Combustion-generated particles detection with a multi-wavelength UV photoelectric charging setup

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INTRODUCTION

Vehicles powered by direct injection engines, both diesel and gasoline, are considered a significant source of ambient particle-related pollution[1]. Particles generated by internal combustion engines mainly consist of black carbon, metals, inorganic oxides, and condensed volatiles that, among other compounds, contain poly-aromatic hydrocarbons, PAHs. From a public health perspective, some PAHs have been listed by the International Association for Research on Cancer as definitely carcinogenic. In this study, we present **a new aerosol detection instrument, the multi-wavelength UV PhotoElectric Charger (UV-PEC) that facilitates the on-line detection of PAH content of ultrafine particles.** The principle of operation is based on the photoelectric effect: when an aerosol is irradiated with UV-light of energy below the ionization threshold of the carrier gas but above the photoelectric threshold of particle surface species, photoelectrons are emitted from the particles which then acquire a positive charge[2]. It is well-established that PAHs generate a high photoelectric yield compared to other particle components in ambient air, permitting the selective charging of particles that consist of or carry residuals of incomplete combustion[3].

UV-PEC & EXPERIMENTAL SETUP

UV-PEC consists of a precipitator that removes the naturally charged particles, a UV light source (deuterium lamp), an ionization chamber, and an ion trap that removes the photoemitted electrons. The UV light beam has tunable wavelength (206, 214, 228, 239, and 250 nm) which is modified by using bandpass filters placed at a filter wheel. Downstream the UV-PEC, an electrometer measures the charged particles number concentration, C_{ch}, while a CPC measures the total, C_{tot}. The charging efficiency is defined as,

$$Charging\ Efficiency = \frac{C_{ch}}{C_{tot}}$$

In parallel, an SMPS that operates with and without a neutralizer, measures the charging efficiency. At diesel engine measurements the effect of a catalytic stripper[4] is also studied. Figure 1 presents the experimental setup.

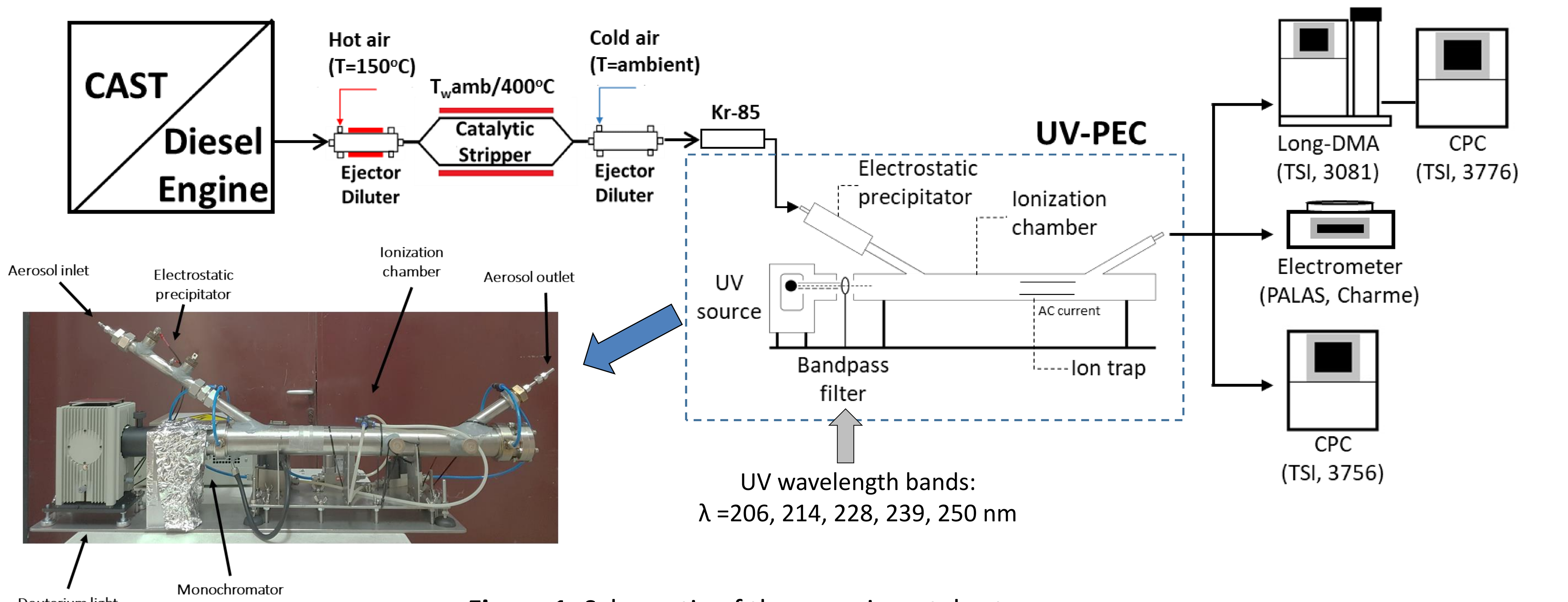

Figure 1. Schematic of the experimental setup.

RESULTS

CAST generator

The UV-PEC was initially employed to characterise CAST-generated particles. CAST produces soot particles with stable and repeatable size distribution. We used 3 CAST set points (SPx): SP80, SP40, and SP20, the suffix x indicating the mean mobility diameter. Figure 2 presents the charging efficiency at different light wavelengths, λ (Fig. 2a) and the CAST-generated particle size distributions compared to the size distributions measured downstream the UV-PEC at λ=206 nm (Fig. 2b). We note that charging efficiency is larger at λ=206 nm and decreases as λ increases. Moreover, larger particles (SP80) are charged more efficiently due to their larger active surface area[5]. However, all particles are charged showing that they carry products of incomplete combustion.

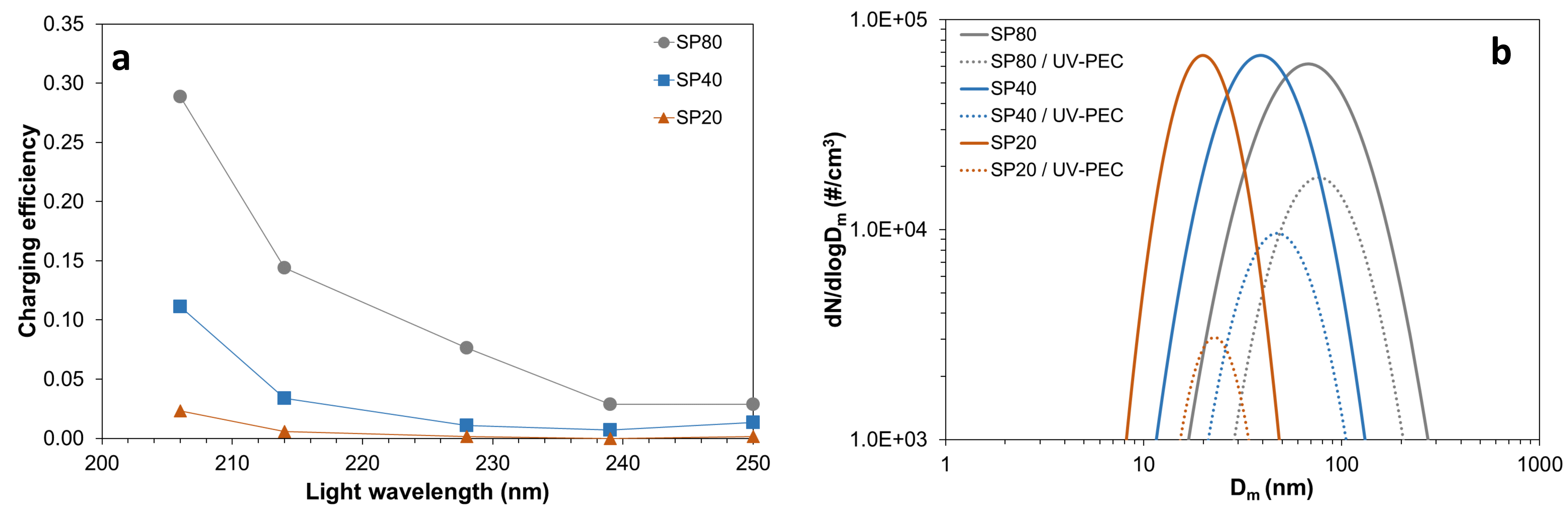

Figure 2. a) The charging efficiency of CAST-generated particles against the light wavelength, b) the particle size distribution of CAST-generated particles and the particle size distribution measured with UV-PEC (λ=206 nm).

Diesel engine

We used a single cylinder, four-stroke, 5kW, air-cooled direct injection diesel engine that operated at 27% of maximum load. Table 1 presents the three different fuel modifications that were tested.

Table 1. The modified fuels that were used to test the UV-PEC with diesel engine's exhaust .

FUEL A	FUEL B	FUEL C
Low sulphur Diesel	Fuel A + 30 ml/L of a Ce-based fuel additive	Fuel; A + 60 ml/L of lubrication oil

Figure 3 presents the results of tests performed with fuels A & B while Figure 4 with fuels A & C. Figures 3a and 4a show that the (excessive) addition of catalytic fuel additive or common lubrication oil to the fuel decreased the charging efficiency and, thus, the total PAH content. Moreover, the catalytic stripper increased the charging efficiency possibly due to the removal of a film of volatile material that was covering the exhaust particles.

Figures 3b and 4b plot the particle size distribution for the 3 fuels when catalytic stripper was used. For fuel A we observe a monomodal size distribution typically produced by diesel engines. UV-PEC charged all the particles without any size selectivity. With fuels B & C a second peak appeared at small sizes. These nucleation particles were not charged by UV-PEC showing that they probably did not originate from incomplete combustion but from metals contained in the fuel additive and lubrication oil, respectively.

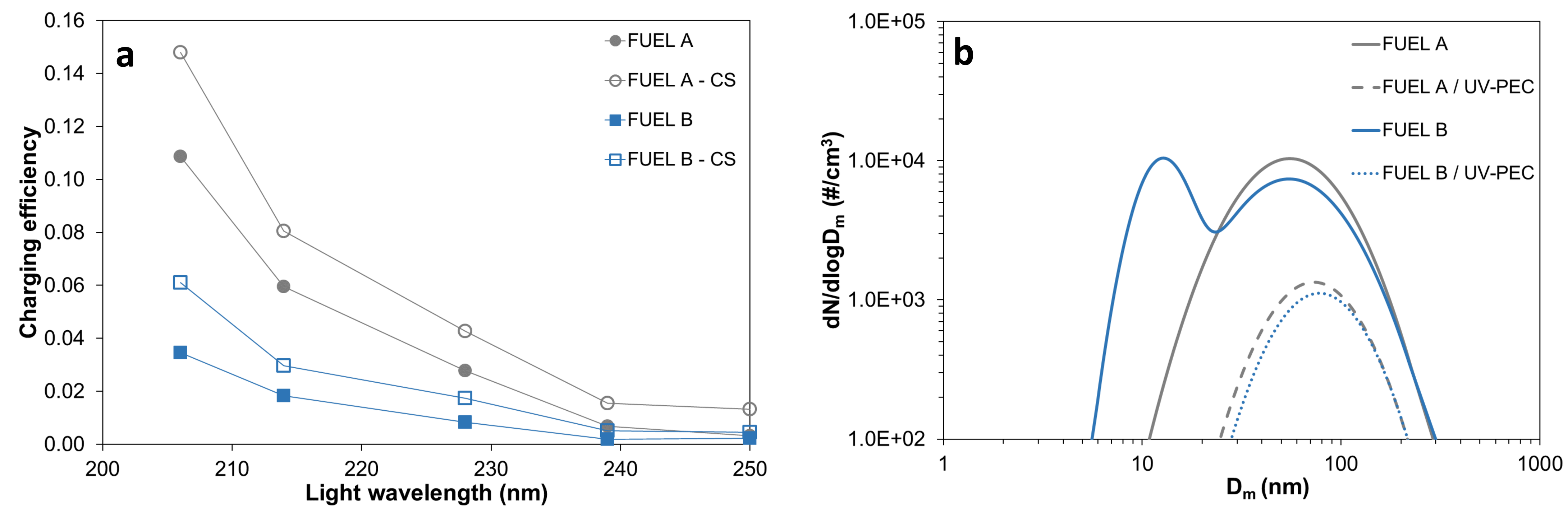

Figure 3. a) The charging efficiency of diesel engine exhaust particles (fuels A & B) against the light wavelength, b) the emitted particle size distribution and the particle size distribution measured with UV-PEC (λ=206 nm).

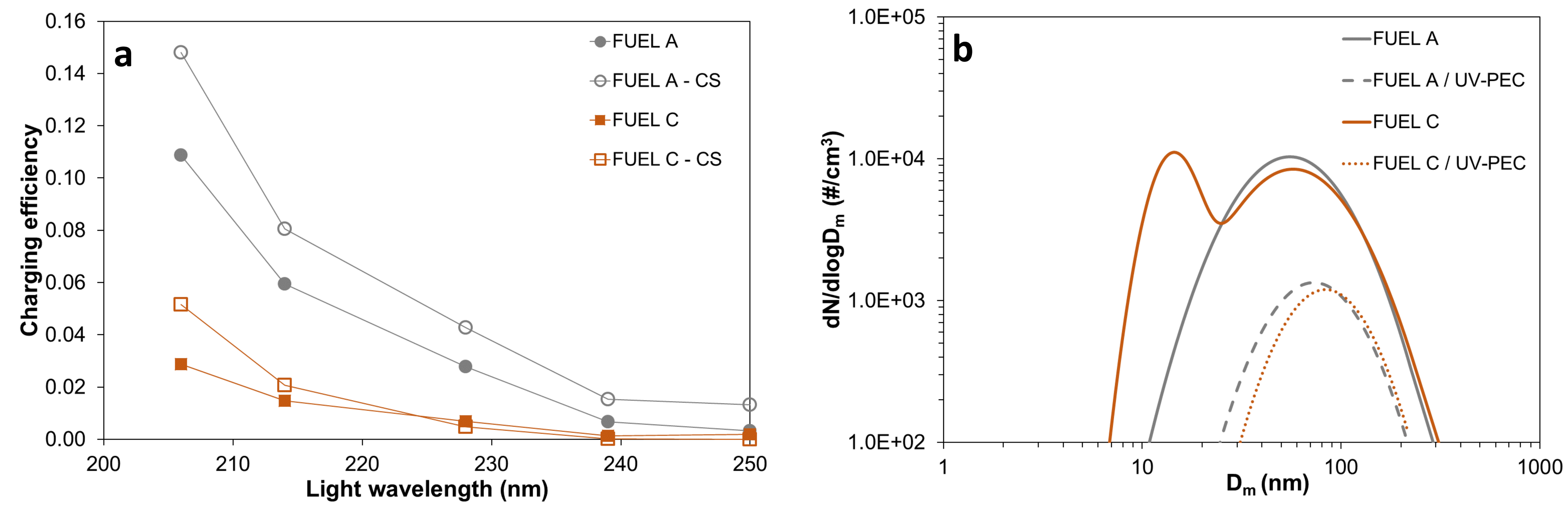

Figure 4. a) The charging efficiency of diesel engine exhaust particles (fuels A & C) against UV light wavelength, b) the emitted particle size distribution and the particle size distribution measured with UV-PEC (λ=206 nm).

CONCLUSIONS

- UV-PEC managed to charge CAST-generated and diesel engine exhaust particles with efficiency up to 30%.
- The higher charging efficiency was observed at light wavelength 206 nm.
- The use of a catalytic stripper increased the charging efficiency of diesel exhaust particles possibly due to the removal of volatile material attached on their surface.
- Nucleation mode particles emitted by a diesel engine with fuel additive or lubrication oil do not necessarily consist of or carry PAHs.

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