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Magnetic Sector Hydrogen Analyzer for Direct and Continuous Wet Measurements of Engine Exhaust

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The ongoing transition from conventional to alternative fuels, especially those rich in hydrogen, has brought increased attention to the analysis of Hydrogen levels in combustion exhaust as it travels through the aftertreatment system, as it promotes the reduction of NOx emissions from the engine. Mass Spectrometry offers the most reliable analysis of Hydrogen as it is exhibits excellent repeatability and linearity across the measurement range. Despite being practically immune to cross-interference, the Mass spectrometer requires stable gas pressure and temperature sampling conditions which pose a challenge when analyzing high-moisture gases. Conventional Mass Spectrometry Hydrogen analyzers thus dehumidify the sample gas prior to analysis with the intent to improve sensitivity. However, such approach can introduce further uncertainty on the real-time correlation between Hydrogen emissions and other gas components measured with different gas analyzers. This study introduces a Magnetic Sector Mass Spectrometer recently developed for the analysis of Hydrogen content in high temperature (100-200 °C) and high humidity (0-30 vol%) gas samples. This analyzer is utilized to measure Hydrogen levels within the combustion exhaust from a gasoline engine at different points throughout the aftertreatment systems as the engine is operated under the Worldwide harmonized Light-duty Test Cycle (WLTC) in both Cold and Hot conditions.

Although not commonly measured, Hydrogen emissions can be estimated as roughly one third of CO emissions since both components are generated through the water-gas shift reaction at the high temperatures of the exhaust manifold. Other approaches utilize the air to fuel ratio as well to create a more complex correlation between CO and H_2 emissions. This study finds that while both approaches for estimating Hydrogen are somewhat accurate depending on the emission levels, the relation ceases to hold true after the oxidation of unburnt hydrocarbons where additional Hydrogen is generated, and CO levels further decrease. Since Hydrogen analysis is most important during the optimization of SCR catalysts for the reduction of NOx emissions, where NH_3 is regularly formed as a coproduct from the reactions written below, it is clear that the quantification of H_2 emissions needs to be done after the oxidation catalyst, suggesting that pure estimation of H_2 levels through CO emissions is not a reliable technique for this purpose.

$$NOx + H_2 \rightarrow H_2O + N_2$$
$$NOx + H_2 \rightarrow NH_3 + O_2$$
$$NOx + NH_3 \rightarrow H_2O + N_2$$

The need to measure H_2 in the exhaust as opposed to its estimation is thus clear, but the need for a Hydrogen analyzer that can perform wet measurements still needed verification. For this purpose, a sample gas dehumidifier was used to compare wet and dry Hydrogen measurements. To account for variability between instantaneous H_2O levels, a Hydrogen balance is performed for each test utilizing H_2O and NH_3 readings from an FTIR analyzer, THC readings from an FID analyzer, and correcting the dry H_2 measurements to wet concentration using the FTIR's H_2O readings. The study finds that dry measurements respond poorly to rapid transients in the exhaust, especially under rapid torque variations. Accumulated H_2 emissions during the test are also underestimated when a dehumidifier is utilized. findings of this study support the notion that analysis of H_2 in exhaust for the development of advanced aftertreatment systems should be carried out with a precise gas analyzer such as a Mass Spectrometer and measured without the use of sample gas dehumidifiers. Further studies are required for engines running on Hydrogen enriched fuels, where H_2 emissions can also be used to determine fuel efficiency.

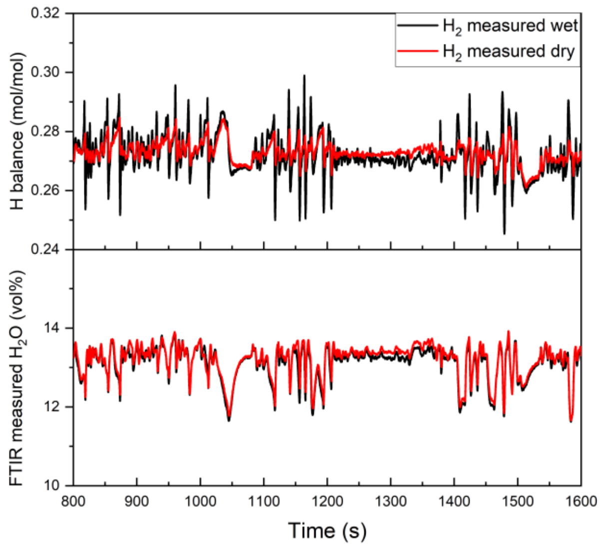

Fig. 1 Hydrogen balance of tailpipe emissions during a Cold WLTC run, utilizing a Hydrogen analyzer with and without a sample gas dehumidifier. Entire duration of test is not displayed for clarity.