ARTEMIS Advanced Renewable Technologies & Environmental Materials in Integrated Systems

Assessing particulate matter emissions from conventional cigarettes and heated tobacco products

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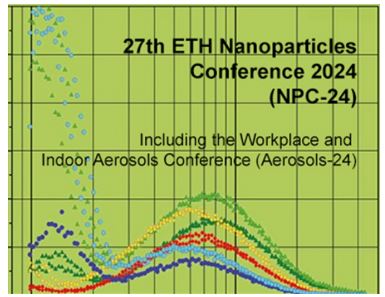


Contents

Introduction

- **Conventional cigarettes (CC)** have long been the most common form of tobacco products, whereas, in recent years, **heated tobacco products (HTPs)** have gained popularity as potentially less harmful alternatives.
- CCs **emit solid soot particles , VOCs and PAHs**; HTPS are claimed to **reduce the levels of harmful constituents.**
- Most studies in the literature show that **HTP aerosol emissions consist of a liquid phase of volatile and semi-volatile species**. However some studies suggest the presence of particulate matter **in the range of 30 nm to 400 nm.**
- **Do HTPs emit solid soot particles?**

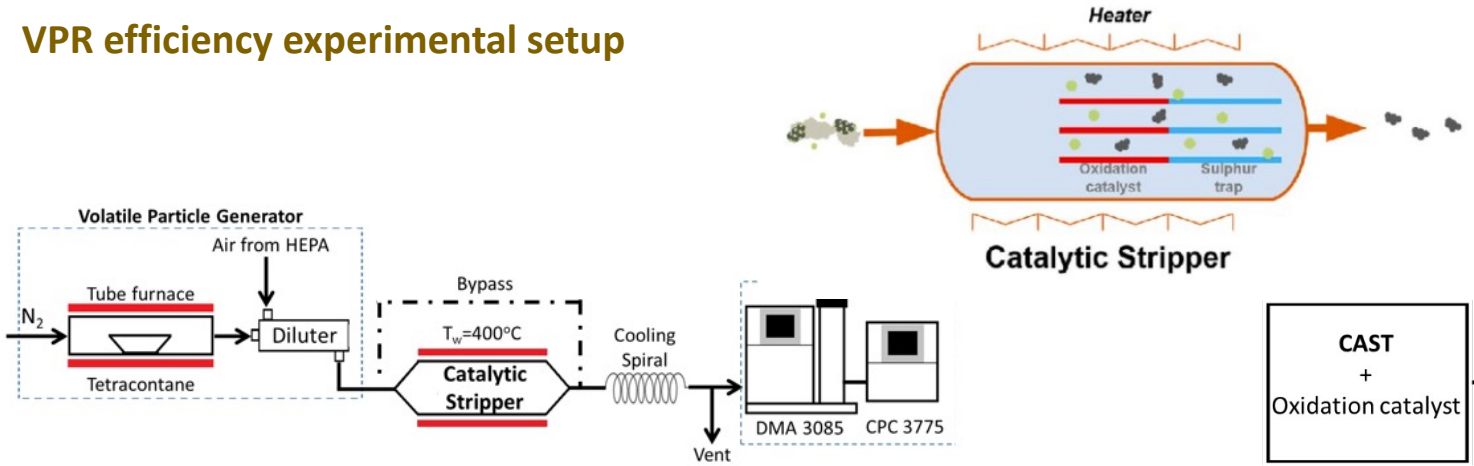
Assessment of HTPs and CCs emissions:

- Total particle concentration
- Particle size distributions
- Particle Mass
- Particle Composition
- Particle Morphology

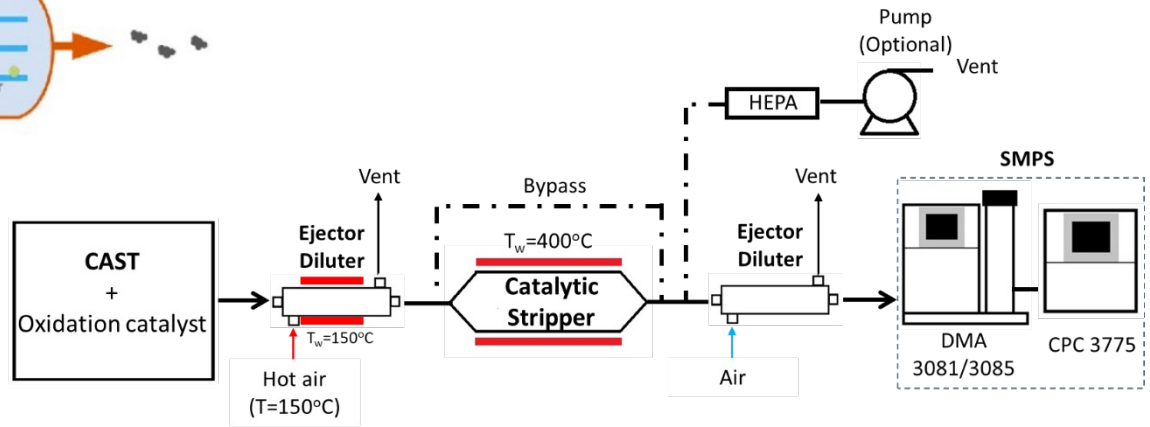
Methodology – The VPR system

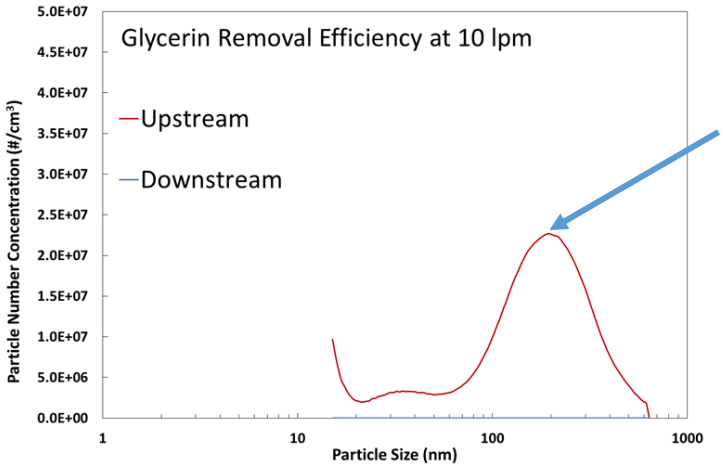
1. Traditionally **Evaporation Tubes (ET) or Thermodenuders (TD)** have been used to **separate the solid from the volatile phases**
2. In this study a previously **in-house developed Volatile Particle Removal (VPR) system** was used which was based on an **Advanced Catalytic Stripper (CS) (**Melas et al., 2020, DOI: 10.1080/02786826.2020.1718061**)**

VPR efficiency experimental setup



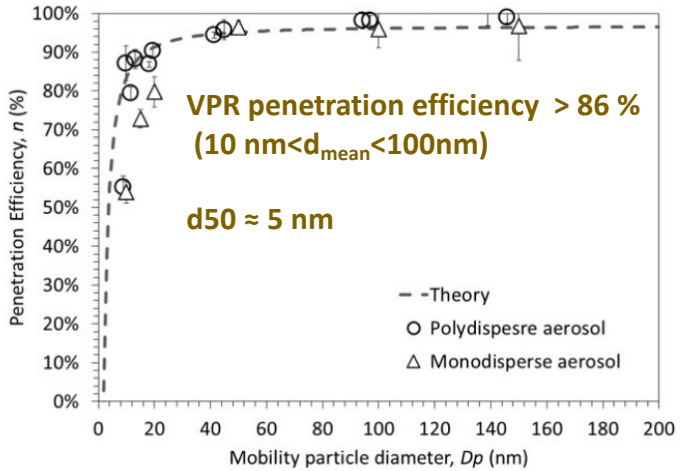
VPR penetration efficiency experimental setup





Glycerin particle removal =99.997 %

Tetracontane particle removal >99.999 %



VPR penetration efficiency > 86 %
(10 nm<d_{mean}<100nm)

d50 ≈ 5 nm

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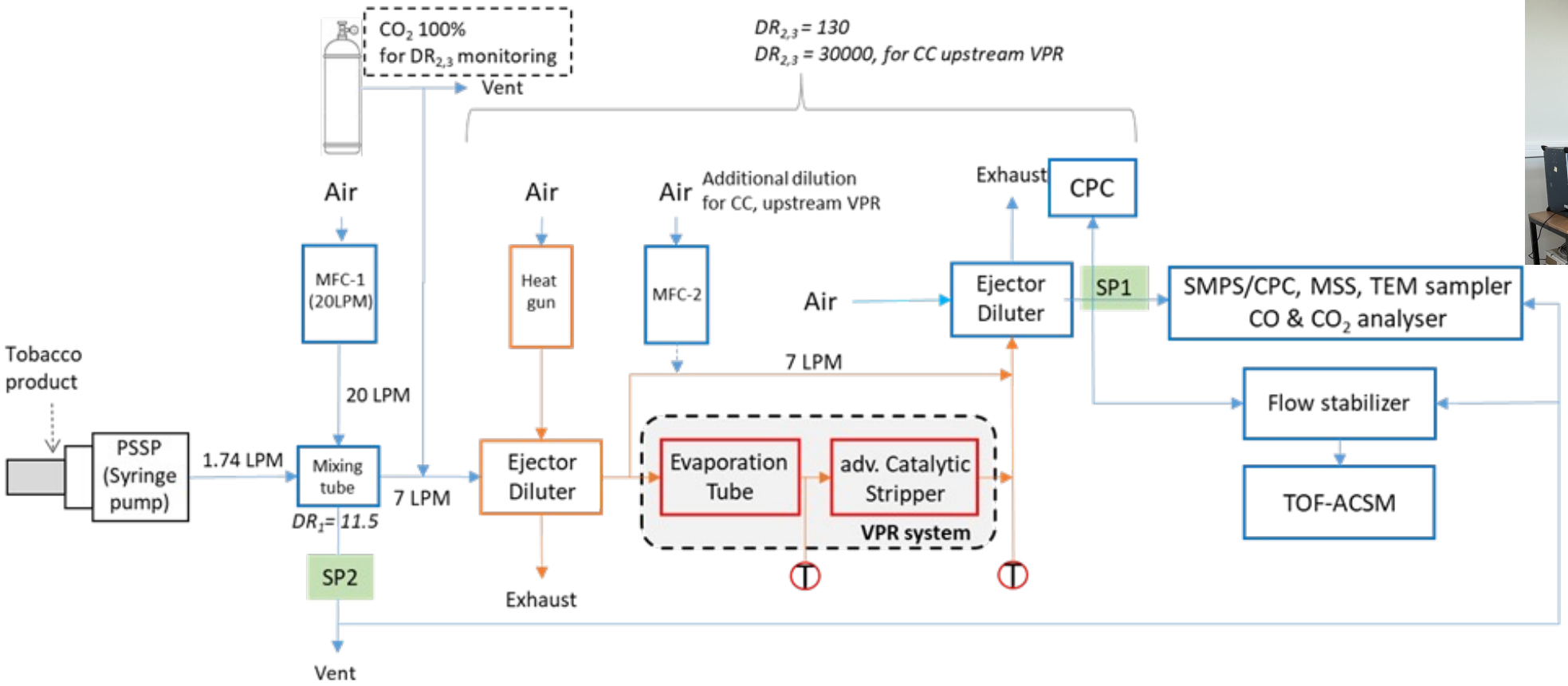
The experimental setup

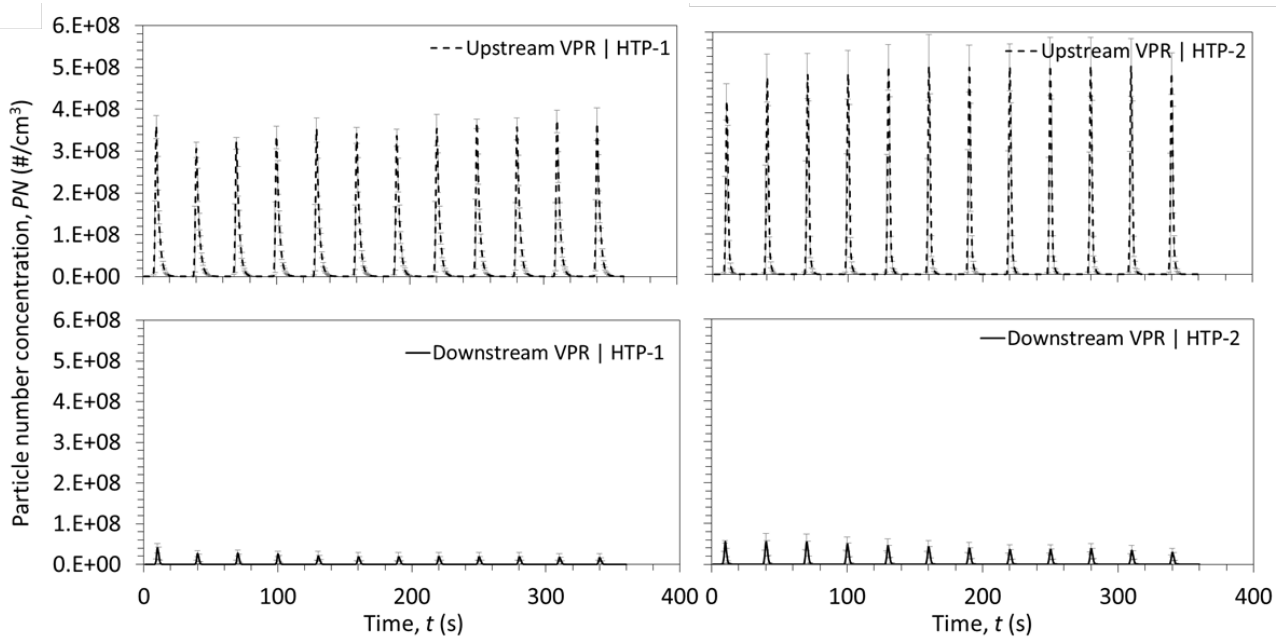
Instrumentation:

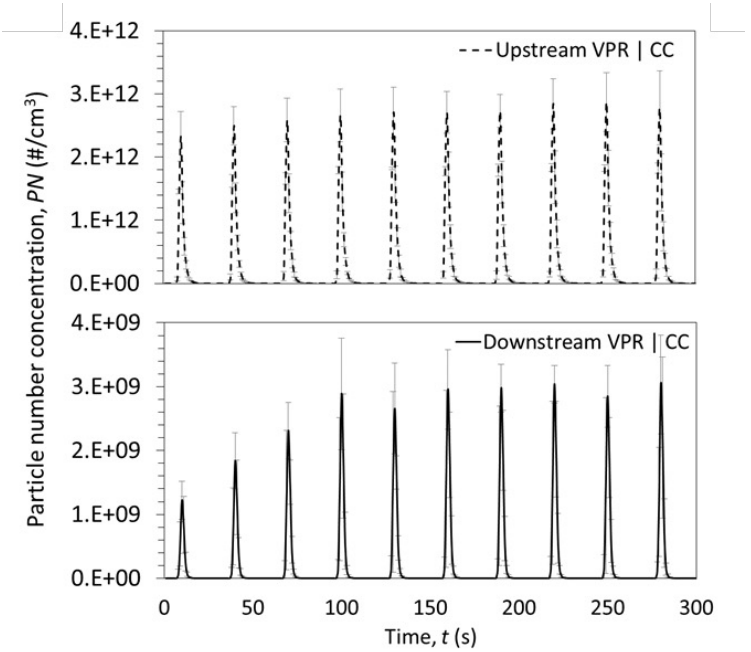
- Programmable single-syringe pump (PSSP, Burghart Messtechnik GmbH)
- Condensation Particle Counter (CPC, TSI model 3752, with cut-off d_{50}=4 nm
- SMPS → DMA, TSI model 3081 and a CPC, TSI model 3776, d_{50}=2.5 nm
- Micro Soot Sensor (MSS) by AVL
- Time-of-Flight Aerosol Chemical Speciation Monitor (ToF-ACSM, Aerodyne Research)
- High-resolution electron microscope (JEOL, JEM-2010)



Results – Total particle Number per stick or cigarette

- **Evolution of particle concentration during puffing**

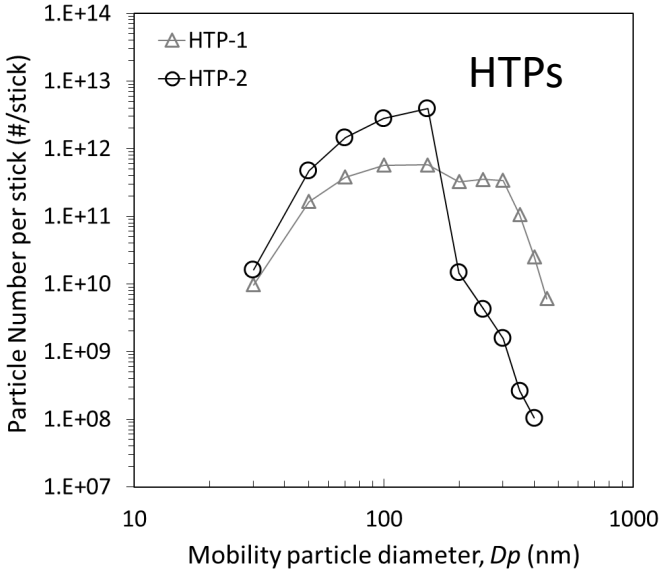


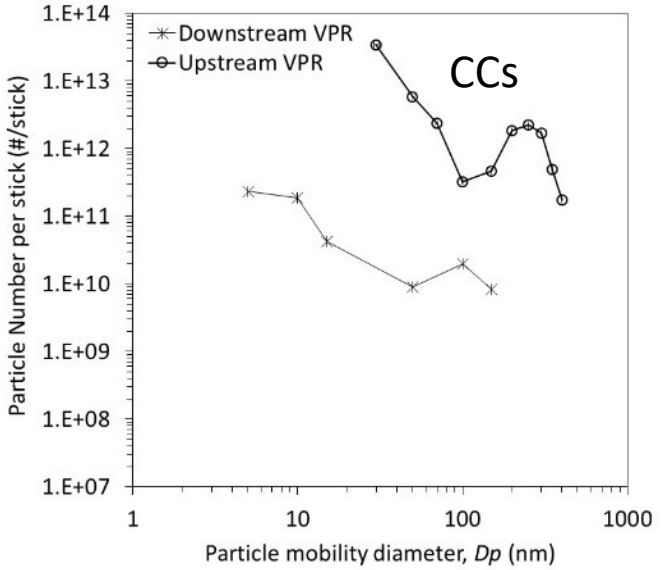


- **TPN**

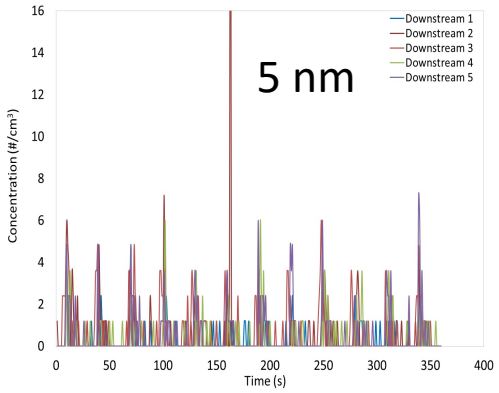
Product Type	Average TPN (#)	CV (%)	Average TPN (#)	CV (%)	Removal efficiency (%)
	Upstream		Downstream		
HTP-1	$5.15 \cdot 10^{11}$	32.61	$1.60 \cdot 10^{10}$	18.76	96.9%
HTP-2	$4.26 \cdot 10^{11}$	32.12	$3.54 \cdot 10^{10}$	18.67	91.7%
CC	$2.10 \cdot 10^{15}$	24.01	$2.01 \cdot 10^{12}$	17.67	99.9%

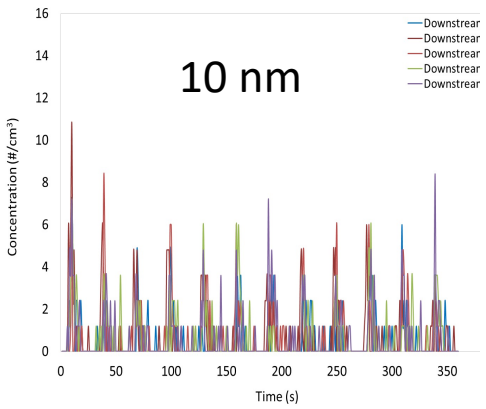
Results – Particle Sizes

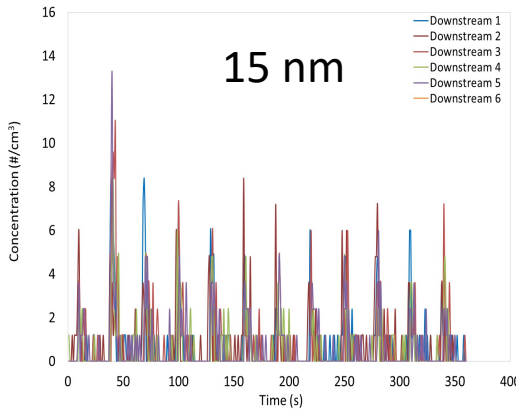


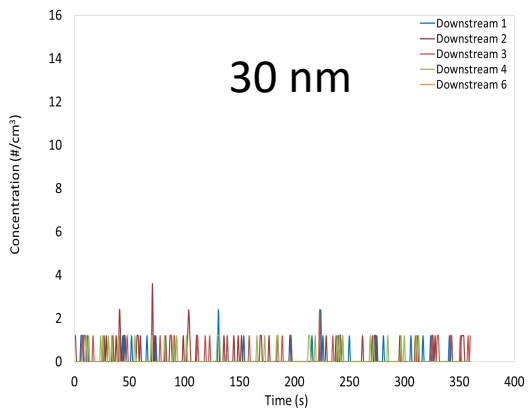


Particle concentration downstream of the VPR for HTP-1









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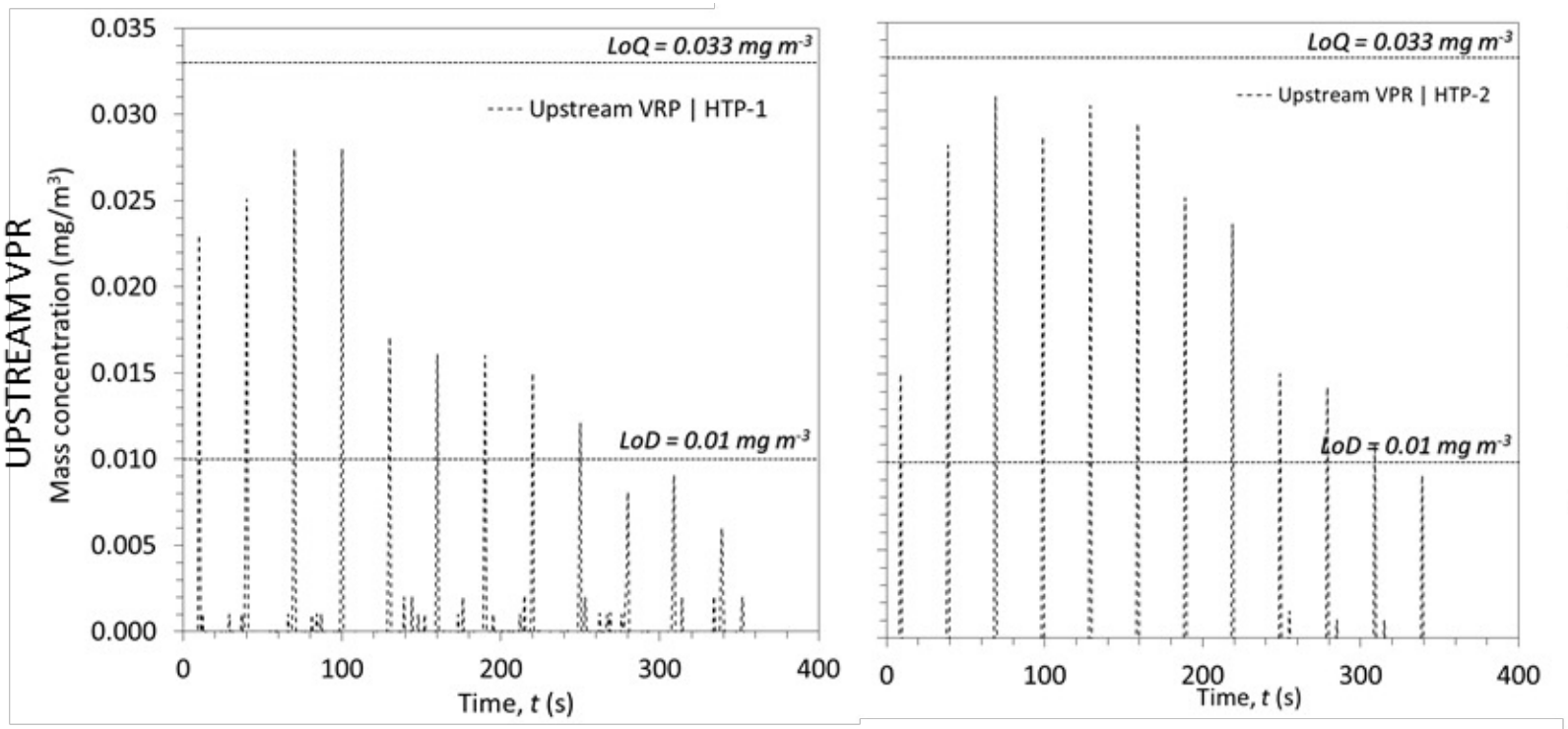
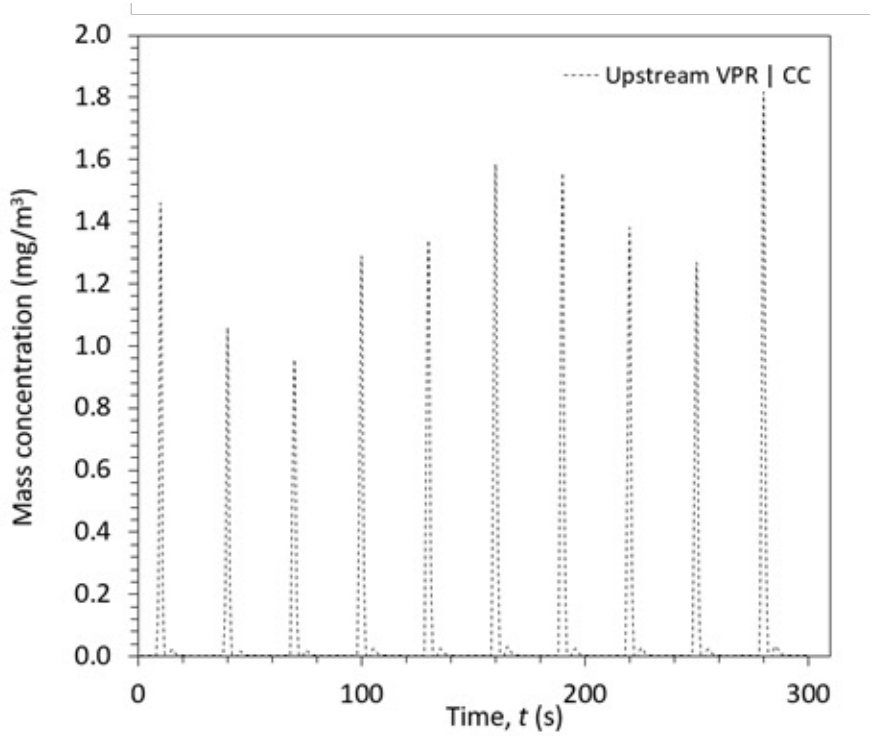
Results – Particle mass and CO emissions

- **Total soot mass per cigarette = 7.76 mg (± 15 %)**

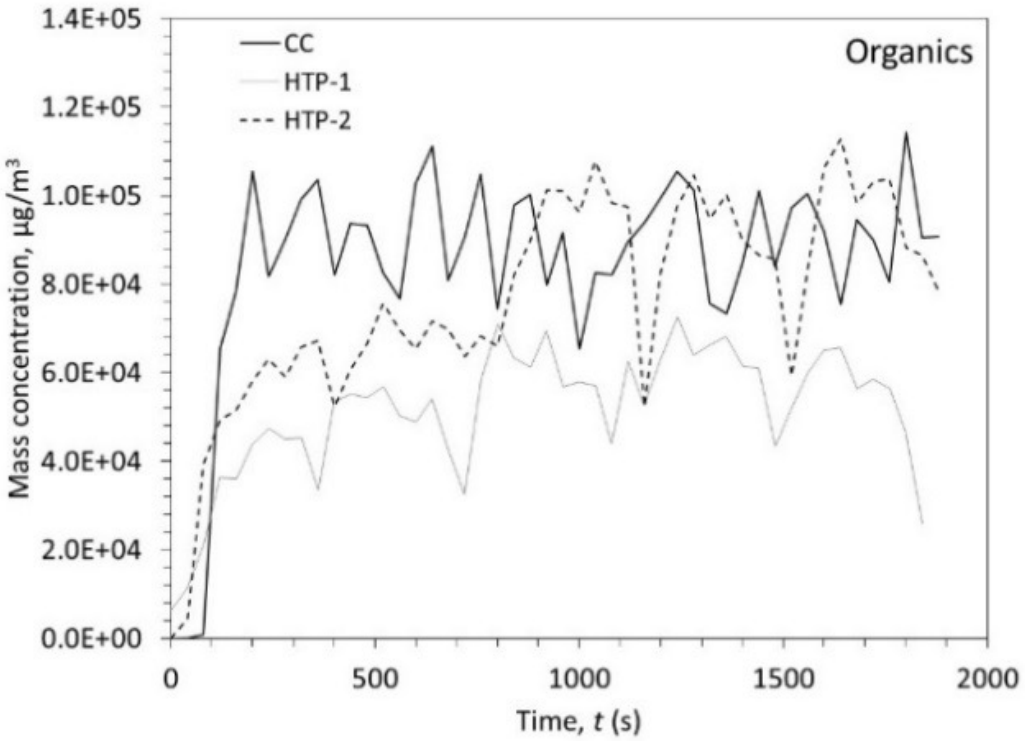


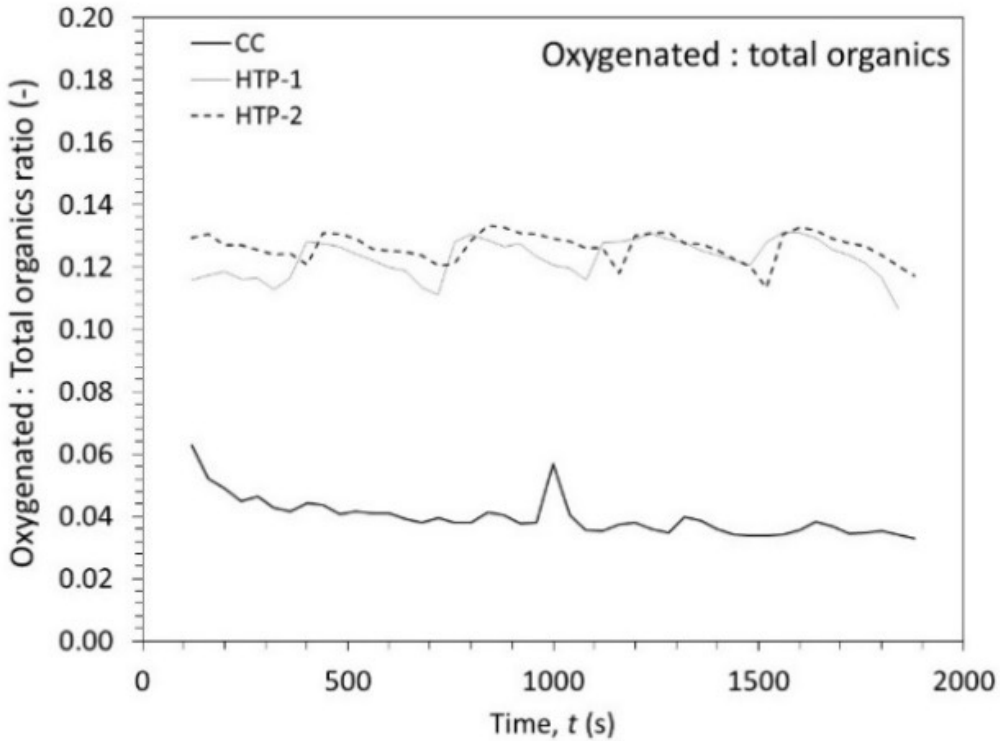


- **Average CO/CO2 during puffing**

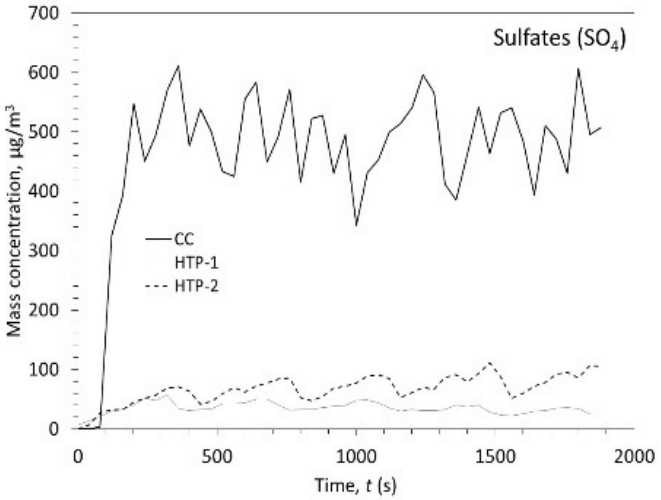
Product Type	CO/CO_2 (-)
HTP-1	0.09 ± 0.01
HTP-2	0.04 ± 0.02
CC	0.71 ± 0.04

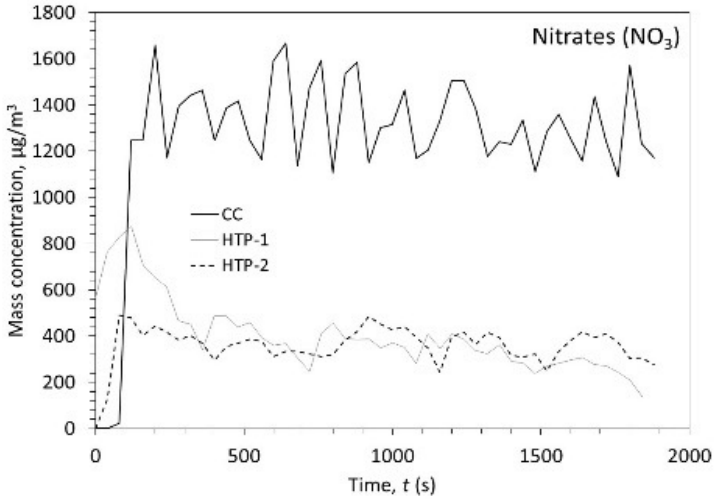
Results - Particle composition: Organic particulate matter

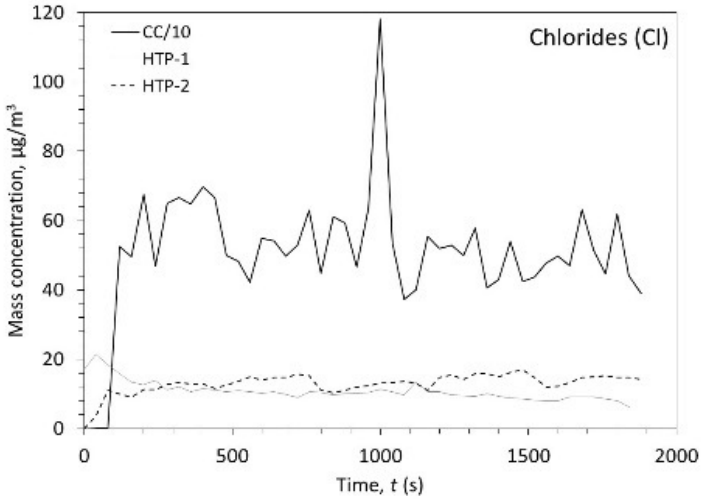




Results -Particle composition: Sulphates, nitrates and chlorides



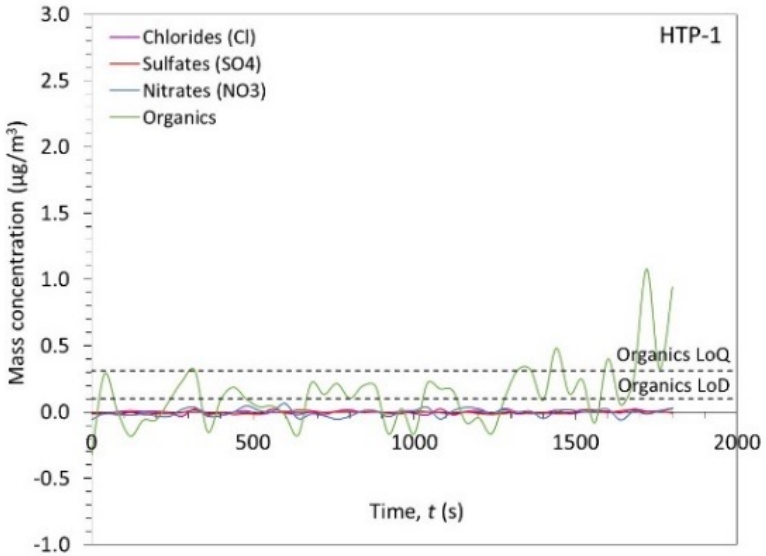


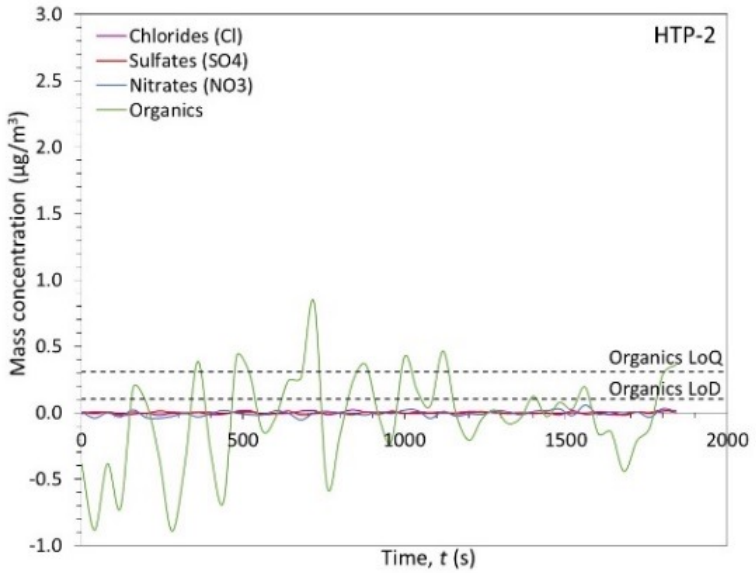


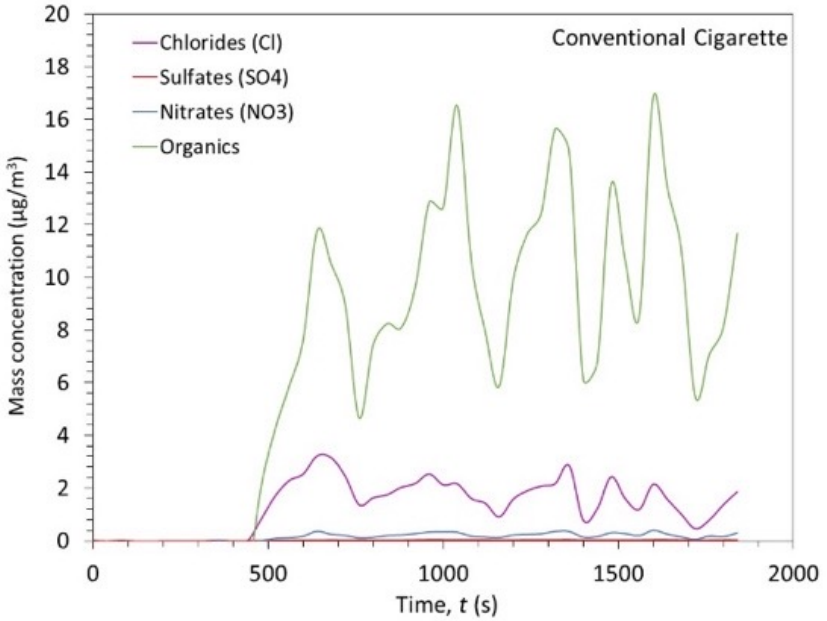
Summary of emissions

Product Type	Organic comp. (mg per stick or cig.)	SO_4 (µg per stick or cig.)	NO_3 (µg per stick or cig.)	Cl (µg per stick or cig.)
HTP-1	6.20	4.20	48.4	1.3
HTP-2	9.98	8.90	43.8	1.6
CC	7.39	40.20	109.0	44.5

Results - Particle composition downstream of the VPR

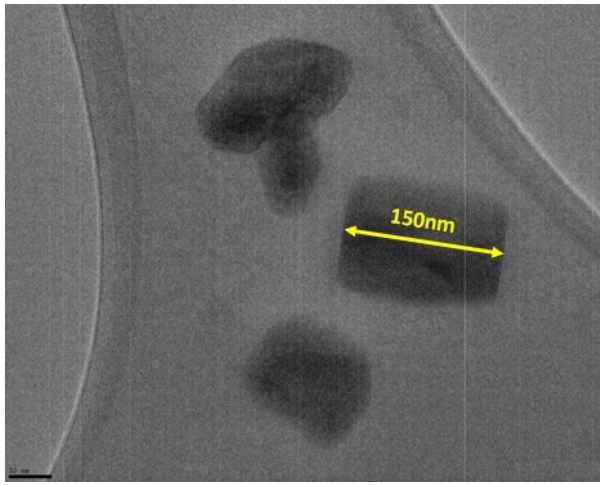


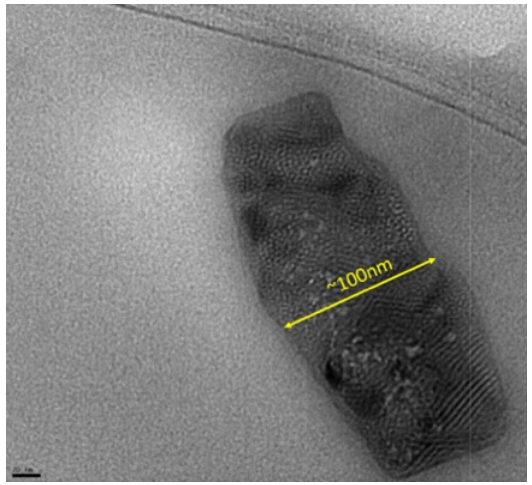




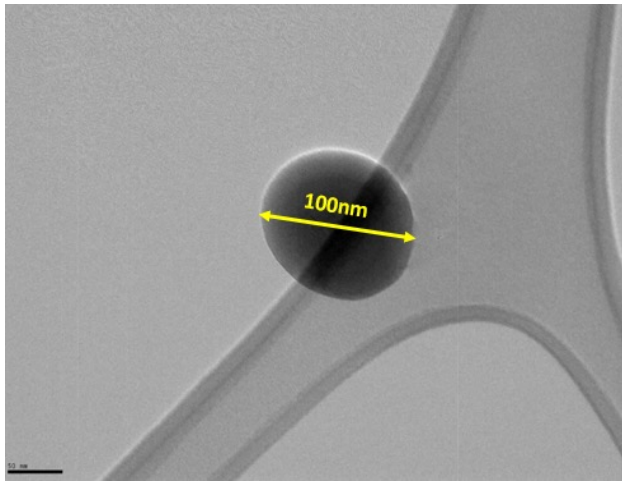
Results - Particle morphology, TEM images: CCs

Upstream of the VPR

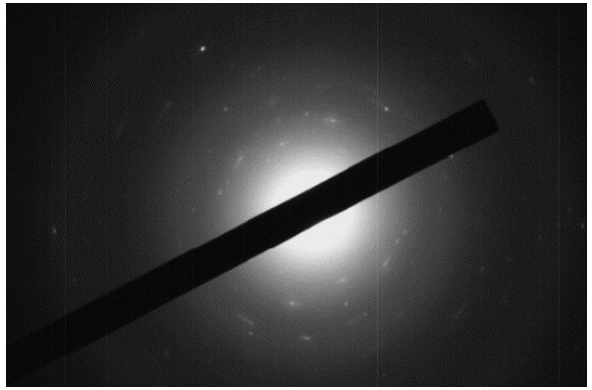


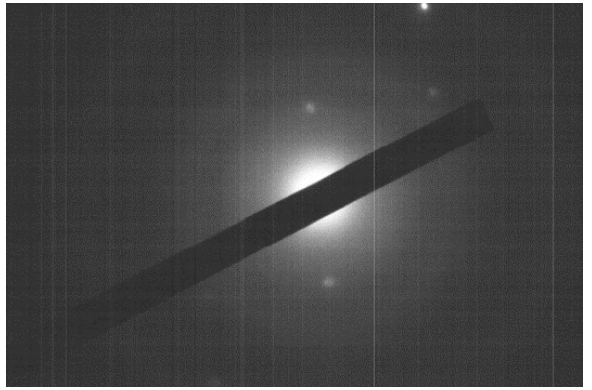


Upstream of the VPR



Electron Diffraction patterns





Summary and conclusions

- **HTPs** emit **significantly fewer particles than CCs** based on the **total particle number concentration measurements**. CCs released **a total number of particles that remained four orders of magnitude greater** than those of HTPs.
- The application of the **VPR system to HTP and CC emissions significantly reduced the particle counts.** However, **CC particle emissions downstream of the VPR were still two orders of magnitude higher than those of HTPs**.
- **HTPs** produce **larger particles (droplets) than CCs**, with particle sizes peaking between 100 and 150 nm. The majority of CC particles were within the size range of 30-70 nm, with an additional peak at approximately 250 nm.
- On average the **CC emitted 7.76 mg of elemental carbon per cigarette**. For **HTPs** the obtained value **were below the LoQ of the instrument**.
- For **CCs the CO/CO2 ratio was 0.7** while for **HTPs below 0.1 demonstrating the absence of combustion**.
- The concentration **of organic compounds was of a similar order of magnitude across all tests**. Sulphates, nitrates and chlorides **were significantly higher in the CC emissions compared to HTPs**.
- **CCs particulate matter** is in the form of **non-spherical crystalline nanostructures**. After the application of the VPR spherical and amorphous particles are observed.
- For HTPs no TEM observations were made possible due to the lack of sufficient numbers of particles.

Thank you for your attention!
Any questions?

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