High-throughput generation of aircraft-like soot

Una Trivanovic, Georgios A. Kelesidis, Sotiris E. Pratsinis
Particle Technology Laboratory, ETH Zürich, Switzerland
Motivation

Ultrafine (< 100 nm) particle air pollution [1]

Specific surface area, SSA, is one of the most important metrics for quantifying toxicity [2]

SSA [3] and pore size distributions [4] determine rate of atmospheric aging

Atmospheric aging

SSA measurement requires 10s of mg of soot!

[1] D. Westerdahl, S.A. Fruin, P.L. Fine, C. Sioutas (2008) Atmos. Environ. 42, 3143–3155.
[2] O. Schmid, T. Stoeger (2016) J. Aerosol. Sci. 99, 133 – 143.
[3] C. Marcolli, F. Mahrt, B. Kärcher (2021) Atmos. Chem. Phys. 21, (10) 7791 – 843.
[4] R. Zhang, A.F. Khalizov, J. Pagles, D. Zhang, H. Xue, P.H. McMurry (2008) Proc. Natl. Acad. Sci. USA. 105, (30) 10291 – 10296.
**Sootmercial Soot Generator**

MiniCAST:

- $d_p$ (Primary particle diameter)
- $d_m$ (Mobility diameter)
- OC/TC (Organic carbon to total carbon)

Cannot produce high-thrust aircraft soot
(OC/TC too high or $d_m$ too large)

Aircraft-like with high throughput

This work, enclosed spray flames:

[1] U. Trivanovic, G.A. Kelesidis, S.E. Pratsinis (2022) Aerosol Sci. Technol. In Press, doi: 10.1080/02786826.2022.2070055
Experimental set-up

- Thermocouple
- Rotating disk
- Sampling tube
- Air dilution
- N₂ dilution
- Pump
- X-ray Neutralizer
- Glass fiber filter
- TGA
- N₂ Adsorption
- TEM
- APM
- SMPS
- DMA
- CPC
- Sheath air
- O₂ dispersion
- Jet A1 fuel
- Premixed flame
- Burner

U. Trivanovic, G.A. Kelesidis, S.E. Pratsinis (2022) Aerosol Sci. Technol. In Press, doi: 10.1080/02786826.2022.2070055
Mobility size distributions

![Mobility diameter](dm (Mobility diameter))

$d_m$ (Mobility diameter)

Richer flame

EQR =1.25

Aircraft soot: 3% thurst [1]

85% [1]

1.59

M. Abegglen, L. Durdina, B.T. Brem, J. Wang, T. Rindlisbacher, J.C. Corbin, U. Lohmann, B. Sierau (2015) *J. Aerosol Sci.* 88, 135 – 147.

[2] D. Delhaye, F.-X. Ouf, D. Ferry, I.K. Ortega, O. Penanhoat, S. Peillon, F. Salm, X. Vancassel, C. Focsa, C. Irimiea, et al. (2017) *J. Aerosol Sci.* 105, 48 – 63.
Dynamics of soot $d_m$ and $d_p$

Median mobility, $\bar{d}_m$, or primary particle $\bar{d}_p$ diameter (nm)

Aircraft soot $\bar{d}_p$ from 10 – 20 nm [1,2]

Equivalence ratio, EQR

1.2
1.3
1.4
1.5
1.6

$EQR = 1.46$

$\bar{d}_p = 14.1$

$EQR = 1.34$

$\bar{d}_p = 13.6$

$EQR = 1.29$

$\bar{d}_p = 13.5$

$EQR = 1.59$

$\bar{d}_p = 14.3$

[1] A.M. Boies, M.E.J. Stettler, J.J. Swanson, T.J. Johnson, J.S. Offert, M. Johnson, M.L. Eggersdorfer, T. Rindlisbacher, et al. (2015) *Aerosol Sci. Technol.* 49, 842 – 855.

[2] A. Liati, B.T. Brem, L. Durdina, M. Vögtli, Y.A.R. Da Silva, P.D. Eggenschwiler, J. Wang (2014) *Environ. Sci. Technol.* 48, 10975 – 10983.
Organic carbon total carbon ratio

![Graph showing the relationship between equivalence ratio (EQR) and organic carbon to total carbon ratio (OC/TC).]

OC/TC from: Thermal Optical Analysis, TOA

High thrust aircraft soot: TOA [1-4]

[1] F. Cavalli, M. Viana, K.E. Yttri, J. Genberg, J.-P. Putaud (2010) Atmos. Meas. Tech. 3, 79 – 89.
[2] D. Delhaye, F.X. Ouf, D. Ferry, I.K. Ortega, O. Penanhoat, S. Peillon, F. Salm, X. Vancassel, C. Focsa, C. Irimiea, et al. (2017) J. Aerosol Sci. 105, 48 – 63.
[3] M. Elser, B.T. Brem, L. Durdina, D. Schönlenberger, F. Siegerist, A. Fischer & J. Wang (2019) Atmos. Chem. Phys. 19, 6809 – 6820.
[4] I. Marhaba, D. Ferry, C. Laffon, T.Z. Regier, F.X. Ouf, P. Parent (2019) Combust. Flame 204, 278 – 289.
Mass concentration

Median mobility diameter, $\bar{d}_m$ (nm)

Mass concentration, $M$ (mg/m$^3$)

0.3 mg/min

18 mg/min

MiniCAST 5201 [1]

Enclosed spray combustion [2]

3 orders of magnitude

[1] M. Ess & K. Vasilatou (2019) Aerosol Sci. Technol. 53, 29 – 44.
[2] U. Trivanovic, G.A. Kelesidis, S.E. Pratsinis (2022) Aerosol Sci. Technol. In Press, doi: 10.1080/02786826.2022.2070055
Pore size distributions

Pore area, $dA/d\log (w)$ (m$^2$/g)

Pore width, $w$ (nm)

100% thrust [1]
1.59
258 m$^2$/g

85% thrust [2]
1.34
239 m$^2$/g

EQR = 1.29
SSA = 160 m$^2$/g

1.46
282 m$^2$/g

[1] D. Delhaye, F.-X. Ouf, D. Ferry, I.K. Ortega, O. Penanhoat, S. Peillon, F. Salm, X. Vancassel, C. Focsa, C. Irimiea, et al. (2017) J. Aerosol Sci. 105, 48 – 63.
[2] M. Abegglen, L. Durdina, B.T. Brem, J. Wang, T. Rindlisbacher, J.C. Corbin, U. Lohmann, B. Sierau (2015) J. Aerosol Sci. 88, 135 – 147.
Conclusions

- Aircraft-like soot is generated here by enclosed spray combustion by varying EQR

- The present reactor can produce up to 3 orders of magnitude larger mass concentrations than existing generators

- Aircraft soot is primarily non-porous but at take-off (100% thrust) there may be an increase in porosity.
Thank you for listening