Cold Temperature Effects on Speciated VOC Emissions from Modern GDI Light-Duty Vehicles

Ingrid George, Michael Hays, Richard Snow, James Faircloth,
Thomas Long, Richard Baldauf
Office of Research and Development
United States Environmental Protection Agency
109 T.W. Alexander Drive
Research Triangle Park, NC 27711
george.ingrid@epa.gov

ABSTRACT

In this study, speciated VOC emissions were characterized from three modern GDI light-duty vehicles. The vehicles were tested on a chassis dynamometer housed in a climate-controlled chamber at two temperatures (20 and 72 °F) using the EPA Federal Test Procedure (FTP) and a portion of the Supplemental FTP (i.e. US06) that represents more aggressive driving conditions. The vehicles operated gasoline blended with 10% ethanol. VOC emissions from diluted vehicle exhaust were sampled with SUMMA canisters for EPA Method TO-15 analysis and with 2,4-Dinitrophenylhydrazine (DNPH) cartridges for carbonyl analysis by EPA Method TO-11A. This presentation will report the impact of ambient cold temperature, driving cycle, and GDI technology on speciated VOC emissions.

INTRODUCTION

The transportation sector contributes approximately 20% of total non-biogenic volatile organic compound (VOC) emissions in the United States.[1] Therefore, it is imperative to obtain a detailed understanding of speciated VOC emissions from mobile sources to accurately assess the air quality and health impacts of the transportation sector. To address the need for mobile source speciated VOC emissions data, one major goal of U.S. EPA Office of Research and Development vehicle emissions research is to comprehensively characterize speciated emissions from modern vehicles and assess the impacts of various fuels, temperatures and newer engine with and without after-treatment technologies. This study will focus on measurements of speciated exhaust emissions from gasoline direct injection (GDI) vehicles representing newer engine technologies. GDI engines were introduced into the vehicle market in the U.S. in 2007, and the technology has since quickly risen in popularity. Currently, GDI vehicles represent nearly a half of the U.S. light-duty vehicle market share.[2] However, the speciated emissions data on these types of vehicles is extremely sparse and the effect of cold temperature on GDI vehicle emissions is not yet known. Therefore, the objective of this study is to characterize speciated emissions from three GDI vehicles at two ambient temperatures.

METHODS

Three light-duty GDI vehicles were tested during this vehicle emissions study. All vehicles were in the U.S. EPA Tier 2 Bin 5 emission standard class and each vehicle represented different types of GDI technologies. The model years (MY), odometer readings at the study start (ODO), engine displacements (ED), and GDI technology types are given below for the three vehicles (V1, V2, V3).

1) V1: MY 2014 (Tier 2, Bin 5), ODO=12,700 miles, ED = 2.4 liter, GDI technology: Naturally aspirated, wall-guided GDI engine

2) V2: MY 2015 (Tier 2, Bin 5), ODO=10,500 miles, ED = 1.5 liter, GDI technology: Spray-guided, turbocharged GDI engine

3) V3: MY 2014 (Tier 2, Bin 5), ODO=9,200 miles, ED = 1.8 liter, GDI technology: Wall and air guided, turbocharged GDI engine

Vehicle testing was conducted on a 48 inch roll chassis dynamometer housed inside a climate controlled chamber. Vehicles were tested at two ambient temperatures (20 and 72 °F) using 10% ethanol blended with gasoline (E10) sourced from a local distributor. Each vehicle was driven on the Federal Test Procedure (FTP) followed by a portion of the Supplemental Federal Test Procedure (also called US06) and vehicle testing for each test condition was conducted in triplicate.

The vehicle exhaust was diluted in a constant volume sampling dilution tunnel, where the flow was controlled by a critical flow venturi. Real-time emissions were characterized by continuous emissions monitors for CO_2, CO, CH_4, total hydrocarbon (THC) and NO_x. Time-integrated samples for VOCs were taken from the dilution tunnel for the three phases of the FTP (FTP1, FTP2, FTP3) and US06. VOC samples taken included SUMMA canisters for EPA Method TO-15 analysis and 2,4-Dinitrophenylhydrazine (DNPH) cartridges for gas-phase carbonyls by TO-11A analysis. Canister samples were analyzed by gas chromatography-mass spectrometry. DNPH cartridges were extracted with acetonitrile and extracts were analyzed by high-performance liquid chromatography.

RESULTS

Real-time Hydrocarbon Emissions

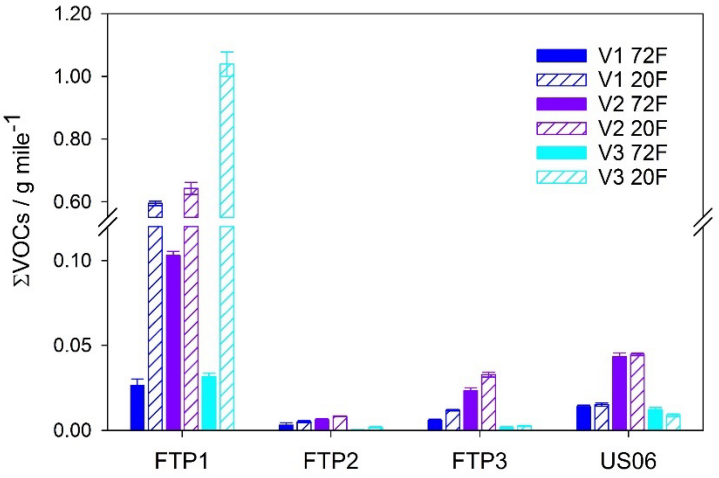
Real-time non-methane hydrocarbon (NMHC) emissions defined here as the difference between the THC and CH_4 measurements from a representative test for V2 were evaluated to better understand how the VOC emissions varied over the driving cycles. The NHMC trace over the FTP driving cycle for V2 showed that there was an extremely large spike early in the cold start FTP1 phase. The majority of the total NMHC emissions over the FTP were represented by this early cold start peak within the first 200 s of the FTP. After this initial peak, a few minor peaks in NHMC emissions were observed during the FTP during driving accelerations. The US06 driving cycle represents substantially more aggressive driving compared to the FTP. As a result,

the NMHC trace over the US06 for the same test showed numerous spikes in NHMC emissions that coincided with intensive accelerations during the driving cycle.

Time-integrated VOC emissions

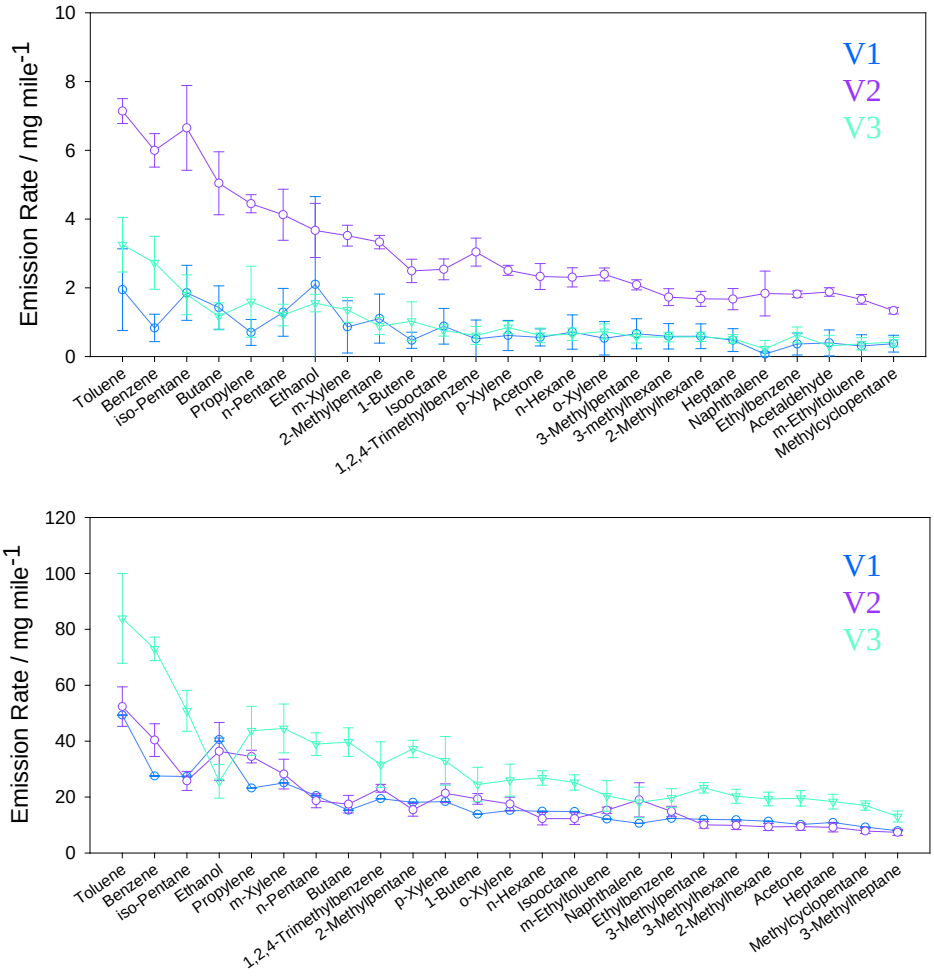
Time-integrated emission rates were calculated for 134 individual VOCs over each driving cycle and test condition for V1, V2 and V3. Figure 1 shows the sum of all speciated VOC emission rates (ΣVOCs) that were averaged over three replicate tests for each condition. It was observed that cold start FTP1 had substantially higher ΣVOC emissions compared to other phases of the FTP and US06, and were between 4 to 400 times higher than warm start FTP3 tests. ΣVOC emission rates during FTP1 20 °F tests, as represented by the striped bars in Figure 1, were strongly enhanced compared to FTP1 72 °F tests, where the cold temperature enhancements varied for each vehicle. However, cold temperature enhancements in VOC emissions were modest for other driving phases and US06. It was also found that VOC emission rates for V2 were substantially higher than for the other two vehicles with the exception of FTP1 V3 testing at 20 °F.

Figure 1. Sum of speciated VOC emission rates for each test condition and vehicle.



Twenty-five of the highest emitted VOC emission profiles for the three vehicles tested during FTP1 cold start are shown in Figure 2 for 72 °F (top panel) and 20 °F (bottom panel). The highest emitted VOCs during the FTP1 include a number of hazardous air pollutants, such as benzene and toluene, as well as a number of hydrocarbons found in E10 gasoline. During the warm temperature tests, VOC emission rates from V2 were substantially higher than for the other two vehicles across all VOCs measured. However, during cold temperature tests V3 emissions were higher for most of the major VOCs shown in Figure 2. It is currently unclear what the underlying mechanism for these vehicle specific temperature effects might be. Real-time measurements and other ancillary data acquired during the study will be further examined to better understand these observed trends.

Figure 2. VOC profiles for FTP1 at 72 °F (top) and 20 °F (bottom)



CONCLUSIONS

In this study, detailed speciated VOC emissions from three GDI vehicles at two ambient temperatures (20 and 72 °F) were measured. We observed substantial differences in VOC emissions between vehicles that were temperature dependent with VOC emissions being higher during the cold start FTP1 compared to other driving phases. Further, cold temperature FTP1 tests compared to warm temperature test conditions also resulted in higher VOC emissions during cold start. This work significantly increases the available emissions data for modern light-duty GDI vehicles that will improve emission inventories and air quality model predictions.

REFERENCES

1. U.S. EPA, Air Pollution Emissions Trends Data website, https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data
2. U.S. EPA, Light-duty Vehicle CO_2 and Fuel Economy Trends website, https://www.epa.gov/fuel-economy/trends-report.

Key Words

Volatile organic compounds
Vehicle exhaust
Gasoline direct injection
Chassis dynamometer