Response to the Reviewer 1:

General Comments

Liang et al. (manuscript) describes the experimental formation of SOA and nitrate through chemical aging induced in an oxidation flow reactor (OFR). The authors injected combustion air from incense burning into the OFR at high RH, which were rapidly aged by controlling UV light and O3 to mimic UV-aged, O3-aged, and OH-aged scenarios. The authors used a single-particle AMS (SPAMS) to obtain the chemical composition of the particles and the Gothenburg PAM OFR (Go:PAM) as the reaction vessel.

The authors use the adaptive resonance theory method (ART-2a) algorithm to perform cluster/categorization analysis with the mass spectra (Zhao et al., 2008). The authors conclude that the OH-aged case generates more secondary nitrate than the O3-aged case based on the higher relative peak area (RPA). The enhanced secondary nitrate formation is attributed to higher uptake of nitrogen-containing species.

The manuscript overall lacks quantitative information, and I am confused about the OFR configuration. The authors provide some [NOx] information in Figure S10 and in the text, but a NOx instrument is not shown in the OFR set up in Figure S1. Moreover, the flow rates entering and exiting the OFR in Figure S1 already match, so adding a NOx monitor would cause a flow imbalance.

Moreover, the methodology and instrument details are lacking for replication, and additional explanations are needed to connect the chemistry in these OFR conditions to those of the atmosphere. For instance, the manuscript is missing the Go:PAM temperature and experiment residence times. The generated particle number concentrations from the WCPC, the particle mass collected on the filters for IC analysis, and the mass of incense used are not available. I do not have a clear picture of how much aerosol entered and exited the OFR.

The experiments and discussions fall within the scope of Atmos. Chem. Phys., and the content is topical to the atmospheric chemistry community. However, the manuscript is currently underprepared for publication, and there are technical issues that need resolution. Given the importance of understanding how chemical aging impacts aerosol evolution, I request the authors perform major revisions and resubmit the manuscript.

Author's Response: Thank you for the constructive comments. Many of the comments/questions are addressed by the addition and clarification of experimental conditions and result discussions. These comments have helped improve the manuscript and strengthen the analysis of the results, but they do not affect the key conclusions in the manuscript.

SPAMS cannot give quantitative mass concentration information of the aerosol samples, especially the organics. The Aerodyne AMS is generally accepted as quantitative. However, the ionization efficiency is often assumed constant, irrespective of the chemical compositions. Hence, we feel that the inability of accurate mass concentration determination is not necessarily a unique shortcoming of SPAMS. Rather, it has less exposure in the scientific community to yield an accepted ionization efficiency for all its analytes. Nevertheless, it is a unique and useful tool to clearly identify the mixing states of particles, which is the emphasis of this paper. For instance, it clearly shows that nitrate preferentially formed in -ON type particles, and dicarboxylates formation in K- type particles prevailed over OC- type particles, though the detailed speciation analysis of the organic compounds is limited by fragmentation. We clarified this limitation of the technique in the manuscript.

We apologized for the confusion from the Go:PAM schematic (Figure S1). It has been corrected to provide additional experimental information. The characterization of the Go:PAM was reported in Watne et al., 2018 and this system has been used in a number of publications in aerosol aging (Le Breton et al., 2019; Watne et al., 2018; Wang et al., 2022; Yu et al., 2022; Zhang et al., 2020; Li et al., 2019; Liu et al., 2019; Xu et al., 2022; Zhou et al., 2021a; Zhou et al., 2021b; Tsiligiannis et al., 2019).

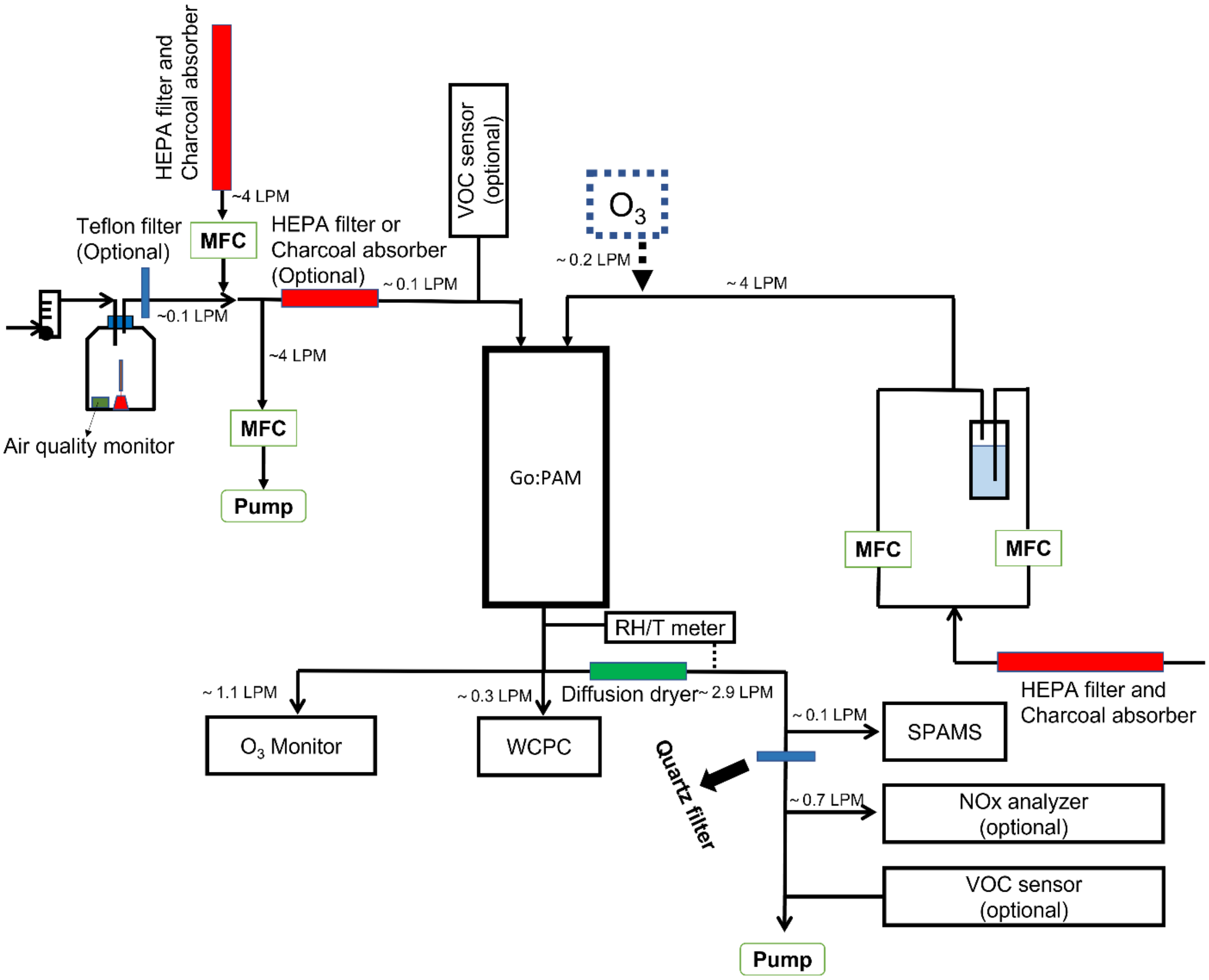

Figure S1. The schematic of the experimental set-up. The NOx analyzer and the VOC sensor were used only in the experiment for determining the gas removal efficiency and NOx decay under OH exposure.

We have also added the temperature, residence time, and WCPC particle counts to the methodology description as shown below. The particles were collected on filters for IC analysis, and the mass of incense used was useful to estimate the emission factor (EF) of incense burning particles, although mass concentration was not the focus of this manuscript.

Line 77-78: The RH and the temperature at the exit of the Go:PAM were monitored by an RH and temperature sensor (M170, Vaisala, Finland). All the experiments were conducted at 80 ± 0.6 % RH and 22 ± 1.7 °C. The residence time in the Go:PAM was ~100 s.

Line 86-89: We also collected particles on 47 mm quartz filters (PALL, USA) at the exhaust of the Go:PAM reactor for offline mass and chemical analysis. The number of particles collected on the filters was estimated by the total WCPC counts during the sampling period. The particle number concentration from the WCPC was 6100 ± 2400 # cm^{-3} and the estimated number of collected particles was around 10^8 #.

Specific Comments

1. The SPAMS calibration is not outlined, and details on the ART-2a solution is inadequate.

Details on the SPAMS operation would help assess the data quality. The Aerodyne soot particle AMS requires laser alignments for consistent measurements (Avery et al., 2020); does the SPAMS in this manuscript need a similar calibration? Particle transmission through the aerodynamic lens is size-dependent (Huang et al., 2013). How would size-dependent particle detection influence the data interpretation?

The absolute peak area (APA), relative peak area RPA, and number fraction (NF) are frequently invoked in the data interpretation. The authors use APA and RPA as analogues to concentration (or fraction of total aerosol). However, I suspect that depends on how efficiently different species are ionized by the pulsed Nd:YAG laser, and I would like to know if adjustments have been made to the RPA based on the ionization efficiency. What is the ionization efficiency (IE) of species mentioned in the manuscript, and is IE consistent across species?

As for the ART-2a solution, Zhao et al. (2008) and Huang et al. (2013) note that there is no general rule for the vigilance factor, and that a comparative approach (like re-grouping or comparing with other clustering algorithms) may be needed. I also note there is no PAH category, despite particulate PAH found in previous incense combustion studies (Ji et al., 2010) and a PAH contribution being found in a similar mass spectrometer with ART-2a (Passig et al., 2022). Can the authors provide more detail and justification for their ART-2a solution?

Author's Response:

The SPAMS we used operates with a principle similar to the ATOFMS, but not Aerodyne SP-AMS. The laser alignment was calibrated by atomizing Polystyrene Latex (PSL) particles with sizes ranging from 200-1000 nm.

The collection efficiency of SPAMS increased with size from ~1% at 200 nm to ~40% at 960 nm (as shown below). Therefore, the secondary aerosol formation in small particles may have been underestimated.

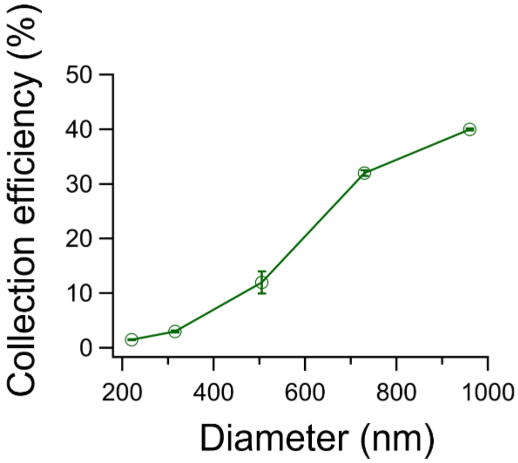

Figure S13. Relation between the particle collection efficiency of Polystyrene Latex particles and diameter in SPAMS.

The matrix effect makes the determination of ionization efficiency (IE) difficult for SPAMS, which is also an issue in other single-particle mass spectrometers (e.g., A-ToF-MS, LAAP-MS). Therefore, unlike the aerodyne AMS, SPAMS is not a quantitative instrument, but is unique for single-particle mixing state characterization, which is the focus of this work. One should note that the Aerodyne AMS is not free from matrix effect either and hence offline chemical composition measurements were usually conducted for comparison. APA and RPA were used as semi-quantitative indicators of the abundance and concentration of chemical species (Zhou et al., 2021b; Cheng et al., 2018). We have changed the title to 'Secondary Aerosol Formation in Incense Burning Particles by Ozonolysis and Photochemical Oxidation via Single Particle Mixing State Analysis' to emphasize the focus of this paper.

There are various algorithms for clustering single particles, but all are based on spectral similarities (Zhao et al., 2008; Rebotier et al., 2007). ART-2a is the sole algorithm incorporated into the commercial SPAMS system, and it is also the most common one for analyzing single-particle data. Although there is no general rule for the vigilance factor in ART-2a, Zhao et al. (2008) reported that both a relatively small vigilance factor (e.g., 0.5 or 0.6) and a relatively high vigilance factor (e.g., 0.8) show very similar clustering accuracies (± 5%). Nevertheless, we have added the vigilance factor and further clarifications to the manuscript:

Line 226-229: The collection efficiency of SPAMS increased from ~1% at 200 nm to ~40% at 960 nm (Figure S13). Therefore, secondary aerosol formation in small particles may have been underestimated. However, this would not affect the conclusion of the results that nitrate formed in incense burning particles upon O_3+Dark and O_3+UV aging.

Line 113-116: In the ART-2a analysis, we used a vigilance factor of 0.85, and more than 98% of the particles were analyzed. Note that there is no general rule for the vigilance factor in ART-2a. Zhao et al. (2008) reported that both a small vigilance factor (e.g., 0.5 or 0.6) and a relatively high vigilance factor (e.g., 0.8) show very similar clustering accuracies (± ~5%) (Zhao et al., 2008).

We have searched for the signals of particulate PAHs. Passig et al. (2022) identified PAH-containing particles by the presence of at least four peaks on the m/z channels 178, 189 (fragment of alkylated phenanthrenes), 202, 220, 228, and 252. We did not find such peaks in any of our samples, although they were detected in an AMS study (Ji et al., 2010). We have added this information to the manuscript:

Line 126-130: Despite that particulate polyaromatic hydrocarbons (PAHs) were found in a previous incense combustion study (Ji et al., 2010) and a recent study of ambient particles based on a single-particle mass spectrometer with ART-2a (Passig et al., 2022), none of the fresh incense burning particles in our experiments contained the PAHs peaks (m/z = 178, 189 (fragment of alkylated phenanthrenes), 202, 220, 228, and 252). Regardless of the presence of PAHs or not, our conclusion on nitrate formation does not depend on the detection of specific chemicals such as PAHs.

2. OFR characterization and operation details are missing.

Offline OHexp calibrations may be inaccurate when OH reactive species suppressed OH. Basically, OH suppression is when the external OH reactivity (extOHR) entering the OFR is high enough to titrate the OH, which results in OH-aging being suppressed. In such scenarios, offline OHexp calibrations become unreliable, possibly by orders of magnitude (see Section 3.1.4 of Peng and Jimenez, 2020). Peng and Jimenez (2020) also notes that OFR254 is susceptible to OH suppression at low O3 injections.

Operational information of the OFR would be valuable for replication and should be mentioned in the supplementary. Watne (2018) describes the Go:PAM as being made of quartz; have there been efforts to constrain electrostatic particle wall loss (Cao et al, 2020)? How would gas wall loss (Palm et al., 2016) affect the results reported, or is gas wall loss negligible? What cleaning procedure was taken to minimize carryover effects between experiments?

Author's Response:

Watne et al. suggested that the penetration of the particles is close to 100% for particles larger than 100 nm. Hence the wall loss is negligible for the 0.2-2 um particles that SPAMS measures. Besides, a control experiment measuring the total VOCs at the entrance and the exhaust of the Go:PAM suggested that the gas wall loss was also minor (6 ± 4%). We have added this analysis to the manuscript:

Line 80-83: Watne et al. suggested that the penetration of the particles is close to 100% for particles larger than 100 nm. Hence the wall loss is negligible for the 0.2-2 um particles that SPAMS measures. Besides, a control experiment measuring the total VOCs at the entrance and the exhaust of the Go:PAM suggested that the gas wall loss was also minor (6 ± 4%).

Also, we have added details on the OHexp calibration with SO_2. The estimation of extOHR requires VOC analysis and is not available in our study. We have also added this limitation to the text.

Text S1. Estimation of the OH exposure.

SO_2 was used to calculate the OH exposure in the Go:PAM. The UVC lamps were turned on to warm up for ~30 min and turned off. Then, O_3 (300, 800, 1500 ppb) and SO_2 (~200 ppb) were introduced to the Go:PAM with the UVC lamps turned off until its initial concentration remained constant at steady-state conditions, which typically took around 5 min. The $[SO_2]$ was recorded as $[SO_2]_{Initial}$. After that, the UVC lamps were turned on until the final $[SO_2]$ stabilized and was recorded as $[SO_2]_{Final}$. The time scale for the stabilization of $[SO_2]$ was around 4 min. The OH exposure at each condition is calculated using Eq. (A1):

$$OH\ exposure = \frac{1}{k_{OH,SO_2}} \times -ln\left(\frac{[SO_2]Final}{[SO_2]Initial}\right) \qquad (A1)$$

where $k_{OH,SO2} = 9 \times 10^{-13}$ cm^3 $molec^{-1}$ is the bimolecular rate constant between OH and SO_2 (Davis et al., 1979). The equation above is the result of integrating the differential rate equation for SO_2 and assuming pseudo-first order kinetics. The estimation of external OH reactivity (i.e., the OH reactivity with VOCs) requires VOC analysis and is not available in our study. Therefore, the OH exposure shown in this study may have been underestimated.

3. Kinetic modeling may be needed for interpretation.

The authors' argument on secondary nitrate formation, either heterogeneously or in the gas phase is limited by the lack of quantification HNO3, HONO, NOx, NOy etc. The difference in condensed nitrate between the O3 and OH-aged cases may be due to differences in HNO3/HONO/NOx uptake as the authors allege. A kinetic calculation showing that the formation of these species under the difference OFR conditions are comparable would be more demonstrative.

Moreover, gas-phase organic nitrate formation, either through VOC+NO3 or RO2+NO (Ziemann and Atkinson, 2012) and condensation should be considered. Kinetic modeling may be needed to *connect the experimental aging conditions in the Go:PAM to those of the atmosphere (Peng and Jimenez, 2020).*

Author's Response: Kinetic modeling will be useful in quantitatively evaluating the multiphase kinetics during aging incense burning particles. However, this is beyond the scope of this manuscript. Hence our data interpretation focuses on the formation of nitrate via mixing state analysis of the resulted particles, but not on the detailed mechanisms. It will require another study to conduct detailed modeling with new experimental data. We understand the limitation of this study that the SPAMS is not quantitative and hence have not attempted to do kinetic modeling.

Line 30: I recall incense burning is found in other cultures and am unsure if the practice is "especially" common in Asian and African religious rituals. I suggest either providing a reference for that point or removing "especially" in this sentence.

Author's Response: Agree, but the use of "especially" has not excluded other possibilities.

Line 35: The incense burning references cited here mention that there is variation in the particle emission factor (EF) across incense varieties. How does the particle EF in these experiments compare with those previous works? Were the combustion conditions comparable to those previous works?

Author's Response: The EF of the incense burning particles can vary by the type of incense and burning conditions. The theme of this paper is the aging of incense-burning particles and the formation of the secondary components of particulates, but not the particle EF. Again, our conclusion of nitrate formation in single incense burning particles is not affected by the EF. We have added additional information for the burning conditions:

Line 62-64: The air exchange rate per hour (ACH) is 0.3, comparable to the typical natural ventilation conditions (Lee et al., 2004). The relative humidity (RH) and the temperature inside the burning bottle were 56 ± 9 % RH and 22 ± 2.7 °C.

Line 62: There is no information on the incense sticks used, like the manufacturer or composition, and Liang et al. (2022) used several as shown in their Figure S21. What type of incense was used here? How much incense was burned? This information could be valuable for replication studies.

Author's Response: We added additional information on the incense sticks to the manuscript:

Line 61-62: In brief, we burnt an incense stick (Figure S2, Kwok Tin Heung, Hong Kong) in a 20 L glass burning bottle for each experiment.

Figure S2. The appearance of the incense sticks.

Line 64: The methods reference (Liang et al., 2022) states there were four UVA lamps, while here the authors say they used "two UVC light tubes." Please confirm that the Go-PAM set up had changed for this manuscript and specify that in the text. Moreover, what lamps were used? Rowe et al. (2020) found that 185 and 254 nm photon fluxes would vary across manufacturers, which may be re

Author's Response: We apologize for the confusion of referring our previous publication for the schematic. We have now removed the reference to our previous work. We have added detailed information on the UVC lamps used in this study including the spectra of the lamp to the supplementary information.

Line 61: The schematic of the experimental set-up is in Figure S1 ~~and our previous publication (Liang et al., 2022)~~.

Line 65-67: Compressed air (~0.1 L min^{-1}) was used to introduce the diluted incense burning particles to the Go:PAM reactor equipped with two UVC light tubes (30W, Philips TUV, λmax = 254nm). The spectrum of the lamp was shown in Supplementary information (Figure S3).

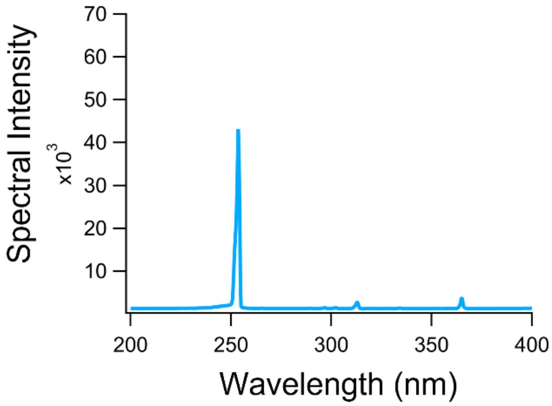

Figure S3. The emission spectrum of the UVC lamps.

Line 65: I am confused on how many experiments this manuscript is describing. I see in Figure 2 that there were 7 involving aging and 1 fresh; were some of these the "control" experiments? From this sentence I expect at least 2 types of controls, with either a charcoal absorber or HEPA filter. Were the control cases then also aged?

Author's Response: The data from the control experiments are available in the supplementary information, but not Figure 2. These control experiments are aged experiments. We have further clarified the availability of these data.

Line 67-70: In the control experiments, a charcoal absorber or HEPA filter was used to remove the gaseous pollutants or particles prior to the introduction to the Go:PAM. The data of these control experiments can be found in the supplementary information (Figure S4, S5). All these control experiments were aged experiments.

Line 66: How did the authors obtain these removal efficiencies?

Author's Response: We have added the explanation for the removal efficiencies evaluation:

Line 70-73: The removal efficiency of NOx, VOCs, and particles were ~85%, ~90%, and ~100%, respectively, determined by the concentration reduction after applying a HEPA filter or charcoal absorber at the exhaust of the burning bottle, using a NOx analyzer (T200, Teledyne) or a Total VOC analyzer (Yuante) (Figure S1).

Line 67: Compressed air or zero air? If the air is coming from a compressor, were efforts made to scrub the air of contaminants?

Author's Response: The compressed air was treated by a HEPA filter and a charcoal absorber prior to the experiment system. We have clarified this in the manuscript and the schematic figure.

Line 72-75: A controlled dry-wet mixed carrier flow of compressed air (~4 L min^{-1}) and a flow of O_3 (~0.1 L min^{-1}) generated by passing O_2 (99.995%, Linde) to an O_3 generator (Model 610, Jelight Company Inc, USA) were introduced into the Go:PAM. The compressed air was treated by a HEPA filter and a charcoal absorber prior to the experiment system.

Line 74: The methods reference (Liang et al., 2022) does not mention using a diffusion dryer. At ~0.1 LPM, what was the residence time in the dryer and is there an estimate of particle loss in the dryer? Was the dryer effective in removing H2O?

Author's Response: The RH at the exhaust of the diffusion dryer was ~15%. The residence time of the particles in the dryer was estimated to be 5 s and the particle loss was ~4% according to the CPC measurements. We have added this additional information to the manuscript.

Line 83-86: The particles passed through a diffusion dryer before entering the Go:PAM to reduce the matrix effects from water (Neubauer et al., 1998). The RH at the exhaust of the diffusion dryer was ~15%. The residence time of the particles in the dryer was estimated to be 5 s and the particle loss was ~4% according to the CPC measurements.

Line 76: What were the estimated number of particles collected?

Author's Response: The estimated number of the particle collected has been added.

Line 86-89: We also collected particles on 47 mm quartz filters (PALL, USA) at the exhaust of the Go:PAM reactor for offline mass and chemical analysis. The number of particles collected on the filters was estimated by the total WCPC counts during the sampling period. The particle number concentration from the WCPC was 6100 ± 2400 # cm^{-3} and the estimated number of collected particles was around 10^8 #.

Line 83: Please provide additional details on the OHexp calibration with SO2, in particular the concentrations of SO2 used and timescales to reach equilibrium. An estimate of extOHR during the experiments should be compared with that of the SO2 calibrations.

Author's Response: We have added details on the OHexp calibration with SO_2. The estimation of extOHR requires VOC analysis and is not available in our study. We have added this limitation to the text. As discussed earlier (Line 169-182 in this file), the lack of the extOHR does not affect our conclusion that O_3+UVaging by OH leads to more significant nitrate formation than aging by O_3 alone in incense burning particles.

Line 101: See specific comment 1.

Author's Response: Please find our response above.

Line 113: Explaining the abbreviations would improve readability. For instance, OC and ONEC do not appear prior in the text?

Author's Response: The explanation of the abbreviations has been added to the manuscript.

Line 132-135: ART-2a categorizes fresh incense burning particles into K-ON, K-ONEC, K-Cl, and OC-ON. EC, Cl and OC are abbreviations of elemental carbon, chloride and organic carbon, respectively. Briefly, the "K" and "OC" before the hyphen indicate the characteristics of the positive spectra, while "ON", "ONEC" and "Cl" after the hyphen indicate the characteristics of the negative spectra.

Line 147-149: How does the charcoal absorber remove NOx without removing VOC? How would the removal of VOC affect the interpretation here?

Author's Response: The charcoal absorber removes both NOx and VOC. However, the VOC contents were not expected to be important in the observed nitrate RPA reduction, as the amount of nitrogen-containing VOCs was minor in the incense burning plume, according to the literature (Manoukian et al., 2013).

Line 166-170: However, control experiments using a charcoal absorber to remove NOx only show ~20% decrease in RPA of total nitrate in O_3 aged particles (Figure S4), indicating that NO_2 hydrolysis and nitration may not be the main contributor to the nitrate formation. The charcoal absorber removes both NOx and VOC. However, it was not expected to be important in the observed nitrate RPA reduction, as the content of nitrogen-containing VOCs was minor in the incense burning plume, according to the literature (Manoukian et al., 2013).

Line 156: How would the loss of SVOC/LVOC in the HEPA filter (Shilling, 1997) affect the conclusion of the control experiment?

Author's Response: The addition of the charcoal to remove VOCs at the exhaust only caused ~6 % variation of the NF of -ON type particles and nitrate-containing particles (i.e., -ONN, -N). Hence, we considered the loss of SVOC/LVOC unimportant to our conclusion. We have added this to the manuscript:

Line 177-183: A control experiment with a HEPA filter before the Go:PAM showed no detectable particles by SPAMS. Thus, we assume the total SPAMS-detectable particle number was constant before and after aging, and O_3-aging may have preferentially converted some -ON type particles to nitrate-containing particles (i.e., -ONN, -N). It has been reported that the HEPA filter would cause the loss of semi-volatile VOC (SVOC) or less-volatile VOC (LVOC) (Schilling, 1997). However, the addition of the charcoal to remove VOCs at the exhaust only caused ~6 % reduction of the NF of -ON type particles and nitrate-containing particles (i.e., -ONN, -N), suggesting the roles of SVOC and LVOC were minor to our conclusion.

Line 182: How did the authors arrive at the "~90 % reduction of [NOx]"? Was this a separate test? If so, please add a quick summary of how that test was performed.

Author's Response: Yes, it is a separate test. We have clarified in the caption of the schematic.

Figure S1. The schematic of the experimental set-up. The NOx analyzer and the VOC sensor were only used in the experiment determining the gas removal efficiency and NOx decay under OH exposure.

Line 183: Was a NOx monitor available? If so, please provide the monitor's location in Figure S1 and specify in the text. Also, please explain how the flow rates entering and exiting the Go:PAM would be reconciled.

Author's Response: We have revised the experimental schematic.

Line 191-193: Do OH and O3 oxidation form similar functional groups? Are those functionalities evenly represented in these general markers? The RPA increase of SOA markers in OH over O3-aging may be skewed if these markers overrepresent one oxidation case over the other.

Author's Response: These marker fragments may not be directly related to the functional groups. Rather, they are just an indicator of the abundance of oxygen in the particulate matters. We have clarified this in the manuscript.

Line 214-217: Using the common general markers of oxidized/aged organics in single-particle mass spectrometric studies of -16[O], -17[OH], +42[C_2H_2O], and +43[C_2H_3O] as examples (Taiwo et al., 2014; Denkenberger et al., 2007; Qin et al., 2006), their RPA increase in O_3-UV-aged particles are 18, 10, 3, and 17 times higher than in O_3-aged particles. This significant enhancement of RPA suggests that OH aging produced more oxidized ~~and functionalized~~ products than O_3 aging.

Line 214: Do larger and smaller particles have similar surface properties, at least with regards to nitrate uptake?

Author's Response: It has been reported that larger organic and inorganic mixed particles could undergo liquid-liquid phase separation (LLPS) more easily than smaller ones (Kucinski et al., 2019). The organics would mainly locate at the outer layers of the particles, whereas the inorganic components reside as a core. The hydrophobic organic shell may have retarded the uptake of HNO_3/HNO_2/NOx to form nitrate. Profiling the surface composition and properties of the particles is beyond the scope of this paper. We have added this possibility to the manuscript for future works.

Line 241-247: However, the RPA shows an opposite trend, which can be interpreted as lower nitrate concentration in larger particles. Larger particles have larger surfaces but smaller surface-to-volume ratios, which lead to a larger absolute amount of nitrate formed but a lower relative concentration of particulate nitrate (Figure 2c, e). It has been reported that the larger organic and inorganic mixed particles could undergo liquid-liquid phase separation (LLPS) more easily than smaller ones (Kucinski et al., 2019). It is possible that the organics are mainly located at the outer layers of the particles, whereas the inorganic components reside in the core. The hydrophobic organic shell may have retarded the uptake of HNO_3/HNO_2/NOx to form nitrate.

Line 222: I suspect SOA formation is not "potential," but rather inevitable under the aforementioned OFR conditions, so I suggest removing "potential" from the section heading. Also, are oxalate and malonate universal and proportional indicators of SOA? That is, do different SOA *precursors form these indicators evenly under different oxidants (O3/OH)? I am concerned that there are specific chemical conditions where these species are enhanced without a proportional enhancement of SOA, which may skew the NF.*

Author's Response: We have spent a lot of time interpreting the question. It is likely the SOA characteristics and precursors are different under O_3 and OH. Hence, we are conservative and use the term "potential", even though oxalate and malonate are commonly found highly oxidized SOA. The total organic content (TOC) ratio of aged to fresh particles extract, which indicates the formation of SOA, was higher upon OH oxidation than O_3 oxidation (Figure S16). We have added clarifications to the manuscript:

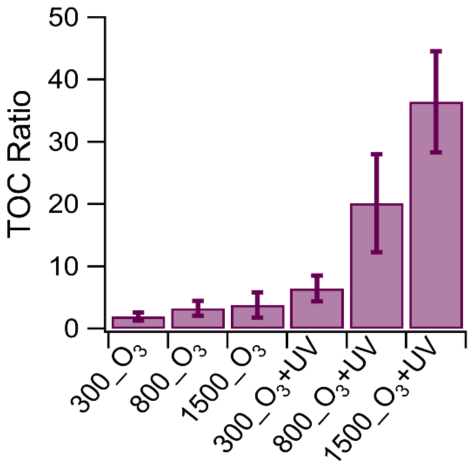

Figure S16. The total organic content (TOC) ratios of aged to fresh particles extract.

Line 89-92: The filter sample was extracted by deionized (DI) water for analyzing water-soluble ions (e.g., nitrate, formate, potassium) by Ion chromatography (IC) using the same protocol reported in our previous work (Liang et al., 2022). The total organic content (TOC) of the water-extract was analyzed by a TOC analyzer (Shimadzu TOC-L).

Line 268-271: In contrast, no oxalate and malonate were observed during ozonolysis, irrespective of [O_3]. It is likely the SOA characteristics and precursors are different under O_3 and OH. Hence, we are conservative and use the term "potential", even though oxalate and malonate are commonly found highly oxidized SOA. The total organic content (TOC) ratio of aged to fresh particles extract was higher upon OH oxidation than O_3 oxidation (Figure S16).

Line 229: Is NF of oxalate and malonate proportional with SOA concentrations? As it stands, "30 and 9 folds" increases of these tracers sounds like SOA increased by that much.

Author's Response: While the TOC ratio at different O_3+UV, which indicates the formation of SOA, shows an overall trend similar to the NF ratios of oxalate and malonate (Figure S15), the TOC ratio was 1.2-7.1 folds higher than the NF ratios of oxalate and malonate. However, this could be due to the formation of many other species as well as the matrix effects. We hesitate to speculate too much here. The SOA formation may have been underestimated due to the matrix effect. SOA formation during aging of incense burning plume should be further assessed by other quantitative online instruments in future works. We have added this clarification to the manuscript:

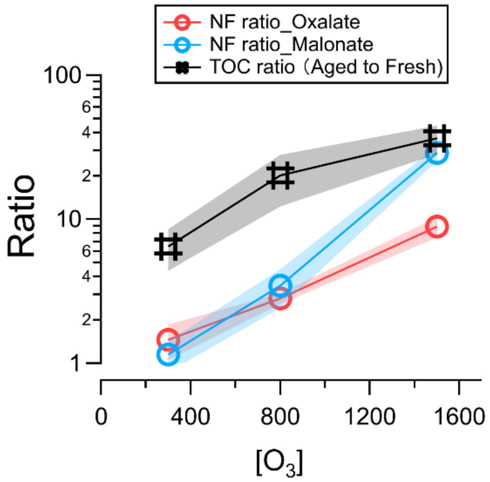

Figure S15. The NF ratios (aged to fresh) of oxalate and malonate, and TOC ratios as a function of [O_3] in O_3+UV aging experiments.

Line 261-268: Compared to 300 ppb O_3 and UV, the NF ratios of malonate and oxalate were 30 and 9 folds higher, at 1500 ppb O_3 and UV, respectively. This trend is different from the independence of nitrate formation on OH exposure, probably because the formation of SOA was slower than nitrate via multiphase uptake. These NFs are lower estimates due to the possible degradation by photolysis of Fe-decarboxylate complexes to CO_2 (Gen et al., 2021).While the TOC ratio at different O_3+UV, which indicates the formation of SOA, shows an overall trend similar to the NF ratios of oxalate and malonate (Figure S15), the TOC ratio was 1.2-7.1 folds higher than the NF ratios of oxalate and malonate. However, this could be due to the formation of many other species as well as the matrix effects. SOA formation during aging of incense burning plume should be further assessed by other quantitative online instruments in future work.

Technical Comments

Line 47: Awkward grammar in "For instance … nitrate."

Author's Response: We have revised the sentence as below:

Line 48-49: For instance, ozone and OH oxidations of NOx ~~by ozone and OH radicals~~ were considered primary sources of particulate nitrate (Seinfeld et al., 2008; Liang et al., 2021; Gen et al., 2022).

Line 325: Please check the citation styles; they are inconsistent.

Author's Response: We have updated the citation styles according to the Endnote tool provided by the website.

Lines 409/412: Same reference cited twice?

Author's Response: We have removed one of it.

Figure 2: The data appears almost randomly scattered in the lower panels, which may be due to points heavily overlapping with each other. The authors may want to replace the box and whiskers/scatterplot with a violin plot for easier visualization.

Author's Response: Thank you for the suggestions, we have replaced the box-whisker plot with a violin plot.

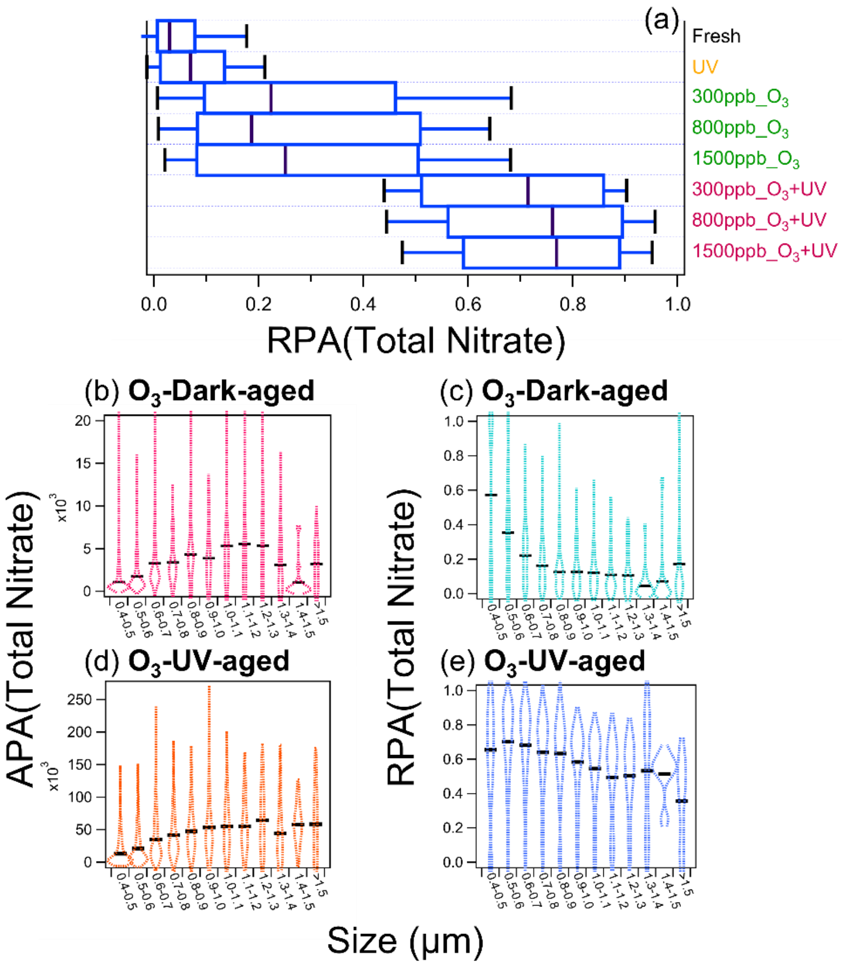

Figure 2. (a) The whisker-box plot of total nitrate RPA of fresh and aged particles. The violin plots of (b, d) APA and (c, e) RPA of total nitrate in O_3- and OH-aged particles as a function of size (unit: µm) of particles aged at 1500 ppb O_3 (+ UV). The medians are shown as the lines, and the kernel densities represent the probability density of the data at different values.

Figure S1: Please display where the charcoal absorber, HEPA filter, and NOx instrument would have been placed.

Author's Response: The Figure S1 has been updated.

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