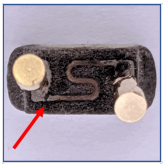

Apr 18, 2021

Measure Effects of Manufacturing Variations of ENDS on coil Lifetime and Aerosol Generation

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1 Works for me dx.doi.org/10.17504/protocols.io.brbvm2n6

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ABSTRACT

Manufacturing variations in coil resistance, initial pod mass, and e-liquid color could have effects on the performance of electronic nicotine delivery system (ENDS). Specifically, these variations could affect coil lifetime, total particular mater yield, and e-liquid consumption rate. This protocol is a step by step explanation of the test procedure used to assess these effects. The steps describe the preparation of test specimens, making measurements, and running puffing sessions on the device under test. While this protocol was used for Vuse ALTO ENDS, it was written in a way to make it as generic as possible so that it can be applied to other brands and types of ENDS. This protocol was successfully used in bigger research project. The article which this protocol is associated with will be added to the Metadata once it is published.

DOI

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PROTOCOL CITATION

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KEYWORDS

Electronic Cigarette, Coil resistance, Coil Lifetime, TPM, Manufacturing Variation

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PROTOCOL INTEGER ID

46165

GUIDELINES

General capabilities:

- Familiar with handling electronic tobacco product for research purposes.
- Trained to work in the lab and dealing with sensitive equipment.
- Familiar with using Digital multi-meter (DMM) to make voltage, current, and resistance reading. It is important that the DMM used provides the option for four-wire resistance measurement. The DMM used in this protocol is a Keysight Model 34465A. This link is for the operating and service guide for 34465A.
- Familiar with using automatic puffing machine.
- Familiar with using accurate gravimeter.

MATERIALS TEXT

- One ENDS device. This experiment use Vuse ALTO ENDS.
- 15 or more Vuse ALTO pods.
- Coil resistance testing apparatus. A step by step protocol to build this device can be found at:

Qutaiba Saleh, Edward Hensel, Risa Robinson. Coil Resistance Testing Apparatus for VUSE ALTO. International Journal of Environmental Research and Public Health. http://dx.doi.org/10.17504/protocols.io.bibnkame

The coil resistance testing device is also presented at:

Coil Resistance Testing Apparatus for VUSE ALTO
by Qutaiba Saleh,
Rochester Institute of Technology

PREVIEW RUN

- A digital multimeter which is used with the coil resistance testing apparatus. In this experiment, we used 34465A KEYSIGHT™ Digital Multimeter. This is a link to the user manual.

- Automatic puffing machine to activate and run the ENDS under test to generate and collect aerosols. In this experiment, we used the previously validated Programmable Emissions System™ (PES™-1). Description of this machine can be found at:

Hensel, E.C.; Jayasekera, S.; Robinson, R.J (2018). Accounting for effects of system dynamics to improve accuracy of emissions reported in e-cig vaping machines. Inhalation Toxicology. https://doi.org/10.1080/08958378.2018.1526232

- Rubber tube to connect the mouthpiece of the pod to the inlet of the filter pad holder.
- Laboratory wrapping film to fix the tube to the mouthpiece. In this experiment, we used Bemis™ Parafilm™ M Laboratory Wrapping Film.
- Filter pads to collect aerosol. The types of the filter pad depends on the filter pad holder and the puffing machine used.
- A gravimeter. In this experiment, we used Mettler AE240 Analytical Balance gravimeter. The manual to this device can be found at this link.
- A camera to document status of the pods under test.

SAFETY WARNINGS

- Use caution when handling of tobacco products.
- Avoid inhaling the aerosol which might be released when opening the filter pad holder or any other parts of the experiment setup.
- The temperature of the pod after use could be high especially after continuous and heavy use such as in this experiment.

Citation: Qutaiba Saleh, Edward C Hensel, Nathan C. Eddingsaas, Risa Robinson (04/18/2021). Measure Effects of Manufacturing Variations of ENDS on coil Lifetime and Aerosol Generation. https://dx.doi.org/10.17504/protocols.io.brbvm2n6

- The aerosol materials collected on the pad holder could be toxic.
- The ENDS devices uses lithium batteries. It is important to use caution when working on the battery even if the battery is discharged. Short circuit connection between the battery terminals could cause fire.

BEFORE STARTING

Assemble all the materials listed in the material page.

This protocol is for pod-style ENDS which typically consist of two user sub-assemblies.
The ENDS Pod is the removable pod which contains the heating coil, wick, e-liquid and mouthpiece.
The ENDS Power Control Unit (PCU) contains the battery, electronic circuitry and user interface.

Samples (pods) Preparation

1 Select the pods to be included in this experiment and execute all steps in this section on each pod.

2 Visually inspect the pod for any damage due to shipping, storage, or any other reason. Exclude any pods with damages.

3 Document the UID for all pods.

4 Visually inspect the color of the e-liquid in the pods and classify the pods based on e-liquid color into Light or Dark. The pictures below gives examples of a pod with light e-liquid color and a pod with dark e-liquid color. If possible, the pods can be classified into more than two color groups.

Vuse ALTO pod with light e-liquid.

Vuse ALTO pod with dark e-liquid.

5

Take a picture of the pod to document its color and undamaged status.

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Before Conducting Puffing Session

6 ⚠

Make sure the ENDS PCU is fully charged. If not, wait until it is fully charged before proceeding to the next step. This step is to eliminate the effects of variable battery level on ENDS performance. In this experiment, the ALTO ENDS was continuously connected to the charger while the ENDS was being used, as allowed by the manufacturer.

The ENDS devices uses lithium batteries. It is important to use caution when working on the battery even if the battery is discharged.

7 Take “Before” reading for coil resistance using coil resistance testing apparatus.
A protocol to build coil resistance testing apparatus for Vuse ALTO can be found using the link below.

Qutaiba Saleh, Edward Hensel, Risa Robinson. Coil Resistance Testing Apparatus for VUSE ALTO. International Journal of Environmental Research and Public Health.
http://dx.doi.org/10.17504/protocols.io.bibnkame

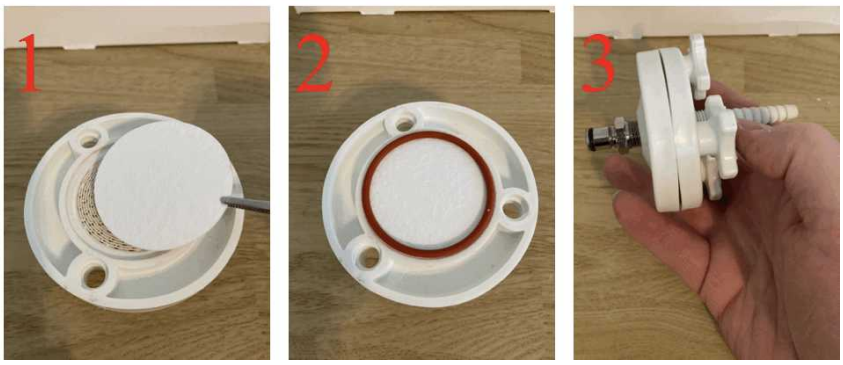
8 Take "Before" pod (the e-liquid reservoir and coil) mass and filter pad mass using gravimeter.

Taking "Before" pod mass.

Taking "Before" filter mass.

9 Install the filter pad in the filter pad holder.

Citation: Qutaiba Saleh, Edward C Hensel, Nathan C. Eddingsaas, Risa Robinson (04/18/2021). Measure Effects of Manufacturing Variations of ENDS on coil Lifetime and Aerosol Generation. https://dx.doi.org/10.17504/protocols.io.brbvm2n6



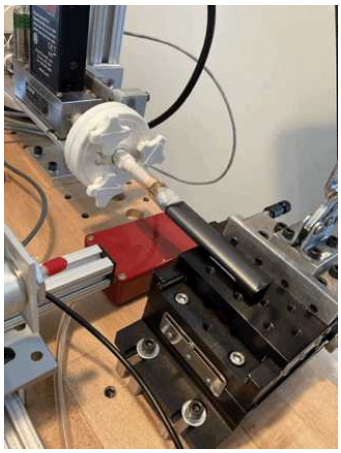
Steps for installing filter pad in the filter pad holder.

10 Connect the filter pad holder to its appropriate place in the emission system (PES-1 in this case).

Hensel EC, Jayasekera S, Robinson RJ (2018). Accounting for effects of system dynamics to improve accuracy of emissions reported in e-cig vaping machines.. Inhalation toxicology. https://doi.org/10.1080/08958378.2018.1526232

11 Install the ENDS pod in the ENDS PCU.

12 Connect the ENDS assembly to the emission system (PES-1 in this case). Use short connecting tube to connect the mouthpiece of the pod to the inlet of the filter holder. Use laboratory wrapping film to fix the tube to the mouthpiece.



ENDS assembly connected to the emission system using short connecting tube and wrapping film.

Run Puffing Session

13 Run trial based on the predefined puffing profile. The puffing profile used in this experiment consists of uniform square puffs with 18.33 mL/Sec flowrate, 5.5 Sec puff duration, and 11 Sec puff interval. Based on the amount of e-liquid

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remaining in the pod, the number of puffs per session is selected to be 20, 10, or 5 puffs. This is to increase the precision at which coil lifetime is measured.

After Puffing Session 10s

14 Remove the ENDS assembly from the emission system within **00:00:05** of the conclusion of the trial. 5s

15 Remove the ENDS pod from the ENDS PCU and take “After” trial coil resistance measurement using the coil resistance test apparatus. This measurement should take place as soon as the session ends, this reading tries to assess coil resistance while it may still be warm due to usage.

Qutaiba Saleh, Edward Hensel, Risa Robinson. Coil Resistance Testing Apparatus for VUSE ALTO. International Journal of Environmental Research and Public Health.
http://dx.doi.org/10.17504/protocols.io.bibnkame

16 Remove the filter pad from the filter pad holder within **00:00:10** of the conclusion of the trial and take "After" reading for filter pad mass. 10s

Removing filter pad out of filter pad holder and placing it on the gravimeter to take "After" mass reading.

17 Take “After” reading for pod (the e-liquid reservoir and coil) mass measurement using gravimeter.

18 ✱

Document any other information relevant to the research question being investigated. It is always important to take notes of facts such as (droplets condensed on the connecting tube between pod and filter pad holder). Such notes

Citation: Qutaiba Saleh, Edward C Hensel, Nathan C. Eddingsaas, Risa Robinson (04/18/2021). Measure Effects of Manufacturing Variations of ENDS on coil Lifetime and Aerosol Generation. https://dx.doi.org/10.17504/protocols.io.brbvm2n6

could be critical in explaining anomalies and understanding the final result.

19 Assess coil resistance of the pod.

If it is in the range of ~ 0.7 - 2 Ω, coil was not damaged (functional). If it is increased to order of 400 kΩ, coil was damaged (failed). These coil resistance ranges are for Vuse ALTO pods. Use appropriate values for other products.

Step 19 includes a Step case.
Functional
Failed

step case

Functional

Coil resistance is between 0.7 and 2 Ω.

20 Assess the amount of e-liquid left in the pod to determine the number of puffs to be used in the next session trial. Profiles of 20, 10, 5 are used. As the amount of e-liquid in the pod was consumed, profiles with a smaller number of puffs are used. This was to increase the precision at which coil lifetime was measured. **go to step #6** to conduct the next puffing session.

Result Analysis

21 Some of the important data points produced in this experiment can be organized in a table to simplified the later analysis as follows. The statistical mean and standard deviation can be also added to this table as applicable.

A	B	C	D	E	F	G	H
Pod ID	**Initial Coil Resistance**	**Initial E-liquid Color**	**Initital Pod Mass**	**End Pod Mass**	**E-liquid Net Mass (Col. C - Col.D)**	**Coil Lifetime**	**Total Particulate Mater (TPM) per puff of First Session**
Pod 1							
Pod 2							
.....							
.....							
Pod n							
Mean							
STD							

Key data points produced in this experiment.

22 In addition to the statistical mean and standard deviation which are already mentionedThe data in the table from the previous step can be analyzed test relations between the desired variables this experiment focuses on.
Next is a list some of the suggested correlation test:

- The correlation between initial coil resistance and coil lifetime.
- The correlation between initial coil resistance and initial TPM.
- The correlation between initial pod mass (or e-liquid net mass) and coil lifetime.
- The correlation between initial pod mass (or e-liquid net mass) and initial TPM.

The MATLAB functions fitllim and corrcoef can be used make these tests

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T-tests can be conducted to test the effects of e-liquid color:

- T-test between coil lifetime of the pod with light e-liquid and dark e-liquid.
- T-test between TPM of the pod with light e-liquid and dark e-liquid.

The MATLAB function ttest can be used.

23 Further analysis can be conducted for more understanding of the data. Plots can be used to show the correlation of the experiment variables at the session level to explain their behavior. Some the the suggested plots are:

- Plot the coil resistance against the TPM at each session.
- Plot the coil resistance against pod mass at each session.
- Plot the pod mass against TPM at each session.

The results of the experiment conducted using this protocol is presented in our article "Effects of Manufacturing Variation in Electronic Cigarette Coil Resistance and Initial Pod Mass on Coil Lifetime and Aerosol Generation". A link to the paper is presented in the Metatdata section of this protocol.

Citation: Qutaiba Saleh, Edward C Hensel, Nathan C. Eddingsaas, Risa Robinson (04/18/2021). Measure Effects of Manufacturing Variations of ENDS on coil Lifetime and Aerosol Generation. https://dx.doi.org/10.17504/protocols.io.brbvm2n6