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White Paper No. 12

Rev. 030306

Combustion Efficiency Calculations.

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 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 or 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.

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:

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

Where :

$[XX]$ = Gas concentration in percent V/V.

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

n = Number of carbon atoms in a molecule of the selected HC.

n = 6 for Hexane (Gasoline), 3 for Propane (LPG), 1 for Methane (CNG).

This method of looking at oxidation efficiency has the combined advantages of being both mathematically and intuitively straightforward. It yields very useful combustion efficiency results, as it tells the user just how effective the process is at oxidizing the carbon in the fuel – a good indicator of overall performance.

CAT Converter Efficiency:

CE has an additional important benefit in that it may also be used to determine CAT oxidation efficiency if the pre CAT gas values can be determined or inferred. The way this is done is as follows:

First, the carbon oxidation inefficiency for the pre and post CAT gases is determined. To do this, the CE value for each gas set (calculated by the equation above) is subtracted from 1.000 to yield COI – Carbon Oxidation Inefficiency. Then, the ratio of these inefficiencies is determined and the result subtracted from 1.000. The 'reduction in oxidation inefficiency' caused by the CAT is the CAT oxidation efficiency.

Let's look at some values.

PRECAT CE = 93.62% *POSTCAT CE = 99.28%*

First determine for each gas set. CIE = 1-CE, so

PRECAT CIE = 6.38% POSTCAT CIE = 0.72%

CATCIE = POSTCAT CIE / PRECAT CIE CATCIE = 0.72 / 6.38 = 11.29%

CATCE = 1-CATCIE *CATCE = 88.71%*

Basically, the CAT Carbon Oxidation Efficiency is:

$$CATCE = 1 - (1 - POSTCE)/(1 - PRECE)$$

Where :

$$POSTCE = \text{Post-CAT Carbon Oxidation Efficiency.}$$

$$PRECE = \text{Pre-CAT Carbon Oxidation Efficiency.}$$

In the case above, CATCE = 1-(1-0.9928)/(1-0.9362) = 0.8871 = 88.71%

Some benchmarks are that the pre-CAT CE (engine CE) should be 95.0% or above, for a properly running engine, and the post-CAT CE should be 99.0% or above – which means the CAT converter efficiency should be 80.0% or greater.

When λ gets below about 0.980 or so, though, the CAT can no longer oxidize carbon very efficiently, so you have to be a little careful of this. With λ above 1.05 or so, lean misfire can occur, and the Pre-CAT CE gets pretty bad – and the CAT has to work very hard to clean up the exhaust gases.