

Enabling Flex Fuel Vehicle Emissions Testing – Test Cell Modifications and Data Improvements

Michael J. Loos, Joel F. O. Richert, Adolfo Mauti, Stephen Kay,
Timothy Chanko and Sandip D. Shah
Ford Motor Company

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ABSTRACT

The challenges of flex-fuel vehicle (FFV) emissions measurements have recently come to the forefront for the emissions testing community. The proliferation of ethanol blended gasoline in fractions as high as 85% has placed a new challenge in the path of accurate measures of NMHC and NMOG emissions. Test methods need modification to cope with excess amounts of water in the exhaust, assure transfer and capture of oxygenated compounds to integrated measurement systems (impinger and cartridge measurements) and provide modal emission rates of oxygenated species. Current test methods fall short of addressing these challenges. This presentation will discuss the challenges to FFV testing, modifications made to Ford Motor Company's Vehicle Emissions Research Laboratory test cells, and demonstrate the improvements in recovery of oxygenated species from the vehicle exhaust system for both regulatory measurements and development measurements. A series of recovery experiments were conducted using controlled injections of known masses of ethanol into vehicle exhaust systems. Results show that heating exhaust sample lines and pre-dilution transfer tubes enable increases in recovery and the use of FTIRs with appropriately designed sampling systems. Modal measurements of cold-start emissions show dramatic improvements with heated systems and provide much needed insight to product development engineers/calibrators. Finally, modifications to impinger/cartridge sampling have improved recovery from ~50% to near 100% while requiring little change to operator standard procedures.

INTRODUCTION

The proliferation of gasoline/ethanol blends for vehicle fueling has opened up a new challenge to automotive manufacturers. Flex-fuel vehicles (FFVs) are in various stages of development throughout the industry. Most manufacturers strive to develop FFVs that can certify to PZEV standards while running both gasoline or E85. Currently PZEV standards are as follows: 0.010 NMOG, 1.0 CO, 0.02 NO_x, 0.010 PM, and 0.004 HCOH. All units are in grams per mile. These are the same values as the SULEV standards with the edition of zero evaporative emissions and an extended warranty up to 150,000 miles. The goal of attaining PZEV certification is hindered by the new complexity of ethanol combustion and its effects on emissions. Of particular concern is the ability to perform accurate measurements of oxygenated species to accommodate the calculation of non-methane organic gases (NMOG).

Certification requirements for the measurement of oxygenated species (such as ethanol, acetaldehyde and other alcohols and aldehydes and ketones) specify the use of integrated sample collection from dilute exhaust and analysis by either chromatographic techniques or photoacoustic analysis of bag samples (2,3). From the engine development standpoint, integrated measurements do not provide a complete picture of areas of concern and potential development. Product development engineers and modelers need modal (second-by-second) data to determine where emissions are exceeding limits and what parts of the engine calibration need modification. Modal measurements of

oxygenates require the use of an online technique such as FTIR or mass spectrometry to sample raw exhaust gas. Currently, FTIR is the method of choice for modal measurements.

Integrated and modal measurements of oxygenates face several similar challenges in the nature of the exhaust gas matrix. Our current sampling systems have been designed to deal with 10 to 12% water content in exhaust gas based on the fuel used. FFV exhaust gas reaches a steady-state water concentration near 18 to 20%. This excess water can easily condense in sample lines and lead to measurement artifacts. In addition to this, oxygenated compounds are notoriously "sticky" and can condense and stick to the walls of sampling systems. The solution for these issues is fairly straightforward: heat. Heated lines and transfer tubes in the sampling system are already the norm for diesel exhaust. The need to use them for FFV exhaust has become apparent as of late.

Beyond the challenge of excess water, integrated measurements of oxygenates depend on a sampled concentration above minimum detection limits of the analytical methods. Impingers, used for alcohol measurements require the passage of sample gasses through a water bubbler, while the photoacoustic instruments extract sample gas from emissions testing bags similar to current regulatory bag measurements. An aliquot of water from the impingers is then analyzed in a gas chromatograph equipped with a FID detector. The ability to obtain meaningful results with the impinger method is wholly dependent on the amount of signal provided to the GC-FID. Thus increases in the mass accumulated in impingers will allow for greater signal to noise in the analytical method and move the measurement far beyond the analytical detection limits. At Ford Motor Company's Central Labs, this detection limit is 0.02 $\mu\text{g/mL}$ of ethanol (EtOH). A simple solution to collect more mass in impingers is to double the impinger sample flow rate and halve the volume of water used in the impinger. This yields a 4x increase in the mass collected.

Currently, CFR does not specify ethanol specific sampling requirements. The guidance provided for FFVs is based on methanol fueled vehicles. Briefly, CFR specifies heated line temperatures of 113°C and exhaust transfer hose temperatures above the dewpoint of the gas stream and below 121°C (1). Provisions are made for heating the transfer hose, however, the limit of 121°C may be insufficient for ethanol fueled FFVs. The limit of 121°C may be due to the apprehension that above this temperature, certain hydrocarbon compounds may decompose in the sample system. Laboratory flow reactor tests conducted with ethanol in N₂ and 12% O₂ show no loss of ethanol up to temperatures as high as 300°C (Figure 1).

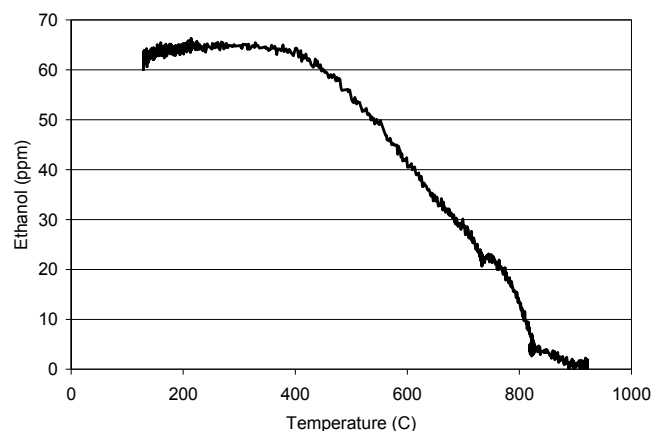


Figure 1: Ethanol decomposition in a flow reactor with 12% O₂ and ramping temperature.

This paper demonstrates the application of heated lines, valves and transfer tubes to increase EtOH recovery in both CVS systems and modal sampling. In addition to this, the impinger method is modified to allow for near 100% recovery of EtOH in the impinger samples. Data presented here are from chassis dynamometer tests using a near PZEV calibrated FFV vehicle.

METHODOLOGY

Emissions response and recovery testing were conducted for a variety of FFVs in the Vehicle Emission Research Laboratory (VERL). Vehicles fueled with E85 (85% ethanol and 15% certification fuel) were operated on a flex-fuel specific calibration. Vehicles were operated on a 48-inch (1.22 m), single-roll, AC electric dynamometer. Vehicle exhaust was diluted after exiting the tailpipe using a Remote Mix Tee (RMT). The connection from the tailpipe to the RMT consisted of a 4 foot long 4" ID flexible stainless steel coupling. After dilution, exhaust was transferred to a CVS. Diluted exhaust samples for oxygenate analysis are collected from the CVS via a Horiba Impinger and DNPH Cartridge sampling cart. Modal sampling of regulated species is also conducted via heated lines connected to underbody sampling lines (which were unheated or heated depending on the test conditions). Sample was drawn into Horiba 7000 series modal analyzers for NO_x, CO, CO₂, THC and CH₄.

An MKS 2030HS FTIR provided oxygenate and water measurements. The instrument was operated at a flowrate of 10 lpm and data were analyzed using MKS's analysis method specifically designed for FFV testing. Instrument sample lines, filters, and cell temperatures were set to 150°C as dictated by the data analysis method.

RESULTS

HEATED SAMPLING LINES – Figure 2 shows water vapor concentration during Phase 1 of the FTP from modal FTIR sampling raw exhaust gas from pre-catalyst locations of a Grand Marquis operated on E-85. The heated lines are connected to probes in the vehicle exhaust system that allow for sampling at pre- and post-catalyst locations. A large peak in water concentration is observed at ~230 seconds from the unheated line. This is water that collected in the line and was seen when temperatures were sufficient to vaporize. In addition to this, water vapor concentrations for the unheated line never achieve the levels seen with the heated line sampling. When heated lines (at 113 and 130°C) were used, water vapor concentration does not show the same vaporization peak at 230 seconds, however a peak at 70-90 seconds is still observed. This peak may be water that has collected in the actual exhaust system as opposed to water that collected in the sampling line. The initial rise of water vapor concentration for the heated lines is also markedly different (faster) than that of unheated lines.

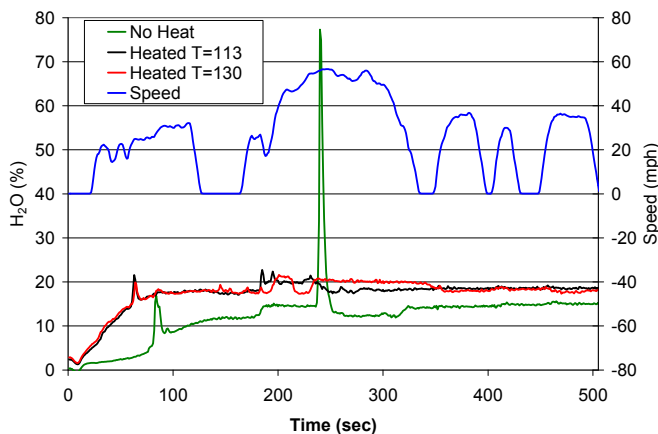


Figure 2: Water concentration measured through unheated and heated underbody sampling lines using an FTIR during phase 1 of the FTP test.

The differences between operating heated lines at 115°C and 130°C seem less discernable for water, but are fairly significant for other species. Figure 3 shows ethanol and acetaldehyde vapor concentrations for the first 120 seconds of Phase 1 from the same tests as Figure 2. Setting the line temperature to 130°C shows a larger peak for both species over the other temperatures. Similar results are seen for the start of Phase 3 where smaller peaks are seen for the no heat and T=113°C conditions. The added benefit of information such as this to product development engineers can be fairly significant when trying to achieve PZEV standards. In cases such as this, the ethanol emissions during cold-start can be considered as the primary hurdle to achieving NMOG certification. If developers are unaware of the true magnitude of EtOH emissions during the start, strategies to control the cold-start emissions will fall short.

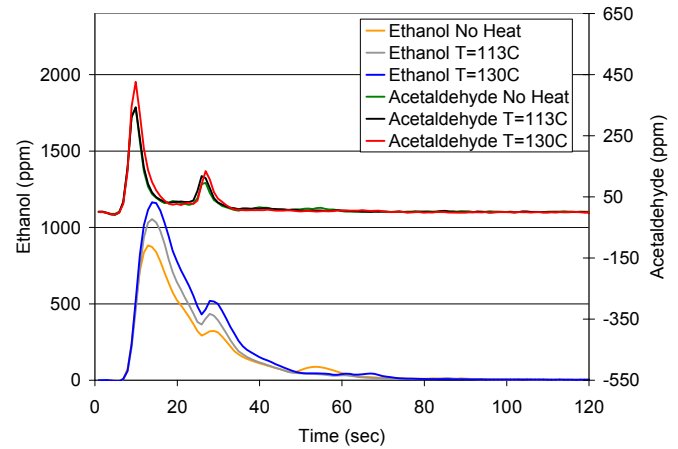


Figure 3: Ethanol and acetaldehyde concentrations measured through unheated and heated underbody sampling lines using an FTIR.

INTEGRATED MEASUREMENTS - The need for heated lines for underbody sampling is only half of the picture. Current regulations specify that alcohol and aldehyde emissions must be determined from integrated measurements of dilute exhaust, namely using impingers and DNPH cartridges or a photoacoustic instrument. The inherent assumption is that once exhaust gas is adequately diluted, concentrations will be low enough that condensation on surfaces will not be an issue. This can be achieved with large amounts of dilution air, however the addition of dilution air must be balanced with the need for sufficient dilute concentrations to remain in a range measureable by the analysis technique. So, assuming post dilution losses are not a significant source of error, there still remains an area where measurement artifacts can be introduced.

The coupling between the vehicle tailpipe and the dilution device (RMT) is a flexible, corrugated stainless steel hose. The RMT also contains a large ball valve for closing off the inlet of the RMT. Although it is recommended that the length of the coupling should be minimized, typical lengths can still be at least 4 feet. Gasoline vehicle testing specifications do not require heating of this coupling, however, once again FFVs demonstrate a need to heat this area. Simple measurements of temperature or heat transfer calculations establish that a significant amount of heat is lost through the transfer hose (a difference of 40-50°C between the inlet and exit, by either method). Additionally, we can visually confirm the presence of puddles of water in the hose after a test is complete. Performing a tracer balance of species at the inlet and exit of the coupling can shed light on this.