Session 4: Emissions: aftertreatment / real world operation / alternative fuels, Talk

Emissions from fuel operated auxiliary heaters of passenger cars

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Due to road transport emissions being significant source of both direct particle emissions and precursors of secondary particles in addition to other harmful substances such as carbon monoxide, nitrous oxides and being major contributor to global warming due to high carbon dioxide emissions, there have been both national and international efforts to restrict and reduce emissions from vehicles. However current regulations mostly account for direct engine emissions an approach which omits auxiliary sources of combustion emissions if they are emitted by heater unit separated from the engine. These separate heating devices are called auxiliary heaters (AH). AHs are typically installed into gasoline and diesel vehicles in colder climates to both provide additional comfort to passengers and improve operation of the engine by preheating it before driving, which would otherwise suffer from reduced performance and increased wear and tear due to the cold started engine.

However AHs have in been observed to produce significant amount of emissions relative to more strictly regulated engine emissions with single 30 minute preheating cycle with fuel operated AH producing as much PN23 emissions as 20 or 97 kilometers of driving for diesel and gasoline fueled AHs respectively if driving would produce as much PN23 as is allowed by regulation.[1] Benefits of preheating with AH to driving emissions were have been found to be smaller than expected with no observable reductions in PN emissions and only minor reductions in PM in some cases,[2] so fuel operated AHs have mostly negative effect on the total emissions of vehicle with AHs installed due to additional direct emissions generated by AH. Preheating with AHs were found to have neglible benefits to fuel economy during driving and if fuel consumed during the preheating is accounted for fuel operated AHs increased overall fuel consumption of driving 13.8 km after preheating by around 30 %.[2] In addition to relatively high direct emissions AHs were observed to produce one to three orders of magnitude greater secondary particle emissions compared to direct emissions.[3] Current AHs lack emission aftertreatment devices comparable to those used to mitigate engine emissions and by accounting AH emissions as part of regulated vehicle emissions would provide appropriate incentive to both vehicle and heater manufacturers to optimize heaters to mitigate their emissions.

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Influence of Lubricant Ash Content on DPF-Performance in Medium-Speed Diesel Engines

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Medium-speed marine diesel engines have only recently been equipped with diesel particulate filters (DPF), despite their relevance for particle emission reduction. While DPF technology has been successfully applied to smaller high-speed marine engines comparable to off-road machinery, early attempts on large medium-speed engines were not successful [1]. More recently, vessels operating medium-speed engines equipped with combined DPF and selective catalytic reduction (SCR) systems have entered service, achieving unprecedentedly low emissions for this engine class [2].

As heavy-duty, megawatt-scale medium-speed marine diesel engines typically operate for several thousand hours per year, downtime associated with DPF ash cleaning can become a critical operational parameter. Even when switching from heavy fuel oil to marine distillate fuels, sulfur levels remain higher than in on-road applications. This also applies to partial substitution with bio-, waste-derived, or synthetic distillates with reduced CO□ footprint. To ensure sufficient corrosion protection, marine lubricating oils therefore require elevated base numbers. Consequently, lubricating oil formulation and oil consumption rate become the dominant factors governing ash accumulation in the DPF and, therefore, the achievable maintenance interval.

In this study, the influence of lubricating oil sulfated ash content on DPF performance, pressure drop evolution, and particle emission characteristics is investigated. Laboratory experiments were conducted using a Cambustion Diesel Particulate Generator to expose a marine-relevant DPF to particle-laden exhaust gas under controlled flow and thermal conditions. Three trunk piston engine oils with sulfated ash contents of 0.7 wt% (low-ash reference oil), 1.45 wt% (standard ash), and 0.5 wt% (ultra-low ash) were evaluated under identical conditions. Accelerated testing simulated approximately 6,000 equivalent operating hours within a reduced test duration.

The results reveal a clear ash-dependent trend in DPF behavior. Higher sulfated ash levels led to a faster increase in DPF pressure drop due to ash accumulation, pore blockage, and partial channel plugging. Field data from megawatt-scale engines equipped with DPF-SCR systems confirm sustained particle number (PN) and particle mass reduction efficiencies above 98 % over operating periods exceeding 6,000 h when using low-ash lubricating oils [3].

Compared to [3], the present work extends laboratory investigations by incorporating real-life PN emission data from a vessel with a medium-speed engine and a DPF-SCR system [2]. On-board measurements using a High Concentration – Nano Particle Emission Tester enable direct comparison between laboratory experiments and real-world emissions.

These findings demonstrate that lubrication oil formulation, particularly sulfated ash content, is a key factor governing DPF lifetime and long-term particle emission control in marine diesel applications.

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Session 4: Emissions: aftertreatment / real world operation / alternative fuels, Talk

Nanoparticle and secondary aerosol emissions of EURO6d passenger cars fueled with gasoline, diesel and natural gas: The role of exhaust after-treatment byproducts

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The latest EURO6 emission classifications have led to significant reductions in primary particulate emissions from passenger cars. However, several studies report EURO6 passenger vehicles as important sources of secondary aerosol precursor emissions, potentially leading to several orders of magnitude higher secondary aerosol emissions in comparison to primary emissions (e.g. Hartikainen et al., 2023). Moreover, methane fuel, originating either as natural gas, biogas or e-methane, has been proposed as a method to improve air quality and decrease climate pollutants. However, ultrafine primary particle emissions and secondary aerosol formation potentials of methane-operated cars have not been extensively reported.

We measured the direct particle emissions and secondary aerosol (SA) formation potential of three Euro 6d-level passenger vehicles: one gasoline vehicle equipped with gasoline particulate filter (GPF), one diesel vehicle with diesel particulate filter (DPF), and one compressed natural gas (CNG) vehicle without particle filter. The vehicles were repeatedly driven 1-hour driving cycles on a wheel dynamometer. At least 29 cycles were run for each vehicle corresponding to more than 1500 km driving distance. The particle number emissions were measured with two condensation particle counters with cut-off sizes of 1.3 nm and 4 nm, and particle size distributions with instrumentation covering size range of 5 – 600 nm. The SA formation potential was measured using PEAR oxidation flow reactor. The formed secondary aerosol mass and composition was determined using Aerosol Mass Spectrometer (Aerodyne Research Inc.) and size distribution measurements. Volatile organics were monitored by a PTR mass spectrometer (PTR-ToF 4000, Ionicon) utilizing two different ionization modes. The overall gas phase composition was monitored using an FTIR analyzer (Gasmet DX4000).

The highest primary particulate number emissions were measured for the CNG vehicle in most driving conditions, whereas the diesel vehicle emissions were close to detection limit. However, the DPF regeneration events generated very high emissions during long distance operation, finally leading to the highest particle number emissions for the diesel vehicle. Comparable SA formation potentials in the range 1-2 mg/km were measured for each of the vehicle, which is roughly 1000 times more than the primary particle mass emission. The major identified secondary organic aerosol precursors were aromatic hydrocarbons for gasoline exhaust, but long-chain aliphatics for the diesel exhaust. Ammonium nitrate was a dominant SA component for gasoline and CNG emissions. This is due to the generation of ammonia emissions in the three-way catalyst of the vehicles, and subsequent reaction of ammonia and NOx during oxidative aging. Overall, this work highlights the role of emission after-treatment byproducts in both primary particle emissions and secondary aerosol formation potential of the emissions.

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Real-world particle number emission factors of heavy-duty vehicles: Contribution of sub-10 nm particles

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More evidence is emerging on the harmful brain impacts of human exposure to ultrafine particles (UFPs; <100 nm) [1-2]. The smallest UFPs (sub-10 nm) deposit efficiently in human extrathoracic airways [3], leading to a potential nose-to-brain pathway via the olfactory bulb [4]. Traffic is a major source of UFPs in urban environments [5], with heavy-duty vehicles contributing significantly [6]. Yet, even the stringent EU emission regulations do not address sub-10 nm particles in current and forthcoming legislations (Euro 7). In this study, we determined real-world particle number emission factors (EFs) for hundreds of passing heavy-duty vehicles, with a particular focus on the sub-10 nm size range.

Measurements were conducted on the causeway to Global Container Terminals Deltaport in Vancouver, Canada, using the UBC PLUME Van, a mobile laboratory, over seven days in October-November 2025. The causeway was dominated by goods-movement traffic, with minimal influence from other pollution sources due to its marine surroundings. The setup included a CO_2 analyser and two water-based condensation particle counters (CPCs) with different cut-off sizes (2 nm and 7 nm), enabling 1-s measurements of particle number concentrations for particles >2 nm and >7 nm. CO_2-based particle number EFs were derived using two approaches: individual CO_2 plume analysis to obtain EF distributions and fleet-averages, and correlation-based fleet-average EF estimation. Additional gaseous and particulate instruments of the broader campaign provided context on pollutant emissions, including non-exhaust particle emissions.

According to the preliminary results, the EFs showed very large variability, ranging from zero to 10^{17} #/(kg fuel). The fleet-average EF for particles >2 nm was approximately twice as large as the fleet-average EF for particles >7 nm, highlighting the significant contribution of sub-10 nm particles to total particle number emissions. Both EF calculation methods produced fleet-average EFs of similar magnitude, on the order of 10^{15} #/(kg fuel). These observations underline that heavy-duty vehicles can have a substantial impact on UFP concentrations in urban environments when operating on urban streets, even though cleaner vehicles also exist.

Measurements were part of the Urban Freight System Emissions program funded by Environment and Climate Change Canada's (ECCC) Climate Action and Awareness Fund (CAAF). Lintusaari's research visit to UBC was supported by the KAUTE Foundation through the Researchers Abroad program. Both Salo and Lintusaari were supported by the GIANT project funded by Business Finland (grant number 5582/31/2023), Helsinki Region Environmental Agency HSY, and several Finnish municipalities and companies. This research was undertaken, in part, thanks to funding from the Canada Research Chairs Program.

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Ammonium Nitrate Nanoparticles from Ammonia Combustion in Engines and Burners

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Ammonia is generally assumed to emit no fuel-derived nanoparticles when combusted because it contains no carbon. This presentation debunks that assumption, revealing through a body of experimental investigations, the formation of particulate-phase ammonium nitrate (AN) from combustion in both flames and engines. Experimental research was conducted on an engine platform [1] and in turbulent [2] and laminar [3] flame setups. In all cases, gaseous emissions were measured using a Fourier Transform Infrared (FTIR) analyzer, while particle size distribution was assessed using a scanning mobility particle sizer (SMPS) following a dual-stage dilution system. The engine was operated on pure ammonia at 1200 and 1800 rpm, 50% load. Burner experiments were conducted over a range of equivalence ratios and thermal input levels. Size-separated particles were collected using a MOUDI impactor and characterized for chemical composition using attenuated total reflectance-FTIR, Raman spectroscopy, and X-ray photoelectron spectroscopy. Additionally, particle morphology was studied using transmission electron microscopy, while energy-dispersive X-ray spectroscopy mapping was performed to confirm elemental composition. In both engine and burner experiments, particle size distributions were monomodal lognormal, with diameters ranging from 6 nm to 224 nm as shown in Figure 1.

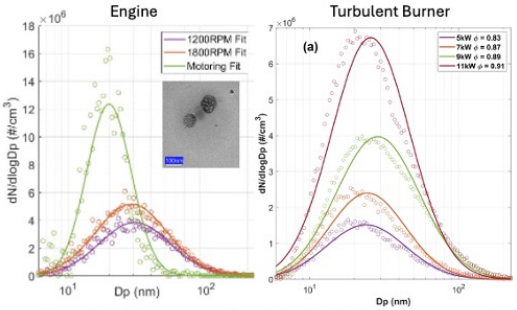

Figure 1. Dilution corrected particle size distributions measured using SMPS from engine experiments (left) and turbulent cyclone burner experiments (right). Raman image of ammonium nitrate particles (inset).

Characterization results indicate that measured nanoparticle emissions primarily consist of AN, but do not conclusively prove where in the exhaust system AN is formed. From the engine data, elemental maps show nitrogen and oxygen, indicating the presence of nitrates, along with sulfur, magnesium, potassium, and calcium, likely originating from lubricant oil additives. One formation mechanism is believed to involve heterogeneous nucleation, during which particles adsorb onto lubricant oil-derived ash particles. Burner nanoparticles contain no ash nuclei, suggesting that AN can also form via homogeneous chemical nucleation, with ammonia driving particle concentration, NO_2 contributing to cluster formation, and water vapor promoting particle growth via heterogeneous condensation. This presentation will clearly review these comprehensive results and provide an outlook for AN mitigation in future ammonia combustion systems.

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Effects of Extreme Cold Climate on Particulate Emissions of Light-Duty Gasoline Vehicles

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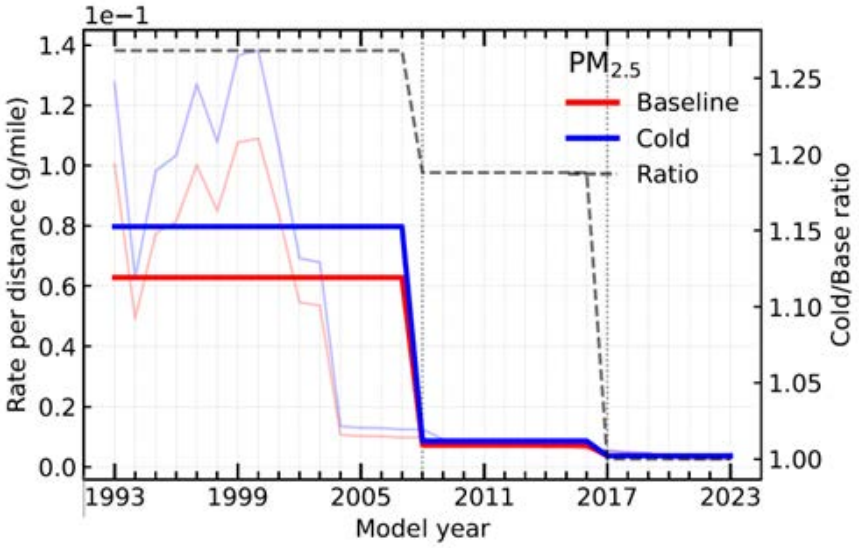
Extreme cold weather affects traffic activity and vehicle emission characteristics, yet the impacts are not represented in urban on-road emission inventories. The efficiency of catalytic converters depends on temperature, and achieving optimal operating temperatures in cold weather is challenging [1]. US EPA Tier 4 standards have recently introduced a PM limit of 0.5 mg/mi that requires a cold temperature test at -7°C [2]. However, in many parts of the world, extremely cold weather temperatures go below this limit value. This study quantifies the effect of cold weather on exhaust air emissions with a focus on light-duty vehicles for urban passenger transport. Using the City of Edmonton, Canada, as a case study, link-level traffic activity data, meteorological observations, and temperature-dependent emission factors were combined in a bottom-up emission inventory model based on U.S. EPA's MOVES. Technology- and model-year-specific emission rate multipliers were applied to account for differences between gasoline port fuel injection (PFI) and gasoline direct injection (GDI) vehicles and for changes associated with emission control standards.

Results show that cold-weather conditions increase running-exhaust emissions for vehicles prior to the Tier 3 regulatory era, with the magnitude of increase varying by pollutant and model-year. For PM2.5, average cold-to-baseline emission rate ratios are highest for pre-2008 vehicles (1.27) and remain elevated for cars produced between 2008 and 2016 (1.19). These results demonstrate that advances in emission control technologies have reduced both absolute emission rates and their sensitivity to cold ambient conditions for particulate matter, while older vehicles remain affected by winter operation.



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