Real-Time Analysis of Particle Size Distribution of ENDS Aerosol at End-of-Liquid Stage Using an Electrical Low-Pressure Impactor

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Background

The particle size distribution (PSD) of aerosol generated from electronic nicotine delivery systems (ENDS) is an important physical parameter that can be used to understand the effects of ENDS Product use on human health, especially those effects related to respiratory illnesses.[1]

Particle sizing techniques for tobacco products, including ENDS, rely on spectral extinction, optical techniques, or cascade impactors, which are time-consuming, prone to sample loss, and lack puff-by-puff resolution.[2-3]

Number and mass concentrations of particles in aerosol are difficult to determine using traditional PSD measurement techniques, but are relevant to understanding deposition patterns of particles in human respiratory systems.[4]

This study presents an online technique for PSD analysis to calculate mass median aerodynamic diameter (MMAD), mass concentrations, and number concentrations of particles in aerosol emitted from various ENDS Products with puff-by-puff resolution as the e-liquid pod approaches the end-of-liquid stage, indicated by the ENDS Product emptying or experiencing dry puff.

Methods

Size and Number Profiling

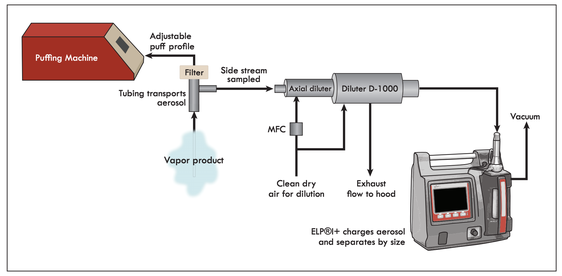


Figure 1. An electrical low-pressure impactor (ELPI®+) was used to analyze aerosol emitted from an ENDS Product. A smoking machine activated the ENDS Product to produce aerosol (55 mL of aerosol drawn over 3 s with 30 s in-between puffs). The aerosol was diluted through a two-stage dilution system with a dilution factor of 790:1 or 1060:1. The diluted aerosol then entered the ELPI®+, which charged the aerosol and separated the particles by size using 14 impactor stages (14 µm - 6 nm).

Quantify PSD with Puff-by-Puff Resolution

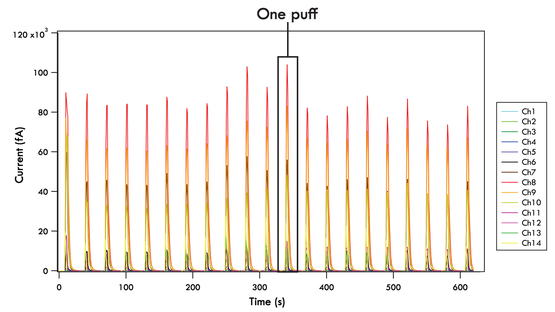
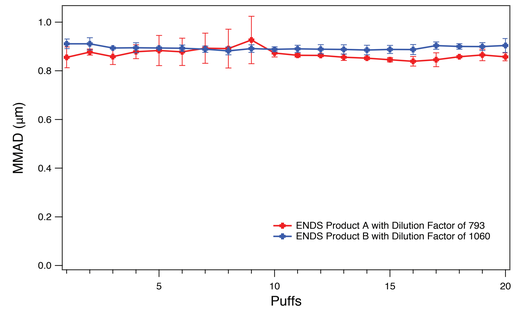


Figure 2. Each measurement represents the electric current generated when charged particles impact a collector stage. The total current measured across all 14 impactor stages is proportional to the MMAD of the aerosol. By incorporating the dilution factor, these currents are transformed into number and mass concentrations of the particles in the aerosol generated from the ENDS Product with puff-by-puff resolution. For this study, three replicate measurements were made for each of the four ENDS Products tested.

Method Validation and Effect of Dilution on Particle Size



ENDS Product A and B (55/3/30 Puff Profile)	Mini-MOUDI MMAD (µm) | Device Mass Loss (mg)	ELPI®+ MMAD (µm) | Device Mass Loss (mg)
ENDS Product A Puffs 1-5	0.86|3.4	0.85|3.5
ENDS Product A Puffs 16-20	0.82|1.9	0.84|1.8
ENDS Product B Puffs1-5	1.00|2.8	1.05|3.1
ENDS Product B Puffs16-20	0.97|1.7	0.91|1.6

Figure 3. ENDS Products A and B were puffed for 20 puffs with a dilution factor of 793 and 1060. The percent difference in MMAD between puffs analyzed at both factors ranged from 1.1-5.8%. The same pod and device was analyzed for PSD using both the ELPI®+ and a Mini-MOUDI cascade impactor. Similar MMADs and device mass loss values were obtained from both techniques.

Results

End-of-Liquid Performance

MMAD

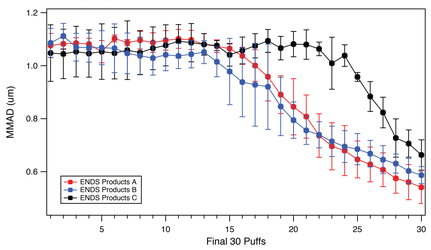


Figure 4. 3 ENDS Products (A, B, C) from different vendors were puffed until the e-liquid pod was empty (n=3, bars represent standard deviations). During the final 15 puffs of ENDS Products A and B, there was a 40-50% decrease in MMAD of the particles. A decrease in MMAD was only observed in the final 5 puffs of ENDS Product C.

Number Concentration

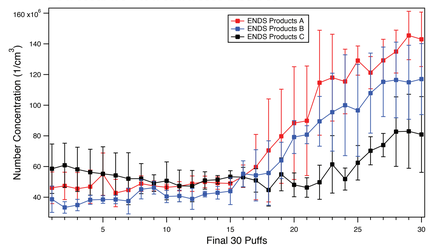


Figure 5. During the final 15 puffs of ENDS Products A and B, before the e-liquid pod emptied, there was a 150-300% increase in number concentration of particles in the aerosol. The number concentration increased by 50% during the final 5 puffs of ENDS Product C.

Mass Concentration

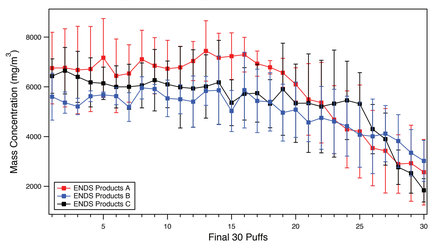


Figure 6. ENDS Products A and B experienced a 40-60% decrease in mass concentration of particles in the aerosol during the final 15 puffs. A comparable decrease was observed in ENDS Product C during the final 5 puffs. As less e-liquid becomes readily available in a pod, the mass concentration of particles in the aerosol decreases.

Aerosol Characteristics Over Sustained Puffing

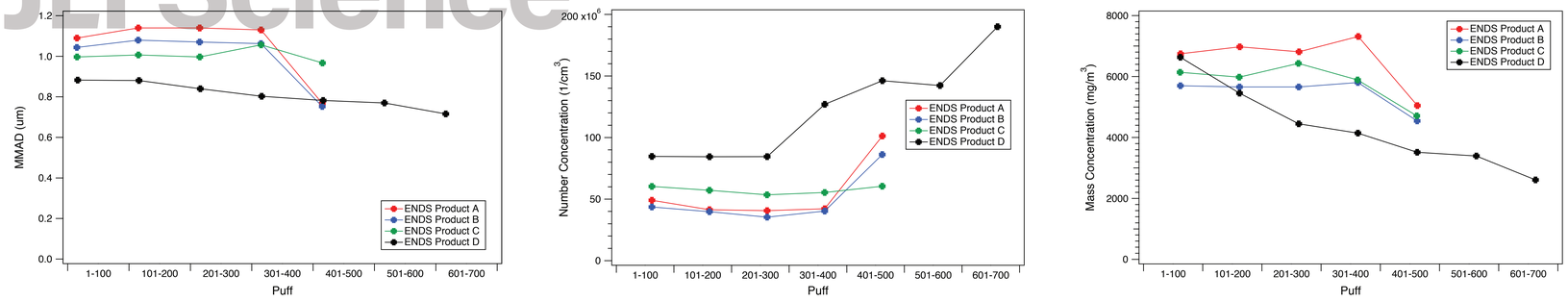


Figure 7. A comparison of average MMAD, number concentration, and mass concentration of aerosol emitted from different ENDS Products across 100 puff blocks. Note that for ENDS Products A, B, and C, the e-liquid volume reached zero between puffs 400-500 and the data points represent the average values from the 15 puffs of the end of liquid stages illustrated in Figures 1-3. The end-of-liquid stage was not verified in ENDS Product D, but the MMAD and mass concentration of the aerosol from ENDS Product D decreased as the puffs increased, while the number concentration of the aerosol increased

Conclusions

We have shown the first particle characterization experiments using an online particle sizer for real time puff-by-puff analysis of ENDS aerosol.

An online method of particle sizing has the potential to be an improvement compared to current measurement techniques with respect to time resolution and variabilities in MMAD, number concentration, and mass concentration of particles within a puff.

An increase in particle number concentration is observed concurrently with a decrease in MMAD and particle mass concentration in aerosol produced by ENDS Products without temperature regulation compared to those produced by a device with temperature regulation as the end of liquid pod stage is reached.

This method can help us understand performances and provide characterizations of different ENDS Products with a real-time quantitative approach.

References

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4. Pichelstorfer, L., Hofmann, W., Winkler-Heil, R., Yurteri, C. U., McAughey, J., 2016. Simulation of aerosol dynamics and deposition of combustible and vapor product aerosols in the human respiratory tract. Journal of Aerosol Science. 99, 125–132.