Measurement of Diesel Solid Nanoparticle Emissions

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Introduction

The current gravimetric methods used for the legal determination of emissions have difficulty in quantifying Particulate Matter (PM) mass emissions as regulations continue to be more stringent. Although the US EPA issued an improved protocol for the current gravimetric method, the accuracy will continue to be an issue at a very low emission from new vehicles. The European Particle Emission Measurement Programme (PMP) is a particle program aimed at measuring solid particle number emissions. The PMP protocol specifies to measure particles larger than 23 nm assuming contribution of sub 23 nm solid particles is insignificant. It is a promising method to possibly complement regulatory mass measurements. The PMP protocol is included in Euro 5/6 proposed emission regulations. The proposed number emission limit of 5 × 10^10 particle/cm^3 would be applicable to all categories of light-duty diesel vehicles at the Euro 5 and Euro 6 stages.

The potential of PMP protocol for heavy-duty vehicles’ engines has been recently studied in Europe and the US. During CARB’s previous studies on PMP they found important issues. They found there are significant number of appearance in Euro 6 substages that particles can make it past the PMP’s volatile particle removal [1]. It is very important to find whether these operationally determined solid particles are real solid particles (such as partially burned soot or ash) less than 23 nm or low-volatility compounds and to compare particle emissions during cycles and real world on-road driving as either case will suggest modification of the PMP method.

A Catalytic Stripper (CS) consists of two catalysts that convert the dilute exhaust gas components as well as volatile species on the surface of the particles. One catalyst is responsible for absorbing sulfur components and the other removes all volatile hydrocarbon compounds to soot [2]. The CS removes all particle precursors (volatile hydrotropics and sulfur) and make nucleation impossible downstream of the CS whereas PMP system prevents to suppress the nucleation by lowering the supersaturation ratio of the particle precursors. Ash particles and partially burned soot particles will make it past the CS, but renucleation will not occur with the CS.

Therefore, the CS is an ideal device to investigate the nature of particles under the PMP system. This study presents laboratory and on-road exhaust experiments of diesel particle penetration/formation under PMP protocol to assess its impact on the PMP measurement protocol using both PMP system and the Catalytic Stripper. The possible outcome of this study is to suggest modifications of current PMP method, which may result in suggestions to future implementation of the PMP method for on-screening and rule making.

Objectives

- To evaluate the volatile species removal efficiency of European PMP system (a) using challenging volatile aerosol in the laboratory; (b) sampling from heavy-duty diesel vehicles operating at certain cycles.
- To investigate the nature of nucleation mode particles retained downstream of PMP system.
- To compare PMP system with catalytic stripper sampling from a heavy-duty diesel vehicle under laboratory conditions on a chassis dynamometer and on-road conditions.

Schematic and experimental conditions

PMP Schematic

Volatilize Particle Remove

The PMP system used in this study was AVL particle counter (APC). It consists of primary chopper diluter heated to 150 °C, a evaporation tube heated to 350 °C, a perifluid tube as the secondary diluter, and a TSI 3780 CPC with cut point of 23 nm.

At dilution ratio of 120, AVL Particle Counter was able to remove 99.9% CAR and HS240 particles. Small amount of nucleation mode particles survived in the evaporation tube.

Catalytic stripper was connected downstream of AVL particle counter to investigate whether these particles were volatile or solid. A large fraction of these nucleation mode particles were detected at downstream of CS, suggesting these nucleation mode particles were solid.

This result is in agreement with previous study of thermal denuder and catalytic stripper [4]. The nucleation mode of solid particle formation downstream of AVL particle counter is unclear. More studies are needed.

Results

Size distributions of tetracontane (C46) and sulfuric acid (HS240) at upstream, downstream of AVL particle counter (APC), and downstream of catalytic stripper (CS).

- Lab test with C46 and HS240 showed that APC was able to remove 99.9% volatile particles. However, nucleation mode “solid” particles were formed downstream of APC. Mechanism of formation is unclear.
- Lower cut point CPCs measured higher concentration than high cut point CPCs for both APC and CS. The differences of lower cut point CPCs and higher cut point CPCs were more significant for APC.
- At 25% load, constant speed of 50 mph, CPC 3025A measured higher concentration than CPC 3771 downstream of APC, indicating the possible presence of sub 23 nm particles.
- At 25% load, concentrations measured by lower cut point CPCs downstream of APC were higher than measured directly from DPF, suggesting new particle formation in the APC.
- Size distributions measured by nanoSMPs showed sub 10 nm solid particles were present downstream of both APC and CS at 75% load.

Conclusions

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References