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### FUEL CONSUMPTION MEASUREMENTS USING CARBON MASS BALANCE METHOD

The exhaust gas analysis/carbon mass balance test is an accurate method for determining the improvement in an engine's performance once a catalyst, like FPC<sup>®</sup>, is added to the fuel. The test involves measuring the consumption of untreated (baseline) and FPC<sup>®</sup> treated fuel with the engine operating under steady-state engine conditions.

The carbon balance method, unlike volumetric and gravimetric methods, requires no modification to engines or fuel lines. Instead of measuring the volume or weight of fuel entering the engine, measurements are made of the products of combustion leaving the engine in the exhaust. In other words, the amount of carbon in the exhaust is measured. Further, the method is more accurate and less time consuming than the collection and analysis of in-house fuel consumption records. The carbon balance eliminates virtually all variables associated with the day-to-day operation of industrial and commercial fleets.

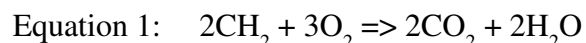
Additionally, the carbon balance is a widely accepted and recognized test method. For example, this is the method used by the Environmental Protection Agency (EPA) in the Highway Fuel Economy Test (HFET) and Federal Test Procedures (FTP) to measure fuel consumption. The method is relatively simple and is based on fundamental principles.

In order to better understand the application of the carbon balance, it is necessary to understand the basic principles of the method.

#### **The Combustion Process**

The fuels used in internal combustion engines are mixtures of hydrocarbons; that is, they are substances composed of the elements carbon (C) and hydrogen (H) generally in the approximate ratio of two hydrogens for each carbon. When fuel is burned in an engine, the carbon and hydrogen elements combine with oxygen (O<sub>2</sub>) from the air to produce carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O) as shown in the equation below.

Hydrocarbons + Oxygen => Carbon Dioxide + Water



The carbon dioxide and water from this chemical process are removed from the engine in the exhaust. When the combustion process is not complete the exhaust gases may also include unburned hydrocarbons (HC), carbon monoxide (CO) and unused oxygen (O<sub>2</sub>). Since air is generally used as the source of oxygen for most internal combustion engines, the exhaust gases will also include nitrogen (N<sub>2</sub>), which is generally non-reactive in fuel combustion, and trace amounts of nitrogen oxides (NO<sub>x</sub>).

### **Conservation of Mass**

Matter can neither be created nor destroyed. The Law of Conservation of Matter states that the mass of the reactants in a chemical reaction must be equal to the mass of the products. For example, equation 2 shows the combustion of 2.805 lbs. of fuel with 9.600 lbs. of oxygen to give a total of 12.405 lbs. of reactants. These in turn produce 8.802 lbs. of carbon dioxide and 3.603 lbs. of water to give a total of 12.405 lbs. of product.

In addition, one element cannot be converted to another: They can only be changed in form. The carbon in a liquid hydrocarbon fuel can be changed to gaseous carbon dioxide and the fuel hydrogen can be changed into water but carbon cannot be changed into hydrogen, nor can hydrogen be changed into carbon or some other element.

The total weight of the carbon present in the fuel-air mixture before combustion must therefore be equal to the total weight of the carbon present in the exhaust after combustion. This is always true.

### **Applications of Principles**

By carefully measuring the concentration of each carbon containing compound in the exhaust (CO<sub>2</sub>, CO, HC), it is possible to calculate how much fuel has been burned in the engine. If the total amount of the carbon present in the exhaust decreases then less fuel is being burned in the engine. If the total amount of carbon in the exhaust increases then the engine is consuming more fuel.

Furthermore, when a particular engine is run at a fixed RPM and load (steady state conditions), the carbon balance method may be used to measure changes in fuel consumption created by the addition of the fuel catalyst FPC<sup>®</sup>.

### **Test Procedure for Measuring Changes in Fuel Consumption**

The carbon balance test procedure is performed by attaching a sampling train connected to a non-dispersive infrared (NDIR) exhaust gas analyzer to the exhaust pipe of the internal combustion engine to be tested. The engine is then operated with fuel not treated with FPC<sup>®</sup> (the baseline) at a fixed RPM and load. The exhaust analyzer is used to measure the concentrations of carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), unburned hydrocarbons (HC), and oxygen (O<sub>2</sub>) in the exhaust gases. Exhaust temperature and flow rate are also measured and used to correct the gaseous readings for changes in exhaust density. Corrections are also made for changes in intake pressure (barometric) and fuel density

(fuel energy content).

After sufficient baseline data has been collected, the vehicle is operated with FPC<sup>®</sup> treated fuel under normal operating conditions for a 400 to 500 hour engine-preconditioning period. At the end of the preconditioning period, the above test procedure is repeated.

The values for each of these components are then used to calculate the change in the amount of fuel consumed by the engine created by the addition of FPC<sup>®</sup>.

### **Advantages of the Carbon Balance Method**

The carbon balance method for measuring fuel consumption is accurate, reproducible, and inexpensive. The entire procedure can be carried out in a matter of hours and the need for sensitive gravimetric or volumetric measuring equipment is eliminated.

The results from the carbon balance method are given by simple mathematical equation and a complicated statistical treatment of long term mileage and fuel use records is not necessary. Difficult to control variables such as road conditions, weather conditions, loading, work cycles, fuel composition changes, tires, drivers and engine tuning and maintenance are mostly eliminated. The carbon balance is simply a more practical way of measuring fuel economy. It is for this very reason the method has been adopted by the US Environmental Protection Agency.

### **Summary**

The carbon balance method for measuring fuel economy is a recognized and widely used method. The method is based on fundamental principles and uses recognized NDIR instrumentation (exhaust analysis equipment). The method is accurate, reproducible, and inexpensive. The carbon balance method is a convenient and practical substitute for more cumbersome methods involving the complicated statistical treatment of long-term mileage and fuel records and other direct methods of fuel consumption determination.

The technical approach for the carbon mass balance as applied in the field by RDI engineers is outlined in the Procedure for Carbon Mass Balance Testing of FPC<sup>®</sup> Fuel Performance Catalyst.

The derivation for the carbon mass balance calculation done by Dr. Geoffrey J. Germane, PhD., Mechanical Engineering and Chairman of the Department of Mechanical Engineering is attached. Also attached is an abbreviated resume for Dr. Germane.

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