2015

Cambridge Particle Meeting

Book of Abstracts

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University of Cambridge, Department of Engineering, Trumpington Street, Cambridge, CB2 1PZ, UK

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Cambridge Particle Meeting

Time	Speaker	Affiliation	Title
08:30	**REGISTRATION**		
	Session I (Chair: Jonathan Symonds)		
09:00	Welcome		
09:10	Jason Olfert	University of Alberta	Monodisperse Aerosol Classification without Particle Charge Artefacts Using the Aerodynamic Aerosol Classifier
09:30	Mark Crooks	TSI Instruments Ltd	Device for Measuring Solid Particle Number Concentration from Combustion Sources
09:50	Imad Khalek	Southwest Research Institute	Comparison Among DMS 500, EEPS SMPS, MSS, EC/OC, CPMA, Using Laboratory "Soot" Particles
10:10	Christian Focsa	Université Lille	Structural and Chemical Characterization of Soot Particles
10:30	**BREAK**		
	Session II (Chair: Adam Boies)		
11:00	David Kittelson	University of Minnesota	Aircraft PM: Estimating Size Dependant Sampling Losses without Measuring Size
11:20	Edward Yapp	University of Cambridge	Numerical Simulation and Parametric Sensitivity Study of Particle Size Distributions in a Burner-Stabilised Stagnation Flame
11:40	Jean de La Verpilliere	University of Cambridge	Gas Phase Production of Self-Assembled Carbon Nanotubes
12:00	Paul Maguire	University of Ulster	Controlled Microdroplet Transport and Charging in a Non-Equilibrium Microplasma
12:20	Georgios Kylafis	University of Leeds	Accidental Release and Dispersion of Engineered Nanoparticles: An Example of the Dispersion of TiO2 Nanopowders within Indoor Environments
12:40	**LUNCH**		
	Session III (Chair: Chris Nickolaus)		
13:40	Jacob Swanson	Minnesota State University	Volatility Characteristics of Electronic Cigarette Aerosols
14:00	Brian Graves	University of Alberta	Morphology and Volatility of Particles Emitted from Two Direct Injection Engines
14:20	Zhriong Liang	University of Birmingham	Investigation of SVOC Nanoparticle Emission from Light Duty Diesel Engine Using GCxGC-ToF-MS
14:40	James Allan	University of Manchester	Chamber Studies of Diesel Aerosol
15:00	**BREAK**		
	Session IV (Chair: Marc Stettler)		
15:30	Marc Besch	University of West Virginia	Characterization of PM Mass and Number Emissions Emitted by Current Technology Heavy-Duty Engines
	Arvind Thiruvengadam	University of West Virginia	Real-World Characterization of Particulate Matter Emissions from Heavy-Duty Trucks Operating in California
16:00	Aaron Lau	University of Oxford	Oxidation of Soot with Modified Silver Catalysts
16:20	Nicholas Ramskill	University of Cambridge	Magnetic Resonance Imaging of Gas Flow in a Diesel Particulate Filter
16:40	Prem Lobo	Missouri University of Science and Tehcnology	Impact of Synthetic Fuels on the Non-Volatile PM Emissions of a Turbojet Engine at Simulated Altitude Conditions
17:00	**END**		

09:10-09:30 - J. Olfert
Monodisperse Aerosol Classification without Particle Charge Artefacts Using the Aerodynamic Aerosol Classifier

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The Aerodynamic Aerosol Classifier (AAC) classifies particles by their relaxation time (or aerodynamic diameter). The AAC consists of two rotating coaxial cylinders. The aerosol enters through a gap in the inner cylinder and is carried axially by particle-free sheath flow. Between the rotating cylinders, the centrifugal force causes the particles to move in the radial direction. Particles with a narrow range of aerodynamic diameters exit the classifier through a gap in the outer cylinder with the sample flow. Particles with larger aerodynamic diameters impact and adhere to the outer cylinder and particles with smaller aerodynamic diameters exit the classifier with the exhaust flow.

Unlike the differential mobility analyser (DMA) or centrifugal particle mass analysers (CPMA or APM) the classification does not depend on the electrical charge state of the particles. Therefore, the AAC is a preferred classifier where a truly monodisperse aerosol is desired.

Previously work has shown theoretical models of the transfer function of the AAC, experimental validation of those transfer functions, and tandem measurements using an AAC and DMA to measure particle mass, effective density, mass-mobility exponent, and dynamic shape factor.

In previous work most of the measurements were made between ~100–1000 nm in aerodynamic diameter due to the limited rotational speed of the first prototype AAC. Recently, a new prototype AAC has been developed with a much higher maximum rotational speed.

The AAC was tested using a scanning mobility particle sizer (SMPS). Atomized NaCl was passed through the AAC operating at a fixed rotational speed. Aerodynamic diameters ranging down to 23 nm were successfully measured.

09:30-09:50 – M. Crooks
Device for Measuring Solid Particle Number Concentration from Combustion Sources

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A new TSI Instrument the NanoParticle Emissions Tester (NPET) is a tool for measuring the total solid number concentration of particulate matter from combustion sources, including the exhaust from a diesel engine. A Swiss Regulation 941.242 mandates biannual in-use testing of non-road mobile machinery to demonstrate the effectiveness of the Diesel Particulate Filters (DPF). Initially for equipment that was to be used in tunnels it now applies to all construction equipment and with current field methods of measuring particle concentrations in engine exhaust mass or opacity based, which are challenged by the very low concentrations of PM downstream of a DPF, a new instrument was required to fit with this regulation.

Exhaust from modern engines with after treatment systems such as DPFs or gasoline particulate filters (GPFs) is extremely clean, and when the after treatment system is working properly the exhaust can have lower particle mass and number concentrations than the ambient air. However; if a DPF or GPF fails, due to separation, cracking, or melting, or due to a malfunctioning regeneration system, it can allow very high levels of particle matter to pass through unfiltered. It is possible for the DPF to still capture the majority of the mass, while still permitting a high number of smaller particles to pass through the DPF. Rather than using mass or opacity, by measuring particle number, the detection limit is pushed to a much lower concentration, making it much easier to delineate between functioning and failed DPFs. The Model 3795 NPET has been developed to fit this requirement. The presentation will describe the instrument design; its comparison with other measurement instruments; the method and effectiveness of the volatile removal and some in field results.

09:50-10:10 – I. Khalek
Comparison among DMS 500, EEPS, SMPS, MSS, EC/OC, CPMA, using laboratory "soot" particles

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There is a strong interest in using instrumentation for engine particle emissions and ambient particle measurement where different moments of the particles such as number, diameter, surface area, and mass can be measured or inferred. Such information can be of high value for health researchers studying the effect of particles on human health. As of right now, there is no consensus among health researchers of singling out a metric of importance, as all metrics are important. The use of different size distribution instruments such as DMS 500, EEPS, SMPS and CPMA may achieve such goal if a large database is developed for different type of particles. Furthermore, understanding how different instruments compare and relate to each other is of critical importance to stakeholders.

In this work, we will compare the performance of various particle instruments relative to different metrics using laboratory soot particles produced by a mini-CAST followed by a catalytic stripper. In addition, we will use the CPMA for particle density measurement of PSL, emery oil, mini-CAST soot at different catalyst temperature.

10:10-10:30 – C. Focsa
Structural and Chemical Characterization of Soot Particles

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The rapid growth of aviation industry and its foreseen expansion during future years have raised a big concern about its potential impact in climate. Its main impact in Earth radiation budget is through aviation-induced cloudiness, in form of contrail cirrus generated by injection of soot particles into the upper troposphere. The impact of these soot particles on cirrus formation depends on their ice nucleating potential. During the last years, different works have studied the ice nucleation potential of soot particles, but there are important discrepancies between the results reported. One of the main reasons behind these discrepancies is the lack of a complete characterization of the soot particles studied. Soot particles can have very different physico-chemical properties depending on their production conditions, e.g. different fuels or combustion techniques. Therefore a complete physico-chemical characterization is needed to link the ice nucleation potential measured with specific soot properties. In the present work we have used micro-Raman spectroscopy, two-step Laser Desorption/Ionization Mass Spectrometry (L2MS) and Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) to characterize the structure and surface chemical composition of soot samples collected from a turbofan airplane engine operating at different regimes and from a Combustion Aerosol Standard generator (CAST) using different combustion conditions. This work was performed in the frame of the French national project MERMOSE (http://mermose.onera.fr/).

We have used micro-Raman spectroscopy to characterize the structure of the selected soot particles. We studied the spectral parameters of the first-order Raman band of different soot samples using the five bands de-convolution approach described by Sadezky *et al.* (2005). This approach provides information about the amount of amorphous carbon and organization degrees of the samples. To determine the surface chemical composition of the samples we have used two different mass spectrometry techniques: L2MS and ToF-SIMS. In L2MS, the adsorbed phase is probed by nanosecond laser desorption (λ_d=532nm), then the ejected molecules are ionized with a second ns laser (λ_i=266nm) and further mass-separated by ToF-MS. While in ToF-SIMS the sample is bombarded with a Bi_3^+ ion beam and the secondary ions generated are detected by ToF-MS. L2MS is especially well suited for the study of poly-aromatic hydrocarbons (PAH) present in the soot surface thanks to the resonant enhanced multi-photon ionization (REMPI) of these compounds at 266 nm. ToF-SIMS is complementary to L2MS since it gives a more uniform response to various families of compounds, moreover the higher resolution achieved with this instrument allows a more precise identification of certain compounds. We will present a comparison of the physico-chemical properties of the two different sets of soot studied, linking specific features with the different combustion conditions of both sets.

Sadezky, A., Muckenhuber, H., Grothe, H., Niessner, R., Pöschl, U. (2005). *Carbon*, 43, 1731-1742.

11:00-11:20 – D. Kittelson
Aircraft PM: Estimating Size Dependant Sampling Losses without Measuring Size

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The International Civil Aviation Organization is in the process of developing new methodology and standards for the measurement of particle emissions from aircraft gas turbine engines. Solid particle mass and solid number larger than 10 nm diameter are to be measured and regulated although not all countries will regulate number. Exhaust sampling from such engines is extremely challenging because of the high temperature, velocity, and volume of exhaust. In a normal regulatory test, it is not possible to put measurement instruments near the exhaust plane of the engine. Consequently, very long sampling lines are to be used, approximately 33 m in the proposed measurement system. The exhaust particles are very small, typically 15 to 30 nm geometric mean diameter and these long lines result in significant size dependent particle losses, especially by diffusion, typically more than a factor of 4 by number and 2 by mass.

In principle, if the dilution and sampling system is well characterized and the exit plane size distribution is known, it should be possible to determine and correct for line losses. In practice, the exit plane size distribution is not known and the only measurements made are solid particle mass and number at the end of the sampling line. Fortunately, exhaust plane size distributions from aircraft engines are typically unimodal and log-normal. Only 3 parameters, concentration, geometric mean diameter, and geometric standard deviation are necessary to describe such distributions. If these parameters are known, total number, surface, volume, etc. can be calculated, and if density is known, mass can also be calculated. The challenge is to link measured mass and number at the end of the sampling line to the size distribution at the engine exit plane, with 4 unknowns and only 2 measurements. The proposed method assumes a geometric standard deviation at the exit plane and a fixed particle density and uses an iterative procedure to determine the exit plane particle size and concentration that will result in the measured mass and number concentrations at the end of the sampling line. Recent experiments are described in which the method was against actual size distribution measurements. Uncertainties are discussed.

11:20-11:40 – E. Yapp
Numerical Simulation and Parametric Sensitivity Study of Particle Size Distributions in a Burner-Stabilised Stagnation Flame

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A detailed population balance model is used to perform a parametric sensitivity study on the computed particle size distributions (PSDs) for a laminar premixed ethylene burner-stabilised stagnation flame. The soot morphology in the post-flame region is studied using computed sintering level distributions, fringe length analysis of the polycyclic aromatic hydrocarbons (PAHs) within the primary soot particles, and TEM-like projections of aggregates. The computed PSDs were sensitive to the minimum particle inception size, the coagulation rate and the inception species concentration. Changes in the particle inception size and the coagulation rate led to an overall shift in the position of the coagulation peak. Only changes in the inception species concentration led to a systematic shift in both the position of the trough between the modes of the bimodal PSD and the coagulation peak at larger diameters. Given the overall model, varying the inception species concentration with each burner-stagnation plate separation was the only means possible to achieve a satisfactory agreement between the experimental and computed PSDs. This study shows that further work is required to better understand the soot precursor chemistry, the inception of soot particles. Additional work may also be needed in the area of experimental mobility sizing for the flame studied here.

11:40-12:00 –J. de La Verpilliere
Gas Phase Production of Self-Assembled Carbon Nanotubes

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In order for the outstanding properties of individual carbon nanotubes (CNTs) to be transferred into commercial products, control of the nanomaterial's organisation at the nano, micro, and macro scales needs to be considered holistically when devising the manufacturing process. Gas-phase processes are continuous and inherently scalable, enabling *large scale* production volumes, while the power of self-assembly allows for a precise control of the final structure at the *microscale* and *nanoscale*. The present work proposes a novel illustration of this concept: so-called self-assembled CNT sea urchins are synthesized after a gas-phase process pioneered by Kim *et al.* (2010), and continuously deposited on a substrate using thermophoresis as the driving force. The resulting nanomaterial presents interesting properties in terms of nanostructure, porosity, electrical and thermal conductivity. Properties of the final material being largely influenced by particle deposition parameters, the design of the custom-made thermophoretic precipitator used in this study will also be discussed.

An aqueous solution of aluminium nitrate $Al(NO_3)_3$ and iron nitrate $Fe(NO_3)_3$ is atomized in a flow of nitrogen using a collision nebulizer followed by a silica gel drier. Upon water droplet evaporation, both metallic salts precipitate, forming spherical composite nanoparticles with an aluminium-enriched surface consisting of small iron nitrate patches in an aluminium nitrate matrix. A first tube furnace is used to thermally decompose the metal nitrates in a reducing atmosphere, thus producing bimetallic Al-Fe nanoparticles. These nanoparticles form the core of the CNT sea urchins that are grown in a subsequent step, whereby a carbon source catalytically decomposes on the small iron patches at the surface of the particles in a second tube furnace, thus enabling CNTs to grow radially from the cores. In-situ and ex-situ characterisation of the as produced nanoparticles was performed in order to optimize the process to synthesize a high density of small diameter, long, straight CNTs on the surface of the cores. A thermophoretic precipitator allowing for high-efficiency controlled thin film deposition on a silicon wafer over a 5 cm^2 area was designed with the help of three dimensional simulations on COMSOL Multiphysics®. Theoretical and experimental deposition efficiencies and uniformities are compared. The thermophoretic precipitator was then used to deposit thin films of CNT sea urchins. Preliminary characterisation of the resulting thin films is discussed. Overall it is hoped that this work will contribute to the development of aerosol-based processes for the commercialization of nano-manufactured products.

Kim, S. H., Wang, C., & Zachariah, M. R. (2010). *Journal of Nanoparticle Research*, *13*(1), 139–146.

12:00-12:20 – P. Maguire
Controlled Microdroplet Transport and Charging in a Non-Equilibrium Microplasma

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Transport of liquid microdroplets through a non-thermal equilibrium microplasma should result in evaporation and droplet charging, among other possible effects. The magnitude of the charge, up to the Rayleigh limit, will depend on droplet size and plasma parameters as well as net recombination in the plasma afterglow/transition region where quasi-neutrality is not maintained. Evaporation within the plasma will reduce size and hence charge. However for short plasma transport times the evaporation may be limited. Charged droplets exiting the plasma would then evaporate without losing charge until the Rayleigh limit is reached. Through control of plasma transport and evaporation, droplet charging with enhanced accuracy and increased magnitudes may be possible.

We have developed a system for entraining micron-sized droplets ($5\mu m$ – $60\mu m$) within a narrow rf-driven cylindrical He-Ne microplasma operated at atmospheric pressure. Transport times can be varied between $20\mu s$ to $>100\mu s$. The droplet size distribution is log-normal with a CMD of $15\mu m$. Droplets exit the plasma with a velocity distribution within a parabolic envelope at ~75% of the local gas speed. The plasma induced evaporation results in an average diameter reduction of $< 2\mu m$, equivalent to an average evaporation rate that is ~ 2 orders of magnitude higher than reported for H_2O droplets of similar size in standard gas flow. We have measured sub millisecond charge pulses equivalent to $10^7 e$ from the droplet stream with ~2.5×10^3 droplets/s at < 20 m s^{-1} demonstrating the ability to extract charged particles from the plasma without neutralisation in the plasma afterglow (jet). The estimated charge per droplet is ~$10^5 e$. An enhanced system is currently under test whereby individual, size selectable, droplets are transported through the plasma for subsequent charge measurement and latest results will be reported.

Plasma – microdroplet interactions offers opportunities for enhanced surface chemistry and in-flight nanoparticle synthesis within the droplet. Droplets carrying bacterial cells offer an unique approach to studying plasma-bacteria interactions for plasma medicine and airborne decontamination. A brief summary of our latest result in these applications will be presented.

12:20-12:40 – G. Kylafis
Accidental Release and Dispersion of Engineered Nanoparticles: An Example of the Dispersion of TiO2 Nanopowders within Indoor Environments

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The paper investigates the potential impact of an accidental release of engineered nanoparticles (ENP) in a well-controlled room sized environment (3.31x4.26x2.26m). It details the development of experimental methods to determine the total particle number concentrations (PNC) and particle size distributions (PSD) following an indoor leak. A log10-normal modal fitting program is then utilised to estimate the mathematical characteristics of the PSD. Moreover, a dynamic model accounting for coagulation and deposition processes is applied for the study of changes in indoor PNC over time following the release, and the results compared with the experimental measurements. Various room ventilation strategies are tested and the corresponding total particle decay rates analysed in order to draw conclusions on their mitigation efficiency against an indoor accidental release.

TiO2 nanopowder (21 nm primary particle diameter) was injected into the chamber as a nano-aerosol generated by a 6-jet collision nebuliser. This approach was used since initial dry dispersion methods using a vortex shaker highlighted that the particles were highly agglomerated in stored form, and that the agglomeration bonds were difficult to overcome using mechanical methods. The particles were therefore sonicated in aqueous solution and the suspension characterised via Dynamic Light Scattering (DLS) showing median diameters of ~120 nm. Following release through the nebuliser, the PSD was recorded continuously by a Differential Mobility Spectrometer (DMS) and an Aerodynamic Particle Sizer (APS), both sampling close to the injection point. Two Condensation Particle Counters (CPC) were also used, one in parallel with the above instruments, and a second further from the injection point. Aluminium stubs were distributed around the floor and wall surfaces in order to analyse deposited particles using SEM and TEM analysis.

The results indicate that an ENP leakage could be detected by a single measurement device because of the rapid and uniform dispersion of the ENP within the room. Even in unventilated situations, the rapid decrease in PNC within minutes of the end of injection indicates the importance of particle deposition. Substantial coagulation during the first minutes of the release resulted in the change of the Count Median Diameter (CMD) so that the dispersed nanoparticles do not reach the sampling point in the form of the primarily released state. The presence of scavenging of the smaller particles by particles~>500 nm was also indicated by the SEM and TEM image analysis. The modelling results suggest that coagulation is an important removal process for ultra-fine particles (UFP) (<100 nm) while for the larger diameter particles (100<d<1000nm), deposition is dominant over coagulation. Finally, the results of the evacuation experiments showed that the most effective way to mitigate the high accidental PNC in an enclosed environment is to set the ventilation system to the maximum rates since medium ventilation rates may have resulted in turbulent re-suspension processes preventing the effective reduction of airborne PNC.

13:40-14:00 – J. Swanson
Volatility Characteristics of Electronic Cigarette Aerosols

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Electronic cigarettes (E-Cigs) have become a popular alternative to or cessation device for conventional tobacco cigarettes. E-Cigs operate employing a battery powered heating coil that is in contact with a wicking material saturated with an electronic cigarette refill liquid (E-Liquid). When the heating coil is activated, the E-Liquid is vaporized and the vapor combines with airflow which causes the vapor to condense and form an aerosol of E-Liquid droplets that is directly inhaled by the user. E-Liquids are composed of propylene glycol, vegetable glycerin, flavoring, and nicotine in various concentrations.

E-Cigs have been characterized in other research by detailing E-Cig aerosol particle size distributions, E-Liquid composition analysis, and evidence suggesting the presence solid nanoparticles in the E-Cig aerosol (E-Particles). Particle concentrations of E-Cig aerosols are extremely high (~1E8 #/cc), and the health effects of inhaling the E-Cig aerosol are undetermined. If solid nanoparticles are present in the aerosol, there are serious health risk implications for millions of consumers around the world that have adopted this growing trend.

The present study provides an analysis of E-Cig aerosols with emphasis on determining the presence, concentration, and elemental composition of solid nanoparticles in E-Cig aerosols. A hypothesis is that carbon built up on the heating coil from pyrolysis of the organic compounds in the E-Liquids is released during extreme heating, in the form of solid nanoparticles that become entrained in the airflow resulting from the user's inhalation.

The search for solid nanoparticles is conducted by flowing E-Cig aerosols through a catalytic stripper and measuring particle size distributions with an engine exhaust particle spectrometer (EEPS). All volatile and semi-volatile compounds are evaporated and combusted in the catalytic stripper, leaving only an aerosol of solid particles that is characterized by the EEPS. The hypothesis that the particles are carbon is tested using an aethalometer which is analyzes the mass concentration of black carbon in an aerosol. The results of this research, which have the potential to change a multi-billion dollar industry, will be presented.

14:00-14:20 – B. Graves
Morphology and Volatility of Particles Emitted from Two Direct Injection Engines

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The particulate matter emitted from two types of direct injection engines was investigated, and characterized by size distribution, morphology, mass-mobility exponent, effective density, and volatility using tandem measurements from differential mobility analysers (DMA) and a centrifugal particle mass analyser (CPMA). The engines consisted of a turbocharged inline-four cylinder gasoline direct injection (GDI) engine fuelled with gasoline and ethanol blends, and a single-cylinder compression-ignition, natural-gas (NG) engine fitted with a High-Pressure Direct-Injection (HPDI) system distinctly different from a duel fuel engine. Three engine loads were tested at 2250 RPM (15 N m, 45 N m, and 90 N m) in addition to an idle condition for the GDI while it was fuelled using gasoline mixed with ethanol fractions of 0% (E0), 10% (E10), and 50% (E50) by volume. Six engine conditions were selected for the NG engine which varied load, speed, EGR fraction, and fuel delivery strategy. An increase in engine load increased particle number concentration for both engines, although at idle the GDI produced approximately as many particles as at 45 N m. An increase in ethanol fraction in the GDI decreased number concentration, but E10 produced more particles than E0 at idle and 90 N m. GDI size distributions were found to be the sum of two lognormal distributions whereas the NG engine had unimodal distributions. The fraction of the number of purely volatile particles to total number of particles (number volatile fraction, NVF) both overall and as a function of particle mobility-equivalent diameter was under 10 percent at all engine conditions and fuels for GDI. The NVF for the NG engine was found to decrease as load increased, although the lower speed, partially premixed mode had the lowest NVF. The size-segregated ratio of the mass of internally mixed volatile material to total particle mass (MVF) was also low for GDI, and while higher for the NG engine, the MVF decreased with load and with particle mobility-equivalent diameter. GDI effective density increased with load, and in general mass-mobility exponent increased as well. Effective density decreased with an increase in ethanol fraction and a slight decrease in mass-mobility exponent was also observed for all conditions except idle, where the exponent increased with ethanol fraction. While no change in effective density or mass-mobility exponent was observed in GDI soot after denuding, denuded effective density trends were observed to collapse to approximately a single line for NG, although engine modes with higher MVFs had slightly higher effective densities suggesting that the soot structures have collapsed into more dense shapes.

14:20-14:40 – Z. Liang
Investigation of SVOC Nanoparticle Emission from Light Duty Diesel Engine Using GCxGC-ToF-MS

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The composition of primary vehicle aerosol and its contribution to secondary organic aerosol (SOA) formation is uncertain. Some of these uncertainties relate to the semi-volatile component of particulate matter. Semi-volatile organic compounds (SVOC) partition between the gas and aerosol phases at ambient conditions and can have an impact on human health, resulting in expiratory, immune and irritation symptoms.

2D-Gas Chromatography Time-of-Flight Mass Spectrometry (GCxGC-ToF-MS), has been utilised to characterise and quantify the composition of particulate matter exhaust emissions, in particularly SVOC. This technique has demonstrated the capability of resolving specific components of the Unresolved Complex Mixture (UCM), the large "hump" that typically makes up approximately 95% of the area of the chromatogram.

Tests were conducted on a Euro5b light duty automotive JLR diesel engine, using a state of the art engine testing facility involving the AVL PUMA and sampling system with a SPC472 partial flow system. A cascade impactor (nano-MOUDI) with 13 stages was used to collect particles with diameters 10-10,000nm. A DMS 500 was exploited to measure the particle size distribution and particulate number. Experiments performed included a range of steady state (variable engine speed and torque) and NEDC transient cycles with warm and cold start conditions. Further investigation will be conducted with differing sulphur containing fuels and different lubricants. Samples will be also collected with and without after-treatment devices.

The SVOC in the diesel engine exhaust emissions was observed to contain n-alkanes, branched alkanes, alkyl-cyclohexanes and cyclopentanes, PAH and various aromatic compounds; all in the C10-C35 range. Using soft ionisation, the degree and positioning of alkyl substituents surrounding the aliphatic chain has been identified, allowing greater identification of isomeric compounds within the UCM. Results indicate that the lubricating oil fraction contributing to particulate emission is large, confirming previous studies which indicate that a significant engine oil fraction exists in the exhaust emissions. At high engine speeds, the contribution of diesel fuel to the exhaust SVOC composition is dominant and at low speeds, a more prominent contribution from lubricating oil can be observed. For transient tests, however, there is a greater overlap between fuel and lubricant fractions.

14:40-15:00 – J. Allan
Chamber studies of diesel aerosol

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Aerosols from diesel engines are known to have major effects on air quality, however measurements are normally either performed either directly from an engine (via an online dilution system) or at roadside. As part of the National Environment Research Council COMPART project, we use a different approach, injecting emissions from a diesel engine dynamometer rig into an 18 m^3 teflon bag containing filtered and chemically scrubbed air. This allows the aerosol to be studied in detail over a period of hours, using the same instruments that would normally be used for atmospheric measurements such as the Single Particle Soot Photometer (SP2), Scanning Mobility Particle Sizer (SMPS), Aerosol Mass Spectrometer (AMS), Thermal Optical Analysis, Photoacoustic Soot Spectrometer (PASS) and Cavity Enhanced Phase Shift Single Scattering Abledometer (CAPS PM_{SSA}). In addition, particles were subjected to treatment or classification using a thermal denuder and Centrifugal Particle Mass Analyser (CPMA). In addition, measurements of the gas and particles phases using gas chromatography provide further insight into the chemistry.

This approach is allowing a number of unique insights to be made. By subjecting the bag to a simulated solar spectrum and injecting VOCs into the chamber, the effects of atmospherically relevant photochemical processes can be studied. Also, the use of a discrete injection into the chamber means that the dilution can be controlled and we can study emissions from transient running conditions (e.g. cold idle) in great detail.

Here we present results from the experiments performed so far, which includes insights gained into our abilities to model the optical properties of the BC in response to different coating thicknesses. This is important to consider when calibrating optical BC instruments but also dictates how BC aerosols impact climate.

15:30-15:45 – M. Besch
Characterization of PM Mass and Number Emissions Emitted by Current Technology Heavy-Duty Engines Trucks

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The reduction in solid particulate matter (PM) via the introduction of diesel particulate filters (DPF) altered the formation mechanisms of particles during exhaust dilution and cooling with ambient air, thereby possibly leading to nano-sized particles via nucleation phenomena downstream the DPF. Furthermore, oxidation of sulfur over the DOC and catalyzed DPF during exhaust gas temperature conditions in excess of ~350°C have shown to lead to formation of sulfate particles upon dilution with moist air. On the other hand, natural gas (NG) and Diesel/NG dual-fueled heavy-duty engines, an emerging technology making use of the waste natural gas resources, exhibit PM emissions different in composition and physical properties when compared to typical Diesel soot. Thus, depending on the overall combustion and after-treatment strategy employed, DPF's are subjected to very different soot loading rates, hence, directly affecting regeneration strategies and frequencies.

The primary objective of this study, funded by SCAQMD, was to characterize and quantify particulate matter emissions in terms of mass as well as number concentration and size-spectrum for current technology heavy-duty trucks and vocational vehicles under simulated real-world driving conditions. This allowed for comprehensive comparison of PM emissions from current technology vehicles with PM collected during previous test programs at West Virginia University (WVU) using pre-2010 technology engines, giving a holistic picture of how PM emissions have evolved as a function of technology and engine applications. Additionally, the study aimed at giving insight into real-time DPF filtration efficiencies by employing two real-time, in-line particle sensors measuring simultaneously concentrations up and downstream the DPF. Engine and after-treatment technologies investigated in this research encompassed diesel, natural gas, and diesel/NG dual-fueled engines equipped with either DPF only, DPF/SCR or TWC systems. Test vehicles included over-the-road-tractors (OTR), drayage trucks, refuse haulers and natural gas engine equipped transit buses. All vehicle testing was performed using WVU's chassis dynamometer and Transportable Emissions Measurement System (TEMS) with vehicles being operated over real-world cycles pertaining to their specific vocation, including a set of cycles representative of typical drayage truck operation in and around the ports of Los Angeles for the OTRs.

The study will present particle number (PN) concentration and size distributions measured directly from the CVS tunnel using an Exhaust Emission Particle Sizer (EEPS™) spectrometer, and total PN concentrations sampled from the raw exhaust stream downstream the DPF using a PMP-like setup comprising a hot and cold dilution stage. Two diffusion-charging type particle sensors (Pegasor PPS-M) were employed to measure total particle surface and number concentrations in the raw exhaust stream up and downstream the particulate filter, ultimately allowing to calculate real-time DPF filtration efficiencies. Finally, total gravimetric PM (TPM) and size specific PM10, PM2.5, and PM1.0 along with EC/OC contribution to TPM will be presented across all engine and after-treatment technologies.

15:45-16:00 – A. Thiruvengadam
Real-World Characterization of Particulate Matter Emissions from Heavy-Duty Trucks Operating in California

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Since the promulgation of the United States Environmental Protection Agency's 2010 emissions regulation, the use of diesel particulate filter (DPF) and selective catalytic reduction (SCR) has become the norm. With continuous advancements in exhaust after-treatment technology the mass emissions of particulate matter have decreased to levels that are close to detection limits of the gravimetric system. However, studies have shown the particle number emissions are elevated under certain real-world operating conditions. The objective of this study is to investigate the particulate matter number count and size distribution characteristics from modern heavy-duty diesel and natural gas goods movement trucks. The study measured particle size distribution and number concentration from different dilution methods (raw exhaust dilution using ejector, constant volume sampler and European PMP compliant setup) to study the real-world particulate matter emissions from heavy-duty trucks. The study used West Virginia University's transportable emissions measurement system to conduct on-road real-world emissions measurement for over 1500 miles in State of California. The study is unique in characterizing exhaust particle emissions during real-world operation of heavy-duty trucks as opposed to traditional chassis dynamometer or engine dynamometer studies. The study tested vehicles equipped with engines from all major heavy-duty manufacturers. Hence, the results provide an insight into the DPF management strategies employed by the different engine manufactures and the resulting impact on PM emissions characteristics. Particle size distribution were measured using TSI EEPS, while solid particle counts were measured using a Horiba SPCS 2000 and a TSI-Dekati thermodilutor. The routes where characterized by varying road grades and traffic conditions that are unique to California. The results of the study show continuous measurements of DPF efficiency and emissions of solid particle as measured using a European PMP compliant measurement system. The results also illustrate the storage and release of sulfate based particles during high temperature operation of the SCR. The results will show the solid particle emissions from current technology heavy-duty trucks in comparison to the European number count regulation.

16:00-16:20 – A. Lau
Oxidation of Soot with Modified Silver Catalysts

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As the demand for motor vehicles has soared dramatically with the emergence of rapidly developing countries, the need for regulating vehicle emissions and pollutants is increasingly more important. With the newest regulations for diesel particulate emissions soon to be enforced, there is a great need to catalytically convert soot particles from the exhaust into relatively less polluting carbon dioxide.

Here a supported silver catalyst is reported for the soot oxidation reaction. The silver catalyst is protected and supported using various capping agents and metal oxides, and modified using various synthetic methods. The catalysts are then tested with soot using thermogravimetric analysis (TGA) at a reaction temperature up to 700°C.

In order for a better design and modification of the silver catalyst, an improved understanding of the interaction between silver nanoclusters and the metal oxide support must be established.

XPS and UV/VIS spectroscopy are amongst the techniques used to probe the metal/metal oxide interaction. It is shown that the surface plasmon resonance of silver can be perturbed by the metal oxide support, modifying its band structure.

It is also extremely important for the catalyst to be thermally stable up to 600°C for it to be employable in an exhaust system. In-situ XRD can be used to investigate the thermal stability of both the silver and metal oxide species in an oxidising environment. The phase changes, if any, of either species under heating can also provide a better understanding of the metal/metal oxide interaction and ultimately the soot combustion mechanism.

It has been demonstrated that different catalyst surfaces can have different catalytic performances. By altering the morphology of the support, preferential growth of one surface can be achieved, thereby modifying the catalytic performance for soot combustion.

16:20-16:40 – N. Ramskill
Magnetic Resonance Imaging of Gas Flow in a Diesel Particulate Filter

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During the operation of a diesel engine, particulate matter (PM) will form during the fuel combustion process as a result of imperfect mixing between the fuel droplets and oxygen at the molecular level. In recent years diesel engine design has improved to inherently produce lower particulate emissions, however there is still a need for on-board emission control systems to reduce the PM content in the exhaust gas. The diesel particulate filter (DPF) is currently the most widely used technology to achieve compliance with government legislation such as the EURO 6 directive.

Magnetic resonance imaging (MRI) has been shown to be an attractive method for fluid flow visualisation. MRI measurements of flow are truly non-invasive, there is no need for tracer particles and it is also possible to study optically opaque systems. Here we show how MRI velocimetry can be used to non-invasively investigate and visualise the gas flow inside a DPF.

In the present study, images of the axial velocity of the gas flow were acquired at ten evenly spaced positions along the length of the DPF, for three flow conditions corresponding to Reynolds numbers of Re = 106, 254 and 428, based on the average gas velocity at the filter inlet. From the velocity images, channel-scale profiles of the axial and through-wall velocity, as a function of position along the length of the DPF, have been determined.

These measurements have been used in the subsequent analysis to provide insight on how the gas flow field influences the PM deposition pattern and filtration efficiency within the filter during operation. It has been observed that for higher Reynolds number flows, the through-wall velocity profile, and consequently PM deposition profile, became less uniform. Furthermore, it has been seen that for the range of particle sizes expected in the exhaust gas from a modern diesel engine, the filtration efficiency is strongly influenced by the through-wall gas velocity.

16:40-17:00 – P. Lobo

Impact of Synthetic Fuels on the Non-volatile PM Emissions of a Turbojet Engine at Simulated Altitude Conditions

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