Particle Number and Size Distribution Emissions During Light-Duty Vehicle Cold Start Using the Total On-Board Tailpipe Emissions Measurement System

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Introduction

Cold start particle number emissions from light-duty vehicles are significantly higher than after the vehicle reaches its normal operating temperature (Kittelson et al. 2006). Furthermore, most most trips begin in urban environments, resulting in short trips that never allow the vehicle to reach its normal operating temperature (Blaikley et al. 2001). This results in higher particle number emissions than predicted by current models.

Particle number emissions have been found to decrease over time during engine warm-up, with particle size decreasing as well (Price et al. 2007). Ambient temperature has also been shown to influence emissions during cold start, with particle mass increasing by as much as a factor of 19 when ambient temperature was decreased from 22˚C to -7˚C (Ludykar et al. 1999).

Most studies focus on particle mass instead of number, lack high temporal resolution for the particle number distribution, and/or data are collected in idealized lab conditions using a dynamometer. This study examines real-time particle number emissions from 3 to 3000 nanometers during on-road driving. Real-time tailpipe number distributions indicated particles (nearly 100%) were below 300 nanometers in aerodynamic diameter and distribution modes varied with time after engine start.

Methods

Emissions were quantified using The University of Vermont's Total On-Board Tailpipe Emissions Measurement System (TOTEMS). Particle number was counted with a TSI Model 3025A Condensation Particle Counter (CPC) and the size distribution was determined using a TSI Engine Exhaust Particle Sizer (EEPS). (For more detailed methods and further information on TOTEMS, refer to **paper number 10-3023**, "*The University of Vermont Total On-Board Tailpipe Emissions Measurement System Instrumentation Package for Real-World, On-Board Tailpipe Emissions Monitoring of Conventional and Hybrid Light Duty Vehicles.*")

Instrument comparisons were performed between the EEPS and CPC in a laboratory setting using emery oil and sodium chloride particles. In the laboratory tests, constant and transient concentrations were generated using the setup shown in **Figure 1**. In **Figure 2,** typical results from these tests for both constant and transient concentrations are shown. All on-board data were collected from a 1999 Toyota Sienna minivan under different ambient temperatures, ranging from 20˚C to 37˚C. The summary of all runs is presented in **Table 1.** Each on-board dataset was collected at cold start along a specified route.

EEPS and CPC Lab Comparison

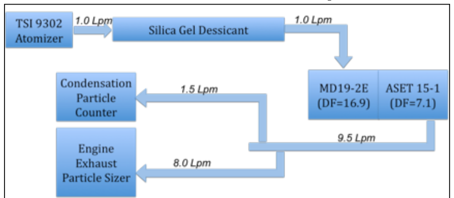

Figure 1: Schematic of and the corresponding flowrates of the laboratory setup for particle instrument validation.

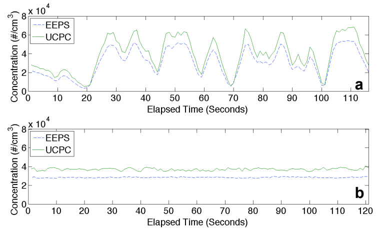

Figure 2: Transient (a) and constant (b) concentration tests results

Observations from laboratory experiments include:

1. EEPS and CPC response consistent and the instruments track well together;
2. EEPS under-predicted concentration changes when compared to the CPC during lab tests;
3. EEPS more inaccurate below 5000 particles/cc due to electrometer noise.

Defining Vehicle Cold Starts

This study used particle number emissions behavior to characterize cold starts in contrast to other studies using catalyst light-off (Andrews et al. 2004) or engine coolant temperature (Price et al. 2007). Three cold start phases were observed/defined (labeled in **Figure 3**):

1. Phase 1 was driver dependent, began at ignition on and ended when the driver put the car in gear;
2. Phase 2 began when the car was put in gear and ended when particle number during idle operation dropped to levels comparable to "hot-stabilized idle" operation;
3. Phase 3 began at the end of Phase 2 and lasted until (a) total particle number reached "hot-stabilized idle," (b) smallest particles (5.6 to ~10 nm) were no longer detectable, and (c) no longer increased when RPM increased.

Cold Start Results

Table 1: Summary of cold start emissions data.

Run No.	Cold Start Duration	EEPS Total Cold Start (#/cc)	CPC Total Cold Start (#/cc)	Ave T (˚C)	Ave RH (%)
1	230	7.11E+08	1.09E+09	20	28
2	165	3.50E+08	6.68E+08	37	23
3	191	7.23E+08	**Ins. Malfunction**	25	42
4	201	5.13E+08	8.35E+08	33	39
5	199	4.97E+08	7.96E+08	32	37

**EEPS and CPC data are sums of entire cold start duration (Phases 1 to 3 inclusive), and CPC data are biased low because the CPC always reached it's max concentration limit.

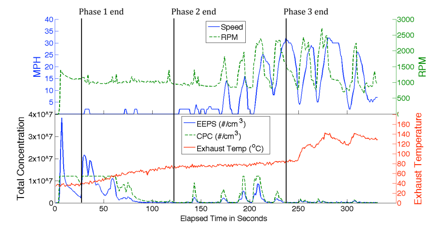

Figure 3: Vehicle parameters and particle number concentrations (#/cc) from EEPS and CPC, displaying different observed phases of cold start.

Flat tops of CPC in **Figure 3** indicate the instrument reaching its maximum concentrations limit. Significant differences in concentrations are most likely due to tiny nucleated particles below the EEPS concentration limit. These tiny particles are no longer present at the end of Phase 3 (shown in **Figure 4**).

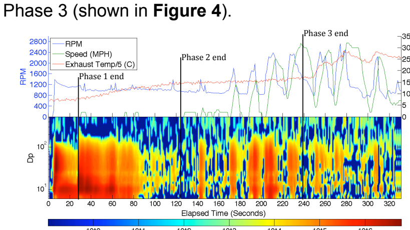

Figure 4: Time series EEPS particle number distribution (colorbar scale is dN/dlogDp). Figure is corrected for instrument noise.

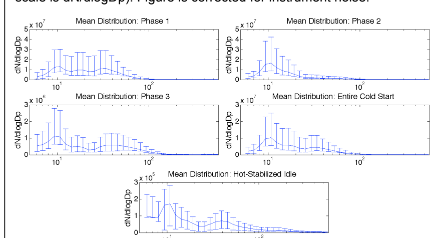

Figure 5: Mean particle number distributions, where the solid line is the average and the error bars represent the overall range for all 5 sampling runs.

Conclusions

Several important observations were seen from this study which have important implications for quantifying cold starts and on human health:

1. Shifting distributions (**Figure 5**) captured by the EEPS indicates slow scanning instruments (i.e. SMPS) are inadequate to fully understand particle behavior during cold start;
2. Magnitude, duration and the distribution of cold starts are important to understand as different particle sizes last different lengths of time and concentrations were 1 to 3 orders of magnitude higher during cold start than during "hot-stabilized idle." Also, most particles (more than 99%) were below 100 nm in aerodynamic diameter;
3. Comprehensive, multi-instrument studies must be conducted because no single instrument can capture the full distribution, indicated by the large difference in concentrations between the on-board EEPS and CPC data that was not seen in the lab.
4. Ambient temperature strongly influences particle number emissions due to increased cold start duration under lower ambient temperatures.

References

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