BRIDGE analyzers, inc.

1805-B Clement Ave, Bldg. 28 Alameda, CA 94501

Voice (510) 337-1605 Fax (510) 337-0388

# White Paper No. 17

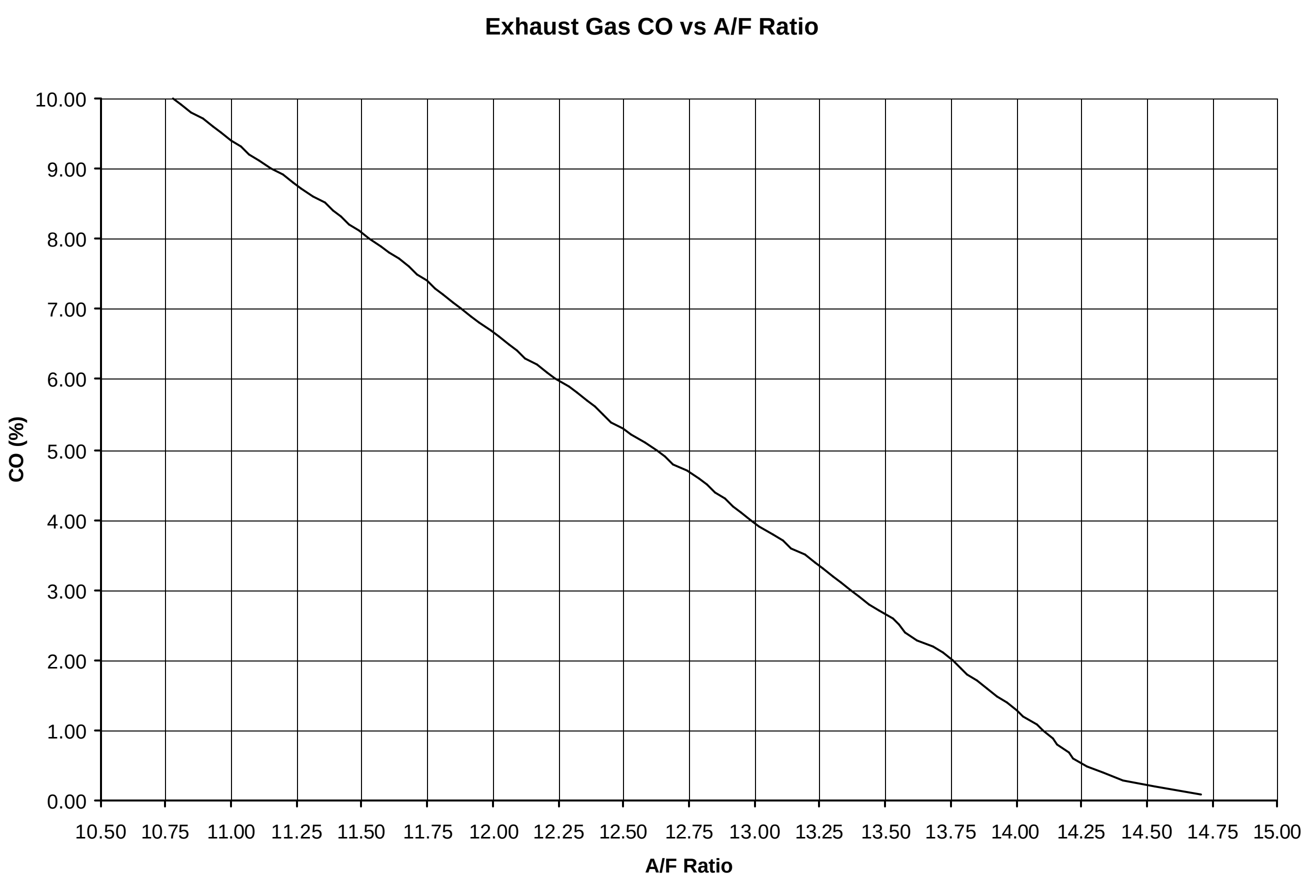
Rev. 031027

## Using a Model 9003 2-Gas (CO/HC) Gas Analyzer for Motorcycle Tuning: CO as an indicator of Air/Fuel Ratio, and HC as an indicator of Combustion Efficiency

The Model 9003 is a hand-held 2-gas (CO/HC) analyzer which can be used for basic small engine tuning using the CO gas reading to set fuel mixture, and the HC level to confirm running efficiency. The purpose of this white paper is to provide technical background on the use of the analyzer in this method.

### CO variation with Air/Fuel mix:

For some time, it has been recognized that the Carbon Monoxide content in engine-out exhaust gas for a well running engine is closely related to the air/fuel ratio. The following curve has been found in the public domain for many years:




The almost perfectly linear relationship between CO and A/F ratio yields a very simple way to setup a carburetor or fuel injection – but it is wise to understand just where this comes from first.

**Carbon Monoxide Production as Part of the Combustion Process:**

When fuel is burned, power is produced as the H's in the fuel are oxidized to H2O (Water) and the C's are oxidized to CO2 (Carbon Dioxide). However, the Carbon oxidation path goes to CO (Carbon Monoxide) first, and then the CO is finally oxidized to CO2 as the final process.

If there is not enough air to completely oxidize the fuel, there will be free Hydrogen and CO in the exhaust gas. While free hydrogen is difficult to measure, free CO is relatively easy – and the curve above shows what happens as air (containing oxygen) is gradually reduced.

The curve above shows that there just enough oxygen to fully complete the oxidation of CO to CO2 at 14.7 lbs of air to 1 lb of fuel – a ratio of 14.7 to 1.0 – the stoichometric point. At this point, all of the CO is being burned to CO2, so the CO level in the exhaust is Zero.

As oxygen is gradually reduced (or in this case, fuel is increased), there is simply not enough oxygen to completely burn the CO in the exhaust, and you can see a pretty much linear relationship. As the Oxygen ratio to fuel decreases, the CO remaining in the exhaust gas increases.

Tuning for performance usually occurs on the rich side of stoichometric, so the curve above is very meaningful for performance tuners – who generally tune for between 2.50% and 5.50% CO – an A/F ratio of 12.5 to 13.5. Doing so ensures that under transient conditions, where there may be momentary fuel loss, the mixture still remains a little rich. The downside is that the engine is running a little rich under steady-state conditions to ensure this – so fuel economy is mitigated, and high CO production occurs.

Still, it is relatively common for tuners to set the mixture on a bike to produce 4.00% CO or so at steady-state running in order to get maximum transient performance.

**Using HC as an indicator of Combustion Efficiency:**

HC is unburned fuel vapor. When an engine has high combustion efficiency, it is burning each and every intake charge as well as it can. There may be some CO produced if the A/F mixture is rich, but the amount of HC in the exhaust is still quite low. Thus, the HC content in the exhaust gas is more a function of combustion efficiency than it is a function of A/F ratio.

For example, a lean misfire (A/F ratio much to high) can cause the intake charge to not ignite. If this happens, the unburned fuel vapor will appear in the exhaust gas – and you will see very high values of HC.

The difference in HC content in the exhaust of a well running engine (Combustion Efficiency of 95% or so) and a poor running engine (Combustion efficiency less than 90%) is quite extreme – going from 100's of ppm to 1000's of ppm. So, the HC level in the exhaust can be a reasonably good measure of combustion efficiency.

**Errors in this Method:**

CO to A/F Ratio:

CO production is also a function of combustion efficiency. If the intake charge does not burn completely, then there will be CO in the exhaust gas. For example, while the published curve shows that CO goes to about 0.00% at 14.71 to 1.0 A/F ratio, this rarely happens. The combustion efficiency of an internal combustion engine is generally less than 95%, and at this level, there will still be 1.00% CO produced – even if the air and fuel are in perfect balance.

So – the true relationship between CO in the exhaust gas and Air/Fuel ratio is not quite what the curve above suggests. The effect of combustion efficiency has to be taken into account here as well – and this can get somewhat complex.

Suffice it to say that this method of relating CO to A/F ratio is a good first approximation. It is not quite accurate, but it is close – A/F within about 0.75 (Lambda = 0.025).

HC to Combustion Efficiency:

HC is an indication of pretty gross combustion inefficiency. It does not take into account at all of partial combustion effects – but only focuses on truly unburned fuel. As such, it is a good misfire indicator or an indicator of seriously incomplete combustion, but that is about it.

**A Better Way – 4-gas analysis:**

When CO2 and O2 are measured along with CO and HC, then the problems above are resolved, and Lambda, A/F Ratio, and Combustion Efficiency can be directly calculated from the exhaust gases:

Lambda (A/F Ratio) Calculation:

Lambda is the ratio of oxygen **available** to complete the combustion process vs oxygen **required**. If there is just enough, then Lambda= 1.000. If there is 5% less than needed, (5% rich) then Lambda=0.950. If there is 5% too much (5% lean), then Lambda = 1.050.

Lambda exactly relates to A/F ratio. If at Lambda=1.000 (the stoichometric point) A/F ratio is 14.7 to 1.0, then A/F ratio = Lambda x 14.7. So, for example, at Lambda=0.950, the A/F ratio would be 13.97.

The equivalent Lambda for tuning at an A/F ratio of 13.0 is 0.884 – 11.6% rich. So, something in the order of 10% rich is typically required for performance tuning.

Lambda calculation (which is done by calculating the oxygen and combustibles content in the exhaust gases) is exact – and is NOT a function of combustion efficiency. If the Lambda value (or A/F ratio – both are reported by the Model 9004) is stoichometric – then it really IS stoichometric, regardless of how well the engine is running at the time. This is because all of the Oxygen and Carbon and Hydrogen atoms are measured and accounted for in the exhaust gas, whether or not they are oxidized.

Combustion Efficiency Calculation:

Combustion Efficiency is the degree to which the fuel is completely burned.

The Model 9004 measures unburned fuel (HC), partially burned Carbon (CO) and fully burned Carbon (CO2) and calculated how complete the oxidation process is. Point is that this value is a function only of how fully the carbon in the fuel is being fully converted to CO2 (Hydrogen follows along with carbon, so it is similar) – and gives a very good indication of the running performance of the engine – largely independent of A/F ratio.

Having both Lambda (A/F ratio) and Combustion Efficiency directly calculated from exhaust gas levels provides the engine tuner with more exact measures of engine performance than the CO/HC method above.

However, the tuner himself should make the decision of the value of each of these methods based on his needs and experience.