A ROCKET SCIENTIST PONDERS SCIENCE AND LIFE: AUTOMOTIVE EMISSIONS AND OUR AIR ENVIRONMENT

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You have undoubtedly heard or read about the Fraudulent Emission Testing of Volkswagen's diesel engine. How could VW have cheated the system to make pollutants appear lower only while testing emission, then disable the system during normal driving to deliver higher engine performance while expelling higher noxious emission? I am not an Automotive expert, but I am a competent Rocket Scientist with a detailed technical background of Combustion. I can explain the physical mechanism of Combustion, whether it applies to internal combustion Automotive engines or Rocket propulsion systems.

First, I must describe the different types of automotive engine cycles and the basic principles which make them work. Next, I will discuss historical methods by which emissions have been reduced since the 1960s when the L.A. basin SMOG was at its worst. Finally, I will hypothesize how I think VW controlled engine operation differently only during emission testing to reduce NOx emissions.

Automotive Engines Prior to 1970:

The most common engines used to depend upon carburetion in which gasoline was injected into warmed air coming from an intake manifold at a single point (the carburetor) then being channeled to separate cylinders (usually 4, 6 or 8) through valves being alternately lifted and closed by a rotating crankshaft. These earlier engine cycles were hampered by three negative emission sources: incomplete combustion of the fuel emitting un-burned hydrocarbons (UBH), carbon monoxide (CO), and Nitrogen Oxide (NOx) emissions. These are the three components measured during emission testing. All three contribute to formation of SMOG (SMoke + fOG). Those of you younger than 30 probably do not remember the SMOG problems we had in the L.A. basin prior to that time. [See images on the internet of suffocating SMOG today in large Chinese metropolitan areas and you will appreciate our clean air today.]

What Contributes to Un-burned Hydrocarbons?

The volatility of Hydro Carbons (HC) depend upon the fuel temperature. The gasoline refineries adjust the fuel mixture between colder winters and hotter summers as well as by local regional climate differences. For example, during the winter, refineries send higher volatility gasoline to Minnesota rather than to Florida. The fuel only partially vaporizes during the carburetion process. More of it vaporizes when it enters the distribution passages heated by the engine block. Denser gas mixtures rich in cooler fuel travel in as straight a path as possible and are richer at the end cylinders, while less dense warmer fuel vapor and air mixtures more readily turn into the closer cylinders resulting in leaner mixtures. Thus, it is understandable that the fuel-to-air (f/a) mixture ratio varies from cylinder to cylinder. The "lean" (low f/a) cylinders burn completely; whereas, the "richer" (higher f/a) cylinders are more apt to be starved of oxygen resulting in UBH.

<u>What Contributes to CO Formation?</u>

Ideally, the Carbon reacts completely with the Oxygen (O2) from within the air to form CO2 and heat to produce energy. The Hydrogen (H2), likewise, burns with oxygen to form water (H2O) vapor (steam) and heat to produce energy. Too rich a mixture (high f/a) may be starved of oxygen and discharge Carbon Monoxide (CO) a poisonous and potentially lethal gas in addition to UBH.

<u>What Contributes to NOx Formation?</u>

Nitrogen (N2) is always present (~78%) in Air. Normally, N2 is chemically inert (non reactive) at low and moderate temperatures. However, at high temperatures, typically hotter than ~3500 degrees Fahrenheit, it can dis-sociate (separate) into two nascent Nitrogen ions which are highly reactive. Given sufficient reaction time dependent upon its temperature, it can react with O2 forming a mixture of Nitrogen Oxides such as NO, NO2….etc, loosely designated as NOx.

<u>Interim Honda Stratified Charge Engine Cycle</u>

Circa 1970s, Honda developed the novel stratified charge engine cycle which burned all of the fuel with only a small portion of air. This vaporized all of the fuel, had a small amount of H2O and CO, but copious amounts of UBH and CO. It then quickly injected the remaining air to completely burn the UBH and converting the CO to CO2 releasing heat and generating power to produce a clean exhaust. By completely pre-vaporizing the fuel, the secondary air mixing and combustion time could be kept shorter than the necessary reaction time to form NOx and it passed all exhaust emission requirements.

Why don't we still have stratified charge engine cycles today? Because to keep the secondary mixing and combustion time short to preclude NOx formation, the combustion cylinders had to be kept small, such as were used for Honda's small, light weight, compact economy cars such as their initial Civics. It was not scalable to larger physical engines required to drive larger and heavier vehicles requiring greater horsepower and thus fell into disuse.

<u>21ST Century Automotive Engine Technology</u>

Today's modern internal combustion engines virtually exclusively utilize fuel-injection systems, which are computer controlled to deliver precise amounts of air and fuel to each individual cylinder in lieu of carburetion. Their computer algorithms are established to not only deliver clean exhaust emissions, but are also programmed to optimize fuel utilization to provide

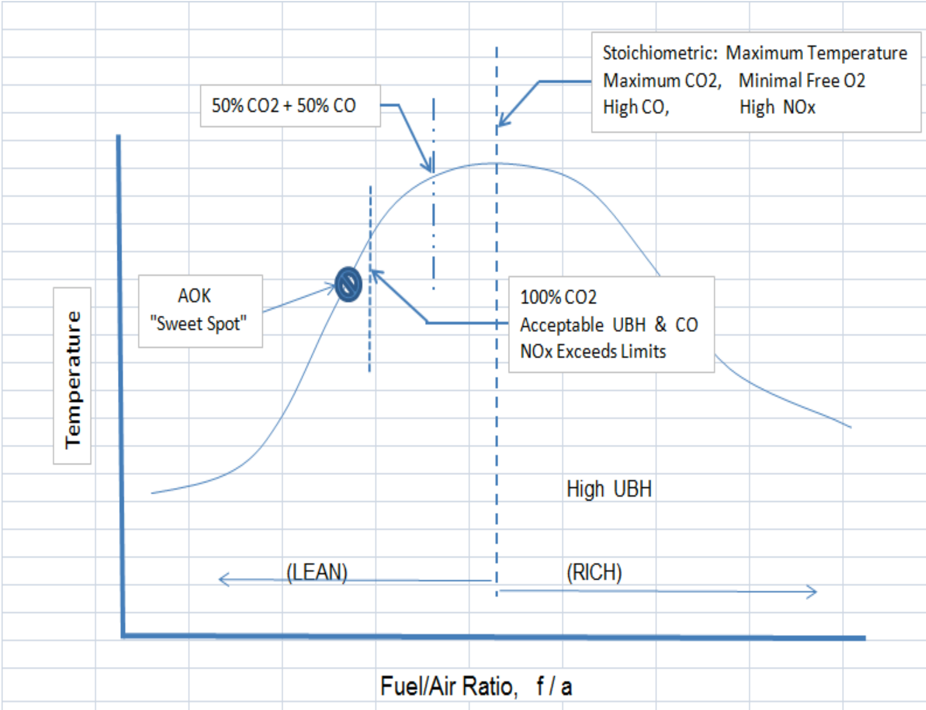

Figure 1. Typical Hydrocarbon/Air Mixture Combustion Gas Temperature vs. Fuel/Air Mixture Ratio

maximum efficiency and fuel economy. New vehicles, or even vehicles with over 100,000 miles which have been maintained in good working order, typically yield zero UBH and CO, and usually less than 5% of the allowable NOx emission standards. Only older vehicles which have been allowed to fall into disrepair fail exhaust emission standards.

<u>What is Different About Diesel Engines?</u>

First of all, one obvious difference is that the diesel engines have no **spark plug** to ignite the fuel/air mixtures within the cylinders. Then, how does it ignite? Diesel engines require inherently higher cylinder **"compression ratios"** than conventional internal combustion engines described above. The compression ratio is the ratio of the non ignited cylinder pressure at maximum mechanical compression divided by the initial ambient intake feed pressure at 1 atmosphere. Diesel engines have approximately twice the compression ratio of spark ignited internal combustion engines. This results in hotter thermodynamic compressive heating of the pre-combustion fuel/air mixture to cause the fuel to auto ignite. Another operational variable is the ratio between the post combustion cylinder pressure divided by the pre combustion maximum (mechanical) compressive cylinder pressure. This is controlled by the f/a mixture ratio within the cylinder which is controlled by the driver depressing the accelerator pedal. For fuel economy, the engine always operates on the lean side of "Stoichiometric." **(See Figure 1)** Stoichiometric is that f/a mixture ratio with exactly sufficient O2 to completely combust all the Hydrogen to H2O and all the Carbon to CO2. However, at this high a temperature, as much as half the CO_2 thermally dissociates to CO with excess free O_2 or nascent Oxygen ions. Under these operating conditions, both CO and NOx emission standards will be grossly violated. This is in addition to the greatly shortened diesel engine life due to thermal erosion (melting) and mechanical material cycle fatigue life due to these excessively hot operating temperatures.

Reducing the f/a mixture ratio in Figure 1 from stoichiometric to a point where the Carbon reacts approximately to 50% CO_2 and 50% CO reduces free Oxygen and its ions to trace amounts, but still violate CO emission requirements.

Further reducing f/a ratio to eliminate CO_2 dissociation to CO in the presence of sufficient excess O_2 can satisfy the CO emission standards. Furthermore, the excess O_2 reduces the UBH to nil. However, it may still be hot enough to cause Nitrogen dissociation products to chemically react with the now sufficient free O_2 to exceed NOx emission requirements.

Further reducing f/a ratio to eliminate N_2 dissociation to create NOx is the optimum operating point, which satisfies all EPA exhaust emission requirements while still providing maximum fuel economy. This should be the operating point (Engine RPM and f/a ratio) that the diesel engine utilizes at freeway cruising speeds and during maximum engine acceleration from a stop.

Diesel engines are inherently more efficient and provide better gas mileage than spark-ignited engines due to their higher combustion-pressure ratio. That is why cross country trucking utilizes diesel engines for their 18-wheelers. Furthermore, whereas diesel automobiles typically have automatic 3- to 5-speed transmissions, the heavy transport trucks utilize manual transmissions (to reduce slippage losses) and have over twice as many gear ratios so that their engines can always operate near this “sweet spot” under nearly all speeds, acceleration, road and traffic conditions.

<u>This is How Volkswagen Cheated!</u>

During static vehicle SMOG testing, the non driven wheels remain still while the drive wheels are rotated by rollers controlled by the SMOG testing device. I believe VW (and now possibly Audi) had sensors to compare the tire rotation between the drive and non drive wheels. If they were vastly different, the diesel engine was being tested for exhaust emissions and the fuel injection system reduced the f/a ratio to the above “sweet spot.” If the tire rotation speeds between the drive and non drive wheels were similar, the diesel engine was on the road and the fuel restriction was bypassed resulting in higher f/a ratio, hotter exhaust temperature, more power, higher fuel economy – **but higher NOx emission!**

<u>Why is This Important to ME?</u>

For two reasons:

1. I am happiest when I fully understand as much as possible surrounding the circumstances around my life and my role within the Universe. I am a graduate of the

California Institute of Technology where my school motto was… ***"The Truth Shall Make You Free."*** I have spent my entire life since then in search of all truths.

2. Last year, my wife and I travelled with the Caltech Associates to visit and tour the Hadron Super Collider in Cern, Switzerland. At that time they were all abuzz over their then recent discovery of the ***Higgs Bosun*** particle. More recently, they also discovered the ***Penta Quark.*** So I am highly motivated to keep abreast of new Scientific discoveries within the Universe. However, I have long realized since childhood that there is more than just the Physical Universe. That is where my upbringing in Gedatsu has supplemented my knowledge of the other half of the universe.

If you wish to join me in my discovery of the other half of the Universe, explore it with me on our Web Site:

gedatsu-usa.org