Real-time Assessment of Aerosol Size Distributions from Vaping Products and Vitamin E Acetate Formulations

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Abstract

Background: Recently, vitamin E acetate (VEA) was identified as the chemical that associated with the vaping-related lung injury. The size distribution of inhaled vaping aerosols, containing these chemicals, correlates to lung deposition with smaller particles penetrating deeper into the lung. In support of the root cause analysis of the severe respiratory illnesses associated with vaping, there is a need to develop methods for real time, high resolution particle size distribution analysis on the vaping products.
Goal: Here, we intend to develop real-time, high resolution methods to investigate particle size distribution and concentration of aerosols produced by vaping products and aerosolized vitamin E acetate formulations.
Method: A sampling system was setup to trigger the vaping products under negative pressure for a single puff for real time measurements. The generated aerosol was drawn into the customized mixing chamber (~6 L) by a time-controlled vacuum pump. The size-resolved scanning mobility particle sizer (SMPS) and size- and time- resolved aerodynamic particle sizer (APS) were used to evaluate the size distribution of the aerosol produced by three vaping products recently acquired from the marketplace and from refillable cartridges loaded with Vitamin E Acetate formulations in different concentrations (20%, 40%, 80%, and 100%).
Results: Among the three vaping products tested, product B had the lowest particle number (9.4x10^5 #/cm^3) and mass concentration; product C had the highest aerosol mass concentration (28.1 mg/m^3), which was around 3 times that of product B. Although the concentrations vary, both number- and mass- based fractions of small particles (<1 um and <5 um) in the three products are more than 64%, which indicates that the particle lung depositions of the vaping products are a large fraction of each puff inhaled. For the aerosol from the Vitamin E acetate (VEA) formulations, in general, higher VEA concentration led to more aerosol mass concentration and potential lung deposition.
Conclusion: The methods developed in this study provided fast particle size distribution evaluation of inhaled aerosols in a wide size range, and valuable tools for the assessment of inhaled aerosols from vaping products that can cause adverse effects or injuries in the lung.

Introduction

An outbreak of severe respiratory lung injury occurred and was associated with the use of vaping products, or e-cigarettes, that has possibly sickened over 800 people from 46 states and 1 U.S. Territory. Twelve deaths have been confirmed in 10 states (As of September 24, 2020, data from CDC). These illnesses did not appear to be due to infectious diseases but rather appeared to be associated with a chemical exposure from vaping products. A broad range of chemicals, including nicotine, THC and other cannabinoids along with cutting agents/diluents and other additives existed in the vaping products in question.
Findings from CDC confirmed vitamin E acetate was detected at the primary site of injury within the lung and was a potential toxin of concern. Previous research also suggested when vitamin E acetate is inhaled, it may interfere with normal lung functioning. For the root cause analysis of the severe respiratory illnesses associated with vaping, we performed chemical particle size distribution studies on the vaping products available on the market.

Due to the fast evaporation feature of the vaping aerosols, it is critical to conduct real time particle size measurement in order to approximate dosing for aerosol inhaled from vaping products. A variety of particle sizing techniques were evaluated for the aerosol produced by vaping products recently acquired from the marketplace. Most suitable techniques should provide real time aerodynamic particle size distribution, and preferably time-resolved size and concentration of vaping puffs to study the rapid changes of the vaping aerosols. Scanning mobility particle sizer (SMPS) and aerodynamic particle sizer (APS) are the selected particle sizing instruments currently available in OTR.

Materials and Methods

Commercial vaping products
- Product A (2.4% nicotine), B (5% nicotine) and C (5% nicotine)

VEA formulations
- Refillable cartridges loaded with VEA Formulations in different concentrations (20%/40%/80% in Tween 80 and 100%)

Aerosol sampling
- The generated aerosol was drawn into the customized mixing chamber (~6 L) by a time-controlled vacuum pump.

Aerosol generation
- Vaping products were triggered under negative pressure for a single puff for real time measurements.

Aerosol analysis
- Size-resolved scanning mobility particle sizer (SMPS) and size- and time- resolved aerodynamic particle sizer (APS) were used to evaluate the size distribution of the aerosols.

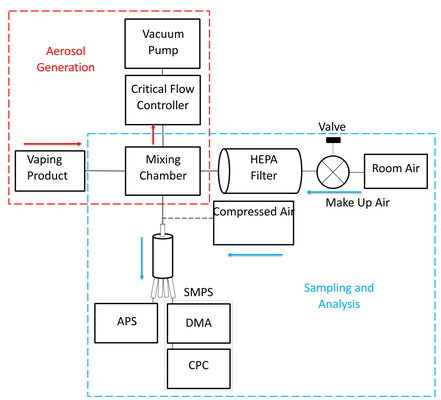

Figure 1. System of aerosol generation (red dotted box) and sampling and analysis (blue dotted box). The compressed air was only used for the test of the vaping products.

Results and Discussion

Average Size and Concentration for Vaping Products

- There vaping devices generated aerosols smaller than 190 nm (mode size: product B<A<C, Fig.2a). Such aerosols can penetrate the deepest region of the lung.
- High levels of respirable particle fraction (more than 99% of all particle counts, or 78-89% of total particle mass are less than 5 µm, Table 1) and high particle concentration in submicron range (up to 7.2×10^8/cm^3 after the dilution ratio compensation, Fig. 3).

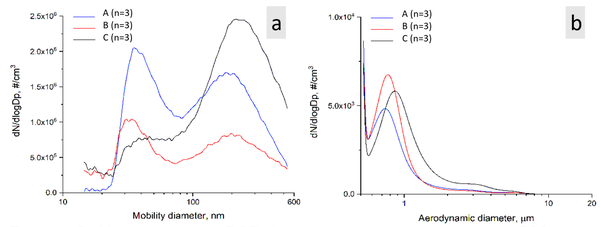

Figure. 2. Number-based PSD (a) in the submicron range (< 530 nm, by SMPS), and (b) in the range of 0.5 and 20 µm (by APS).

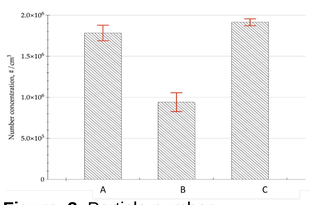

Figure. 3. Particle number concentrations of three vaping products.

Table 1. Aerosol characterization of three vaping products.

Product	A	B	C
Total conc.(mg/m^3)	13.46	9.85	28.13
Median diameter (nm)	105.3	97.1	184.1
Mass fraction <1 µm (%)	74.2%	64.3%	74.0%
Mass fraction <5 µm (%)	86.0%	77.8%	88.5%

Average Size and Concentration for Vitamin E Acetate in Different Concentrations

- The concentrations of vitamin E acetate in the liquid mixture were positively correlated with the aerosol median diameter (Fig. 5) and mass concentration, and negatively correlated with the total aerosol number concentrations (Fig. 6).

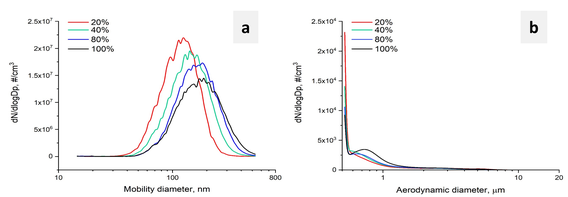

Figure. 4. Number-based PSD (a) in the submicron range (< 530 nm, by SMPS), and (b) in the range of 0.5 and 20 µm (by APS).

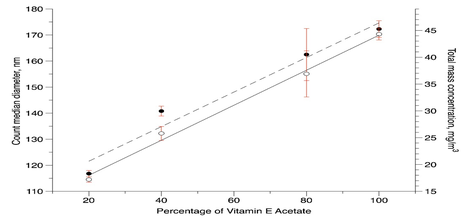

Fig. 5. Average diameter and total mass concentration versus percentage of VEA.

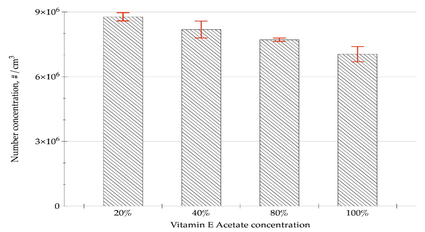

Fig. 6. Particle number concentrations of three vaping products.

Conclusion

- The methods developed in this study provided fast particle size distribution evaluation of inhaled aerosols in a wide size range.
- Among the three vaping products, product B has the lowest particle number and mass concentration; product C has the highest aerosol mass concentration (28.1 mg/m^3), which is around 3 times that of product B.
- Although the concentrations vary greatly, both number- and mass-based fractions (<1 µm and <5 µm) are both more than 64%, which indicates that the particle lung depositions of the vaping products may be high if inhaled.
- For the aerosol from the Vitamin E acetate (VEA, non-vaping products), the percentage of VEA content influenced the aerosol PSD. In general, more VEA lead to more aerosol mass concentration and potential lung deposition rate.
- The real-time, high resolution method developed in this study can be used as valuable tools for the assessment of inhaled aerosols from vaping products that can cause adverse effects or injuries in the lung.

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