White Paper

Title: Combustion Efficiency for Performance Tuning
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Combustion (Carbon Oxidation) Efficiency:

One of the ways to look at the efficiency of an oxidation process is to evaluate how much of the fuel is oxidized by looking at the relative concentrations of oxygen and combustibles in the output gas. For example, a gasoline engine oxidizes a blend of hydrocarbons (containing almost purely hydrogen and carbon atoms), to produce water vapor (H2O) and Carbon Dioxide (CO2). While water vapor and free Hydrogen are relatively difficult to measure, the carbon-bearing gases (HC, CO and CO2) are typically measured in a 4 or 5 gas analyzer. HC is the input hydrocarbon (fuel vapor), and is measured as hexane, propane or methane depending on the fuel selected - equivalent to an 'n' of 6, 3, or 1 carbon atoms per molecule. (Gasoline, LPG or CNG) CO is an intermediate (half-way oxidized) gas, containing one carbon and oxygen atom per molecule, and CO2 (fully oxidized carbon) contains one carbon and 2 oxygen atoms per molecule.

As carbon atoms are neither gained nor lost by the oxidation process but only converted from HC to CO or CO2, and the desired end product is CO2, it is relatively easy to determine just how efficient the process is in reaching the desired result. This is done by determining the conversion ratio of carbon from the input form (HC) to the desired output form (CO2). CO, being an intermediate oxidation form, is weighted at '0.5' – to indicate that the carbon in it is 50% oxidized.

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Therefore, the numerator of the equation should contain all of the successfully oxidized carbon atoms (all of the CO2, and ½ of the CO) – and the denominator should contain all of the carbon atoms going into the oxidation process. Thus, the final equation is:

$$\mathrm{CE} = \frac{[CO_2] + ([CO] \times 0.5)}{[CO_2] + [CO] + (n \times [HC])}$$

Where :

$[\mathrm{XX}] =$ Gas concentration in percent V/V.

$0.5 =$ Oxidation weight of CO. (1/2 fully oxidized Carbon)

$\mathrm{n} =$ Number of carbon atoms in a molecule of the selected HC.

$\mathrm{n} = 6$ for Hexane (Gasoline), 3 for Propane (LPG), 1 for Methane (CNG).

So, if the degree of final oxidized product (CO2 + CO/2) is divided by all the carbon atoms available (CO2 + CO + nHC) you have combustion efficiency. This CE ratio indicates what percent of the carbon atoms have been fully oxidized by the combustion process.

Engine Efficiency – Typical Values:

An internal combustion engine is not 100% efficient. It is difficult for an internal combustion engine to produce a CE higher than 95%, even if it is well tuned and running correctly – so 95% CE is about the best that can be expected for engine-out gases. Poorly running engines (high performance engines are notorious for running poorly at idle) may show a CE of 70% or less. This situation may be normal, and improve greatly when the engine is operated under load and at higher rpm.

A catalytic converter is generally more than 80% efficient at completing the oxidation process on the engine-out gases that are not fully oxidized, so the CE value for the output gases from a catalytic converter should be typically greater than 99% with an engine-out CE of 95%.

Tuning for Performance – Lambda vs CE:

While the performance goal is to make the engine as efficient as possible, the 95% CE target efficiency expressed above may not be desired, as running the engine off tune on the rich side of stoichometric (Lambda less than 1.000) assures higher oxygen utilization, and this is the limiting factor for power generation. Due to this effect, performance tuners generally tune rich of stoichometric – and so the CE value naturally suffers.

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These effects are generally multiplicative – that is, if a tuner has decided that a Lambda of 0.950 is proper for his application (5% rich), then the maximum CE value will be 0.950 x 0.95, or 90.25% So – it is not likely for an engine with a Lambda of 0.950 to produce higher than 90% combustion (oxidation) efficiency due to the fact that there is simply not enough oxygen to fully oxidize the fuel. However, tuning on the rich side is common practice for high performance engines – so some balance has to be struck here. As Lambda effects CE, both parameters have to be evaluated together.

The point is that rich-side Lambda will degrade CE – but provide performance operating margin. The tuner should set Lambda first and then attempt to maximize CE, as when the CE is maximum for a given Lambda, the engine is operating at peak-power-producing efficiency.

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