19)

1. **D**, HC or raw gas that went in will come out when it isn't ignited.

2. **C**, when EGR isn't flowing, the combustion chamber gets hotter and creates more NOx.

3. **D**. Extra carbon causes more pressure in the chamber, which causes more heat, which leads to more NOx formed. An engine that overheats will do the same thing. An ignition misfire will create much less heat, so much less NOx.

4. **B**. The high CO and high HC show a rich mixture. Notice the O_2 is very low and the CO_2 came down too. Without enough oxygen, not all the CO becomes CO_2 and not all the HC can burn. The HC may only come from the rich condition. So first get the air-fuel ratio correct, and then retest to see if the HC are still too high. If it had been running too rich for too long, you may have to clean the carbon out of the combustion chamber with a top engine cleaner to get the HC to lower.

5. **B**. CO, CO_2 and O_2 are measured in percentage, HC and NOx are measured in parts per million.

6. **A**. This is a lean mixture when the HC and O_2 are high, (but there is no air injection) and the CO is low and the CO_2 is lower than our normal 13-14%. With too much oxygen, there is some left over and the fuel is thinned out so it can't all be burned. A plugged exhaust often makes the system richer. The CO being so low and the O_2 being high is a clue that the HC comes from a lean condition, not an ignition misfire. With an ignition misfire you will see excess O_2, but not as much and the CO won't be quite so low.