Applications for the Catalytic Stripper

Background

Aerosol sampling plays a pivotal role across multiple scientific and industrial disciplines, from air quality and emissions control to toxicological research and beyond. The **°Catalytic Stripper** (CS) continues to be an essential tool in the accurate measurement of solid aerosols, particularly in applications where the separation of non-solid fractions is critical. By chemically converting volatile and semi-volatile compounds into non-reactive gases, the CS ensures that only the solid fraction of particles is measured.

Our **°Catalytic Stripper** was introduced to meet the specific needs for measuring solid aerosols, particularly solid black carbon emissions from internal combustion engines. However, its versatility allows it to be utilized across various research fields, including those mentioned and beyond.

The **°Catalytic Stripper** (CS) operates on a principle similar to that of an evaporation tube or thermal denuder, which are commonly used in aerosol measurement. Both devices involve heating an aerosol inlet to a specific temperature to separate volatile materials by converting them to the vapor phase. However, the key difference with the CS is its catalytically active design. Unlike an evaporation tube, which merely allows volatile materials to condense on inner surfaces or re-condense into aerosol form, the CS uses a heated catalyst to chemically convert hydrocarbons and other non-solid materials into non-reactive gaseous species. This ensures that the aerosol exiting the CS consists solely of the solid fraction of the original sample.

The below sections outline some of the latest advancements in the application of the **°Catalytic Stripper** across various fields, highlighting its versatility and impact on modern research. The state-of-the-science research applications for the CS split into the following topics:

- Aircraft Emissions
- Ambient Air Measurement
- Toxicological Assessment
- Marine Emissions
- Vehicle Emissions

with referenced material at the end of each section.

Toxicological Assessment

The study by A. Das et al. focused on generating reference ultrafine soot particles (UFP) with differing organic content to assess their toxicological impacts on human alveolar epithelial cells. The catalytic stripper (CS) was crucial in this experimental setup, specifically designed to modify the chemical properties of the UFP by removing volatile and semi-volatile organic compounds.

Measurement Setup: The UFP were generated using a miniCAST soot generator under fuel-rich conditions. Immediately after production, the UFP were diluted and passed through a **°Catalytic Stripper** (Model **CS015**, Catalytic Instruments, Germany) operated at different temperatures. The CS, heated to 350°C, effectively removed semi-volatile organic compounds, producing UFP with low organic content (UFP-L). Conversely, operating the CS at room temperature allowed UFP with high organic content (UFP-H) to be generated. A charcoal denuder was subsequently used to remove any remaining gas-phase organics, ensuring the purity of the particle sample before exposure and characterization.

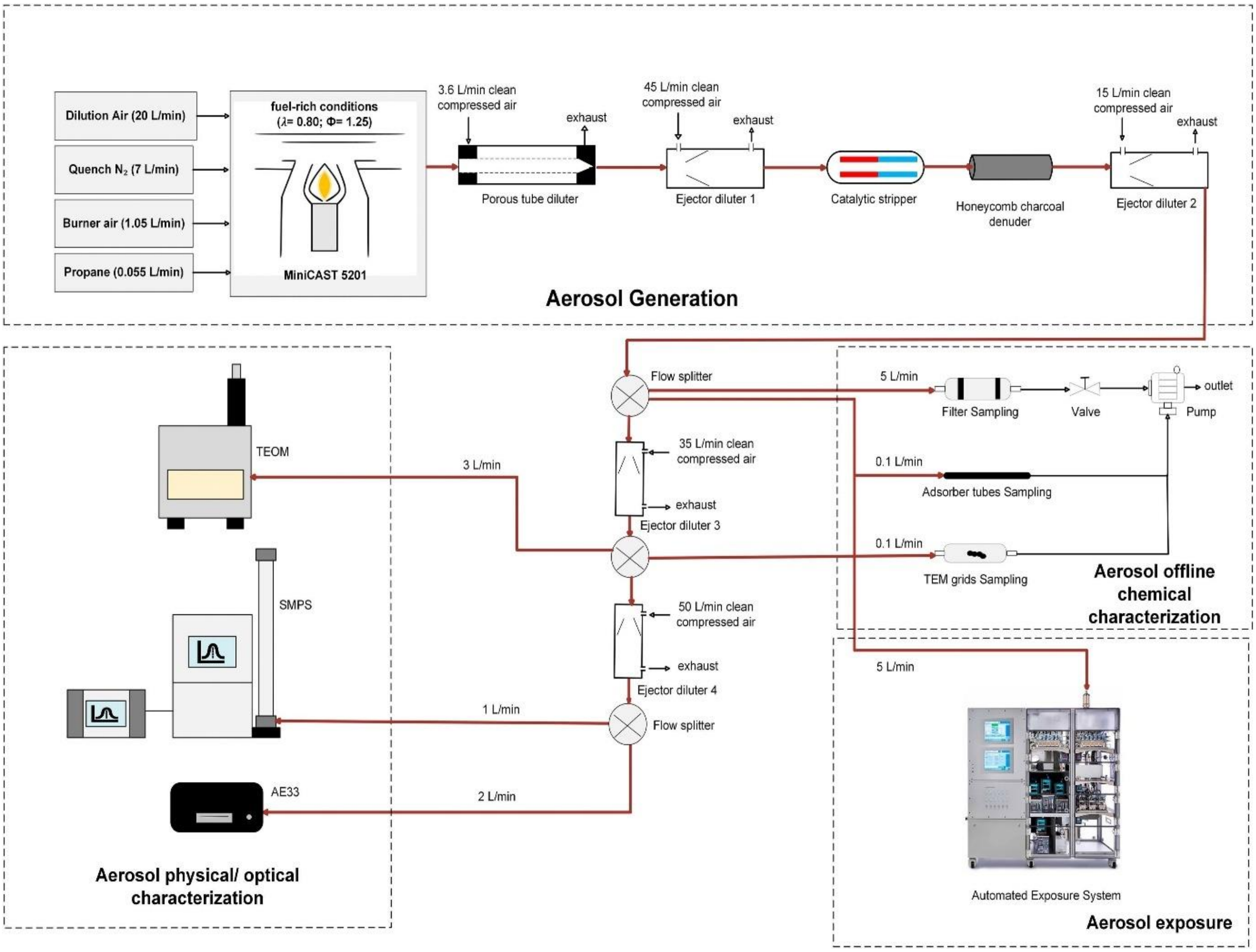


Figure 1 illustrates the detailed experimental setup, highlighting the catalytic stripper's position directly after the miniCAST generator. The figure shows the flow path of the UFP through the CS and other components, such as the denuder and dilution systems, emphasizing the catalytic stripper's role in conditioning the particles for accurate analysis (Das et, al. 2024).

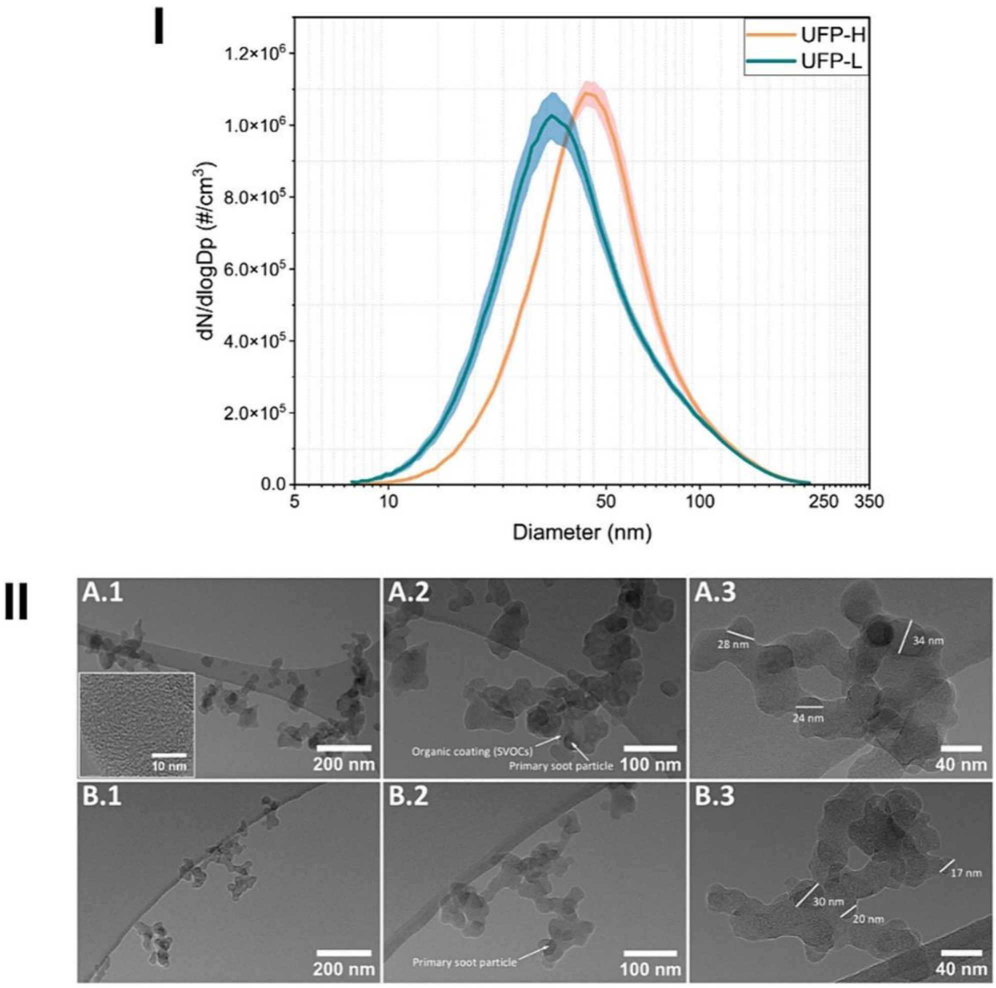


Figure 2 provides Transmission Electron Microscopy (TEM) images comparing the physical structure of UFP-H and UFP-L, demonstrating the effect of the CS on particle morphology. The images show that the CS alters the surface characteristics by stripping organic layers from UFP-L while retaining the soot core structure (Das et, al. 2024).

Key Findings: Both UFP types exhibited similar physical properties but varied significantly in chemical composition due to the CS treatment. The toxicological assessments revealed that UFP with high organic content induced stronger oxidative stress and DNA damage compared to those with low organic content, underscoring the catalytic stripper's role in isolating specific toxicological effects of particle-bound organics.

[1] Das, A., Pantzke, J., Jeong, S., Hartner, E., Zimmermann, E. J., Gawlitta, N., Offer, S., Shukla, D., Huber, A., Rastak, N., Mesčeriakovas, A., Ivleva, N. P., Kuhn, E., Binder, S., Gröger, T., Oeder, S., Delaval, M., Czech, H., Sippula, O., Schnelle-Kreis, J., Di Bucchianico, S., Sklorz, M., & Zimmermann, R. (2024). Generation, characterization, and toxicological assessment of reference ultrafine soot particles with different organic content for inhalation toxicological studies. *Science of the Total Environment, 951*, 175727. https://doi.org/10.1016/j.scitotenv.2024.175727.

Aircraft Turbine Engines

The study by Giannelli et al. (2024) evaluated nonvolatile particulate matter (nvPM) emissions from aircraft turbine engines, incorporating a catalytic stripper as part of the sampling system to ensure accurate characterization of particles by removing volatile and semi-volatile components. The experiments were conducted as part of the **VA**riable **R**esponse **I**n **A**ircraft **n**vPM **T**esting (VARIAnT) campaigns, which assessed the response of various mass analyzers and characterized particles from different combustion sources, including aircraft gas turbines.

Measurement Setup: The experimental setup included a **°Catalytic Stripper** model CS15 operated at 350°C, positioned directly after the sampling probe. This setup ensured that only non-volatile particles were analyzed, which is critical for accurate nvPM mass measurements. The **°Catalytic Stripper** played a crucial role in conditioning the exhaust sample before analysis by instruments such as the Micro-Soot Sensor (MSS) and Laser-Induced Incandescence (LII-300).

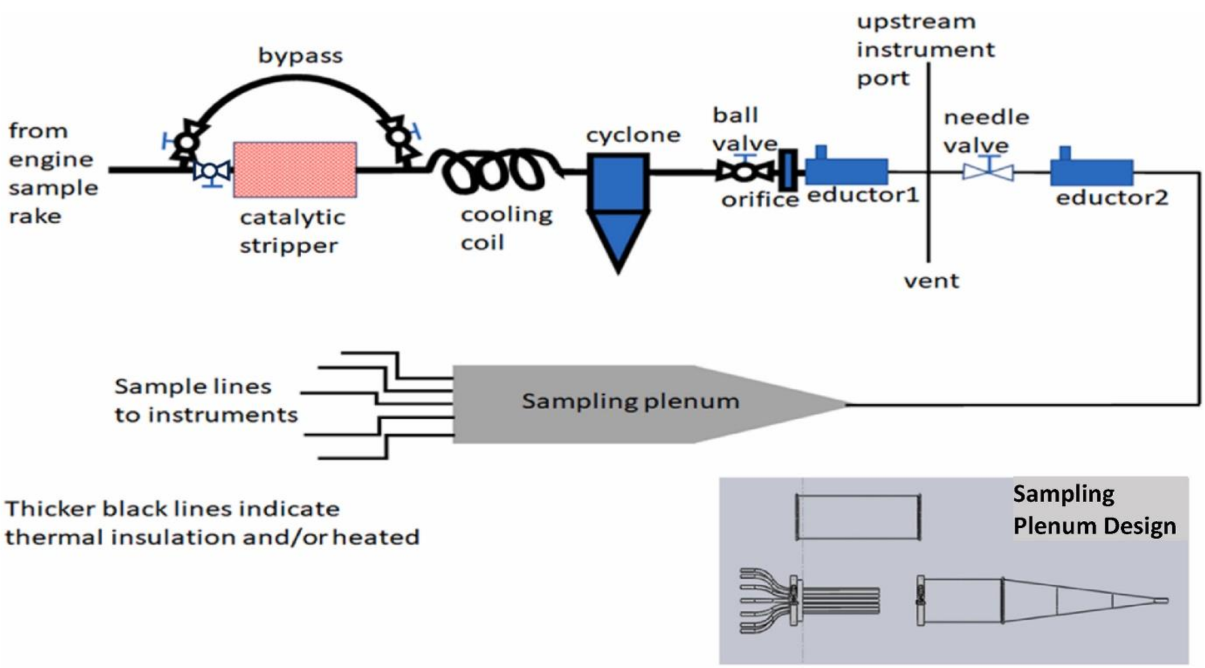


Figure 1 The general sampling and analysis apparatus used in the VARIAnT 3 and 4 campaigns. The catalytic stripper is clearly marked in the setup, showing its role in conditioning the particle-laden exhaust for accurate analysis (Giannelli et al., 2024).

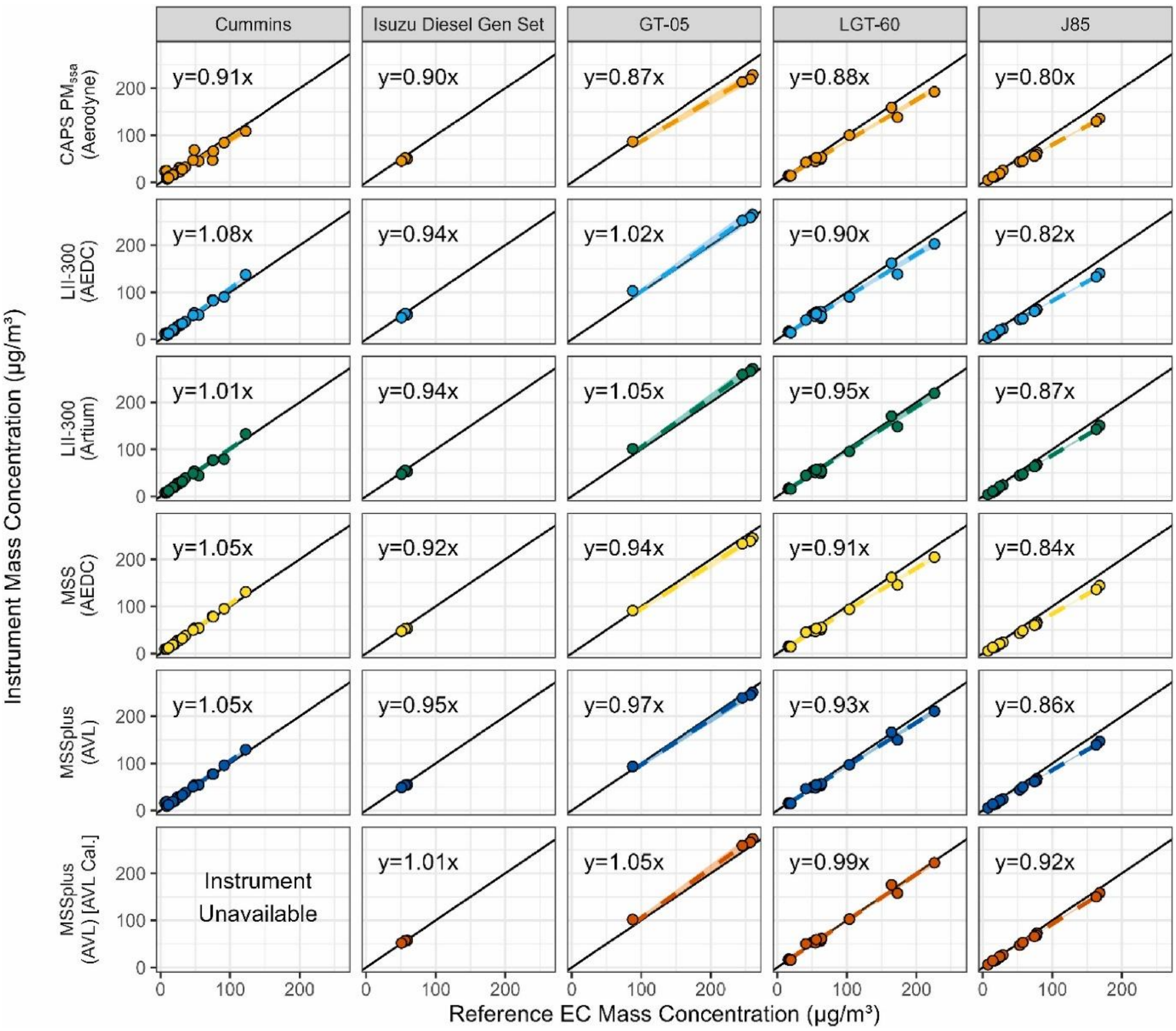


Figure 2 Comparison of nvPM mass measurements with and without the catalytic stripper, demonstrating its impact on the accuracy of readings for the J85 turbojet engine. This figure highlights how the catalytic stripper significantly reduces interference from volatile components, enhancing the reliability of nvPM measurements (Giannelli et al., 2024).

Key Findings: The use of the **°Catalytic Stripper** significantly improved the measurement of nvPM emissions by removing interfering volatile components, allowing for a clearer assessment of the particle emissions specific to the aircraft gas turbine. This approach aids in accurately evaluating the environmental impact of aircraft engine emissions (Giannelli et al., 2024).

Giannelli, R., Stevens, J., Kinsey, J. S., Kittelson, D., Zelenyuk, A., Howard, R., Forde, M., Hoffman, B., Leggett, C., Maeroff, B., Bies, N., Swanson, J., Suski, K., Payne, G., Manin, J., Frazee, R., Onasch, T. B., Freedman, A., Khalek, I., Badshah, H., Preece, D., Premnath, V., & Agnew, S. (2024). Evaluation of methods for characterizing the fine particulate matter emissions from aircraft and other diffusion flame combustion aerosol sources. *Journal of Aerosol Science, 178*, 106352.

Ambient Air Measurement

The study by Lin et al. (2018) investigated the effective density of ambient aerosols in Riverside, CA, using a **°Catalytic Stripper** (CS) to remove volatile components before density measurements. The research aimed to understand how the presence of volatile fractions impacts particle density and morphology, using a DMA-CPMA-CPC setup with and without the CS in operation.

Measurement Setup: The experimental setup involved sampling ambient aerosols and conditioning them through a lab-made catalytic stripper operating at 300°C. The CS was alternately used (CS mode) or bypassed (BP mode) to observe its effect on particle density. The setup included a three-way solenoid valve that switched between BP and CS modes every 10 minutes. Downstream of this setup, a Differential Mobility Analyzer (DMA), a Centrifugal Particle Mass Analyzer (CPMA), and a Condensation Particle Counter (CPC) were employed to measure the effective density of particles at selected diameters (50, 70, 101, and 152 nm).

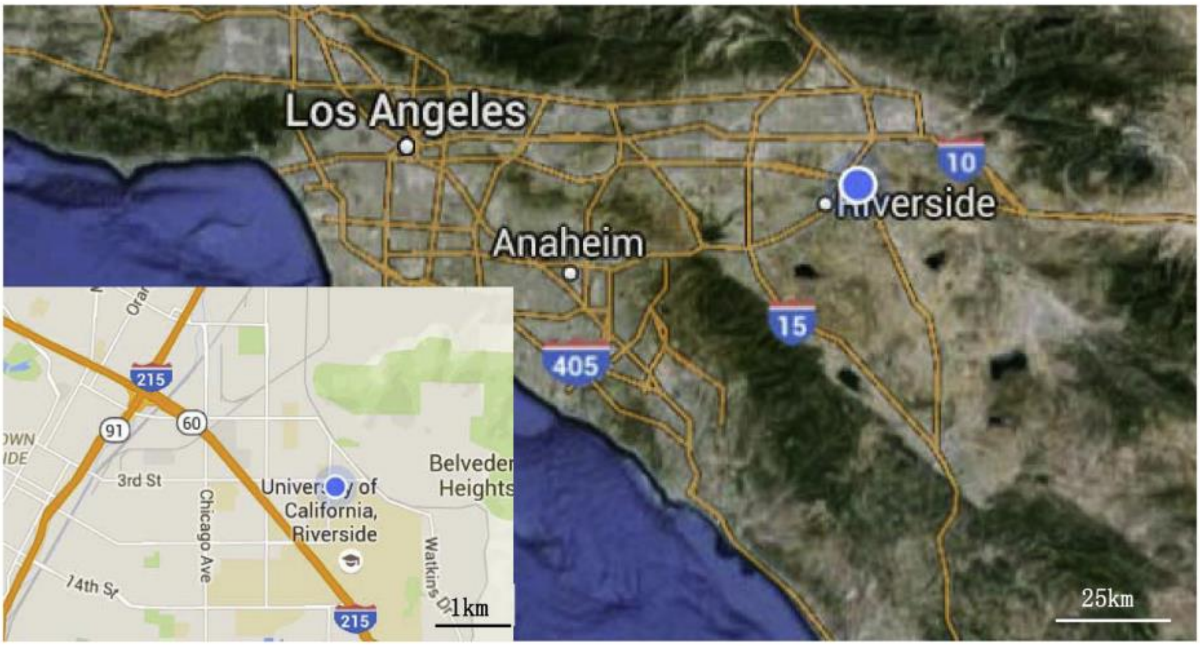
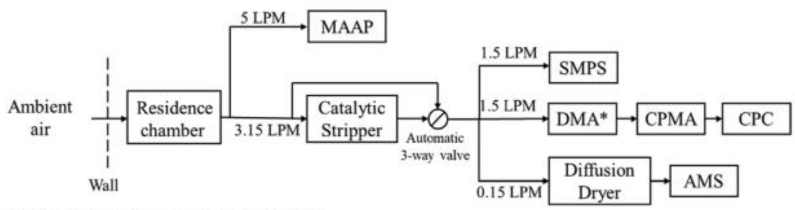


Fig. 1. Map of the sampling site and its distance from the closest highway.



* DMA is operated with sheath flow rate 7.5LPM.

Figure 1 Shows the schematic of the experimental setup, clearly illustrating the placement of the catalytic stripper within the system. The diagram highlights how the CS conditions the particles before they enter the DMA-CPMA-CPC system, ensuring that volatile fractions are removed before density measurements are taken (Lin et al., 2018).

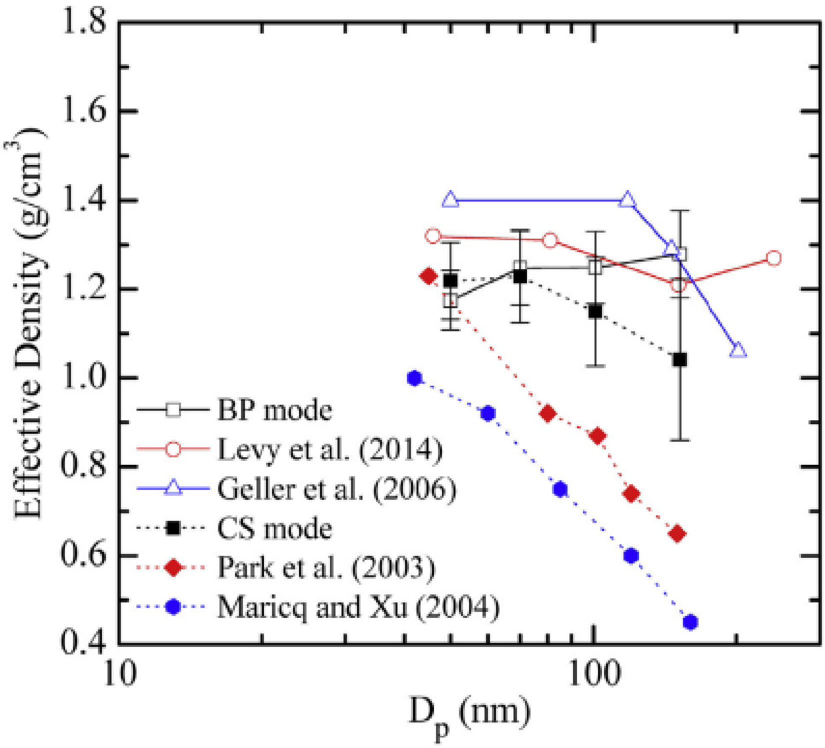


Figure 2 Presents the average effective densities for particles in both BP and CS modes, demonstrating how the catalytic stripper significantly alters the effective density of ambient aerosols. The CS mode consistently shows lower effective densities across all sizes, highlighting the impact of removing volatile compounds (Lin et al., 2018).

Key Findings: The study found that particle effective density decreased when the CS was used, indicating the removal of less dense, volatile components. The CS-treated particles (CS mode) showed more compact and dense characteristics compared to those measured in BP mode, aligning with a mass fractal dimension of 2.85. These findings underline the importance of using catalytic strippers in ambient aerosol studies to obtain accurate measurements of non-volatile particle cores.

Lin, Y., Bahreini, R., Zimmerman, S., Fofie, E. A., Asa-Awuku, A., Park, K., Lee, S. B., Bae, G. N., & Jung, H. S. (2018). Investigation of ambient aerosol effective density with and without using a catalytic stripper. *Atmospheric Environment, 187*, 84-92. https://doi.org/10.1016/j.atmosenv.2018.05.063.

Marine Emissions

The study by Kuittinen et al. (2024) comprehensively characterized the exhaust particles from a modern cruise ship equipped with a scrubber system, assessing particle emissions from marine engines burning heavy fuel oil (HFO) and marine gas oil (MGO). The study highlights the use of a **°Catalytic Stripper** (CS) in the sampling setup to remove volatile and semi-volatile components, providing insights into the non-volatile fraction of marine emissions.

Measurement Setup: The measurements were conducted on two engines of a cruise ship, with sampling performed both upstream and downstream of the scrubber. A **°Catalytic Stripper** was installed upstream of the online aerosol instruments to study non-volatile particles. The CS operated at 350°C and was critical in ensuring that volatile components were removed from the exhaust before particle size distribution (PSD) measurements were taken. This allowed the study to isolate the non-volatile fractions, providing a clearer understanding of the impact of the scrubber system on particle emissions.

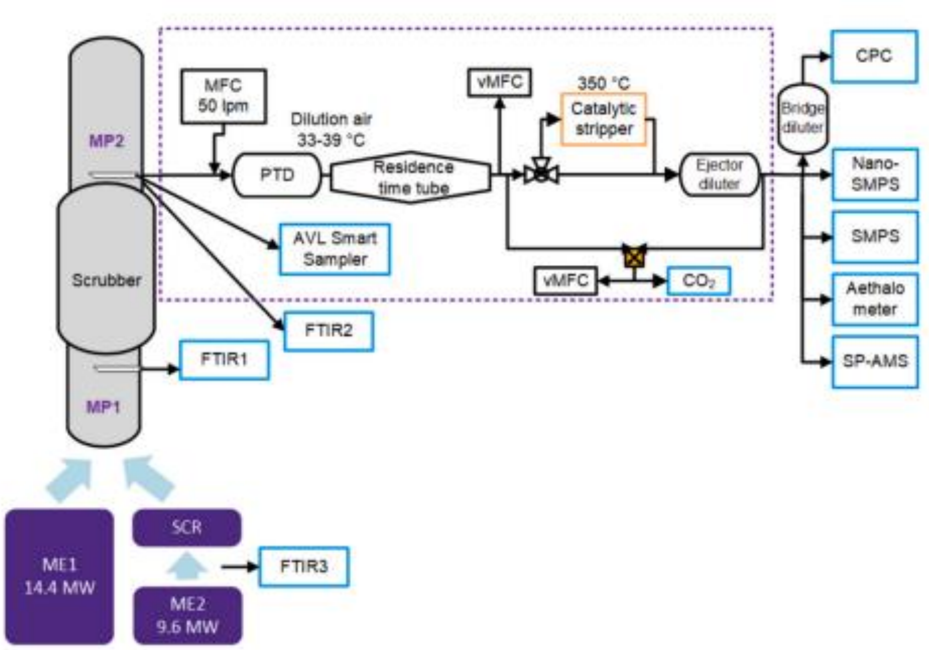


Figure 1 Shows the layout of the instruments, including the positioning of the Catalytic Stripper in the sampling line. This figure highlights the role of the CS in conditioning the exhaust sample before detailed particle analysis (Kuittinen et al., 2024).

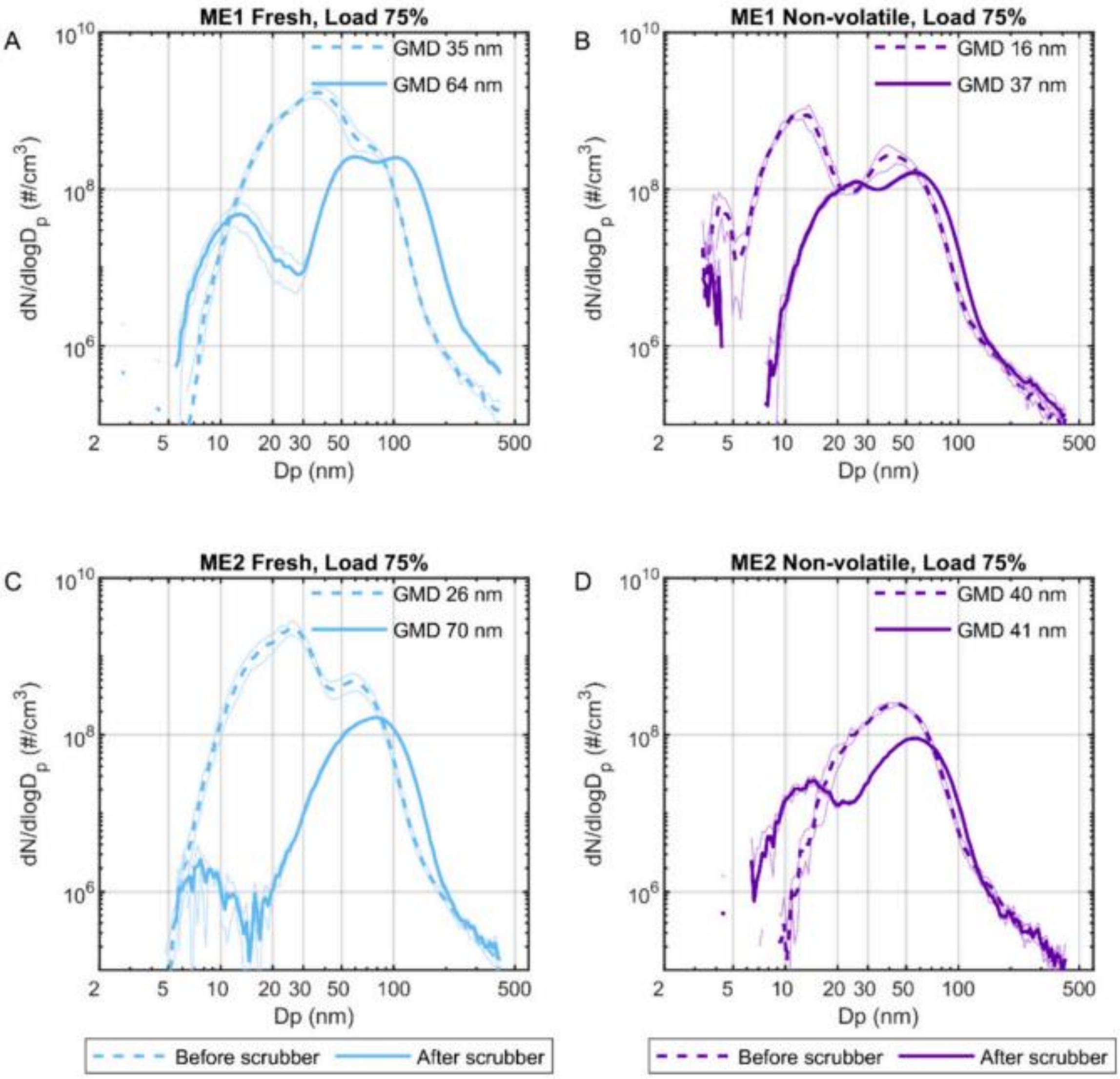


Figure 2 Presents the PSDs of fresh and non-volatile particles before and after the scrubber at 75% engine load. The figure illustrates how the CS effectively removes volatile components, allowing a focused analysis of non-volatile particles, which is critical for understanding the real impact of the scrubber on particle emissions (Kuittinen et al., 2024).

Key Findings: The use of the **°Catalytic Stripper** significantly altered the PSDs by removing smaller volatile particles, highlighting the importance of non-volatile components in marine emissions. The study found that the scrubber effectively reduced fresh particle numbers, particularly in sizes below 20 nm, but had a lesser impact on non-volatile particles above 50 nm, which often include black carbon and metallic compounds from fuel combustion.

Kuittinen, N., Timonen, H., Karjalainen, P., Murtonen, T., Vesala, H., Bloss, M., Honkanen, M., Lehtoranta, K., Aakko-Saksa, P., & Rönkkö, T. (2024). In-depth characterization of exhaust particles performed on-board a modern cruise ship applying a scrubber. *Science of the Total Environment, 946*, 174052. https://doi.org/10.1016/j.scitotenv.2024.174052.

Vehicle Emissions

The study by Duca et al. (2021) investigated the impact of a **°Catalytic Stripper** (CS) on the chemical composition of nanoparticles emitted from a gasoline direct injection (GDI) engine. The research combined laser desorption/ionization mass spectrometry with advanced statistical techniques to explore how the CS affects the chemical characteristics of size-selected particles, particularly ultrafine particles (UFPs) in the 10–560 nm range.

Measurement Setup: The experimental setup featured a single-cylinder GDI engine, with exhaust sampling directly after the manifold. The exhaust was diluted using a Dekati FPS 4000 system before entering the CS. Two catalytic strippers were used: CS1, a Catalytic Instruments CS-015 operating at 350°C, and CS2, a custom-built version designed to handle higher flow rates. The CS was critical in removing volatile organic compounds from the exhaust particles, allowing for a more precise analysis of non-volatile fractions.

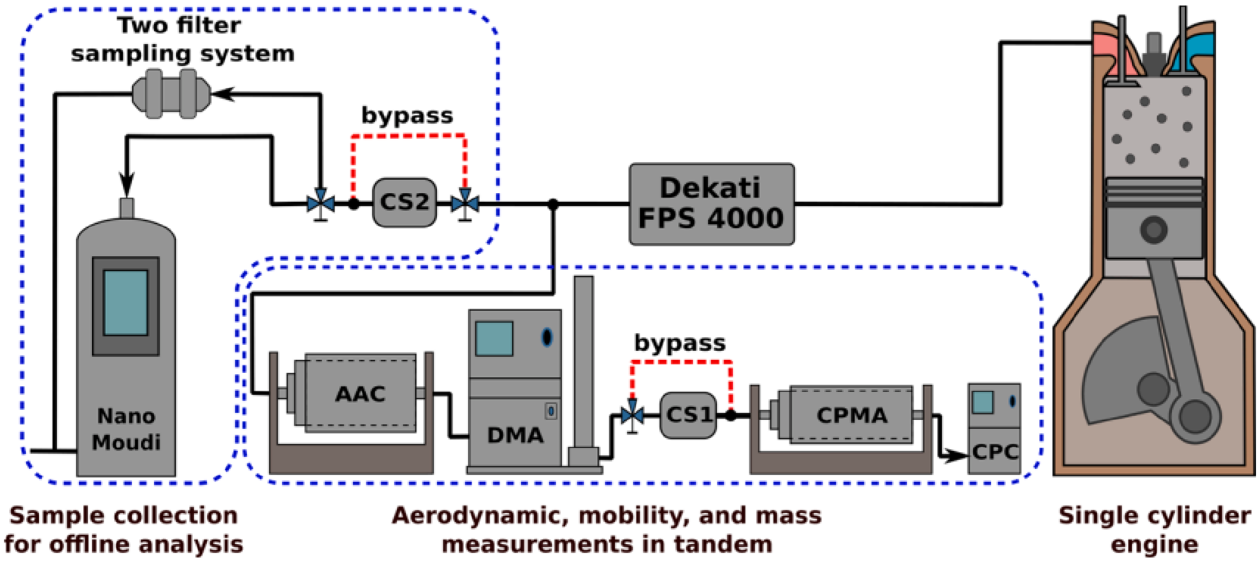


Figure 1 Illustrates the detailed sampling setup, including the placement of the catalytic stripper before particle measurement instruments. The figure shows how the CS is integrated into the system, emphasizing its role in conditioning particles before they are analyzed for chemical composition (Duca et al., 2021).

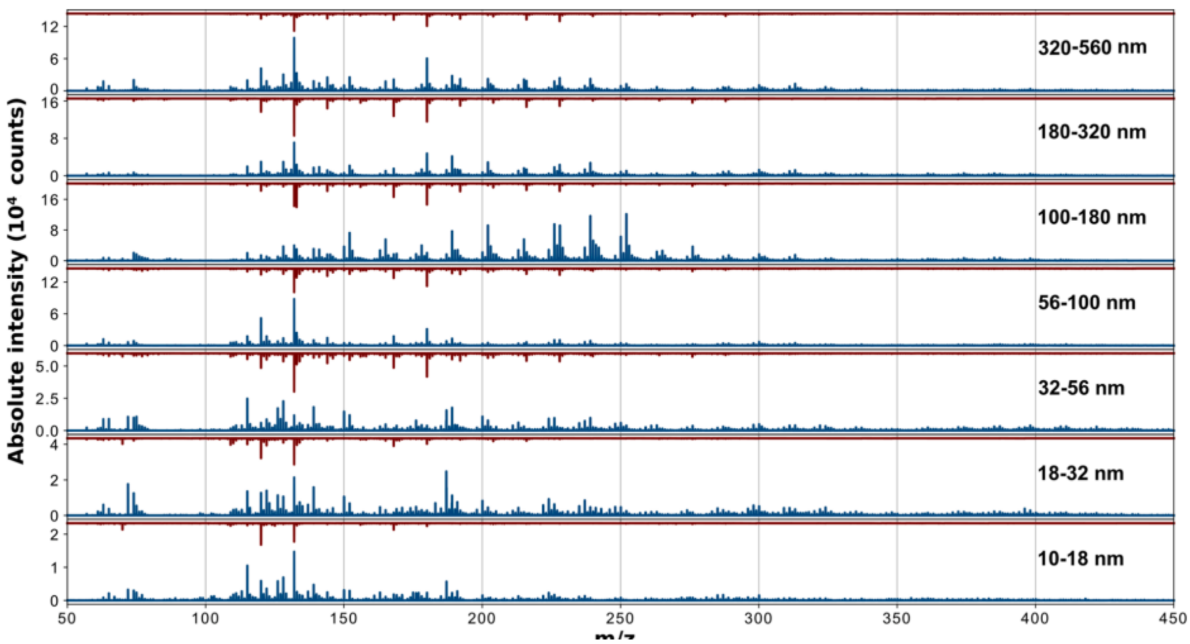


Figure 2 Displays mass spectra of size-selected particles collected with and without the catalytic stripper. This figure highlights the significant reduction of organic compounds when the CS is used, particularly in smaller particle sizes, showing how the CS effectively removes volatile surface fractions (Duca et al., 2021).

Figure 2 displays the mass spectra of size-selected particles produced in the high-speed (HS) engine regime, sampled with (red line) and without (blue line) the catalytic stripper (CS) across various particle size bins ranging from 10 nm to 560 nm (Duca et al. (2021)).

- **Blue Line (Without CS)**: The blue line represents the mass spectra of particles collected without the CS. These spectra show a high contribution of heavy-mass polycyclic aromatic hydrocarbons (PAHs) and other organic compounds, particularly in larger particles. These peaks are associated with unburnt fuel residues or lubricating oil, indicating a high organic carbon content, especially in smaller particles (10–32 nm), which carry a larger volatile fraction.
- **Red Line (With CS)**: The red line shows the mass spectra of particles after passing through the CS. The spectra display a noticeable reduction in the intensity of the organic peaks, with a significant increase in the contribution of carbon clusters (C^+_n), highlighting a much lower organic carbon to elemental carbon (OC/EC) ratio. This change is most evident in the smallest particles (10–32 nm), where the CS has effectively removed nearly all organic content, leaving primarily elemental carbon.

This figure highlights the efficacy of the **°Catalytic Stripper** in removing volatile and semi-volatile organic compounds, especially in ultrafine particles, which are most susceptible to carrying high amounts of organic matter. It emphasizes how the chemical composition of exhaust particles is significantly altered by the CS, allowing for a more accurate assessment of the non-volatile fraction crucial for understanding the health impacts of ultrafine particles.

Key Findings: The **°Catalytic Stripper** played a pivotal role in reducing the organic carbon content of particles, particularly those smaller than 100 nm, which tend to carry a larger volatile fraction. The study demonstrated that particles treated with the CS exhibited a higher elemental carbon content, indicating the removal of the surface organic layer. This result is critical for understanding the health impacts of UFPs, as it isolates the effects of solid particles devoid of volatile organics.

Duca, D., Rahman, M., Carpentier, Y., Pirim, C., & Boies, A. (2021). Chemical characterization of size-selected nanoparticles emitted by a gasoline direct injection engine: Impact of a catalytic stripper. *Fuel, 294*, 120317. https://doi.org/10.1016/j.fuel.2021.120317.

Please contact us with your questions regarding how the **°Catalytic Stripper** can be used to enhance Health Impact Assessments.

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