SMOKE AEROSOL PROPERTIES

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Study Objectives

- Tobacco smoke diameters 180 – 860 nm in literature (e.g. Ingebrethsen (1986), McRae (1990), Bernstein (2005))
- Improve time-resolved measurement of mainstream tobacco smoke particles – by puff?
- Address existing measurement issues
  - Light scattering intensity $\alpha d^{-6}$ and $d << \lambda_{\text{vis}}$
  - Condensation & evaporation effects
  - Coagulation effects
- Validated by measurement of cigarette design matrix for filter ventilation, filter pressure drop and paper permeability
Thermal and Physical Processes Inside a Burning Cigarette

Mainstream Smoke
$10^{10}$ particles/puff

Light gases Diffusing Out

Sidestream Smoke

Sidestream Gases

A: Combustion Zone-950°C
B: Pyrolysis & Distillation Zone <600°C

Air

Coagulation
Condensation
Elutriation
Filtration

Supersaturation
Nucleation
Condensation

Natural Convection
Definitions

GSD = SQRT(d_{84}/d_{16})

Typically = 1.6-1.8 for MS
Cigarette Design Parameters

- Filter Ventilation ▲, smoke yields ▼
- Paper Permeability ▲, smoke yields ▼ (but small magnitude effect)
- Filter Pressure Drop ▲, smoke yields ▼
Measurement Campaign

- **Cigarette**
  - 24.6 mm circumference
  - 84 mm rod
  - 27 mm filter
  - Lamina (Virginia, Burley, 1:1, Oriental)

- **Smoking**
  - 35 ml puff
  - 2 s duration
  - 60 s interval
  - 8 puffs
  - 4 replicates

- **Dilution**
  - 50:1 Dilution ratio

- **Measurement**
  - diameter by Cambustion DMS-500
  - number concentration by TSI Model 3022 CPC
  - calibration with PSL standards
Measurement Sequence

DMS500 Dynamic Particle Spectrum

Particle Diameter (nm)

Count Median Diameter (nm)

Time (s)

Count (Normalised)

Puff 1
Puff 2
Puff 3
Puff 4
Puff 5
Puff 6
Puff 7
Puff 8

Sample aerosol inlet
Aerosol charger
Sheath air flow
Charged particle trajectories
Grounded electrode rings
High voltage electrode

Play Speed
5x
Smoking & dilution
Calculated Transport Times

Rotating Disk

Instrumentation

83 mm (KS) cigarette

Unventilated

0.09s - 0.25s - 0.054s - 0.101s

Ventilated – Puff 1

0.09s - 0.25s - 0.067s - 0.168s

Ventilated – Puff 8

0.09s - 0.25s - 0.067s - 0.021s

Flow = 1.05 l/min
Electrical mobility spectrometer
Data output – 100 ms resolution

DMS500 Dynamic Particle Spectrum

Particle Diameter nm

Time (s)

dN/dlogDp /cc

Play Speed 5x

3.E+08

2.E+08

2.E+08

1.E+08

2.E+08

3.E+08

5.E+07

0.E+00

0.0 3 6 10 18 32 56 100 178 316 562 1000

130.0 130.0 131.0 131.0 132.0 132.0 132.0

0.E+00 5.E+07 1.E+08 2.E+08 2.E+08 3.E+08

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Puff Analysis

Count Median Diameter (nm)

Count (Normalised)

- Puff 1
- Puff 2
- Puff 3
- Puff 4
- Puff 5
- Puff 6
- Puff 7
- Puff 8
Diameter v Filter Pressure Drop

\[ y = 0.29x + 203.33 \]

\[ R^2 = 0.04 \]

DMS d50 diameter (nm)

Filter pressure drop (mm WG)

\[ y = 0.29x + 203.33 \]

\[ R^2 = 0.04 \]
Diameter v Paper Permeability

$y = 0.0229x + 224.45$

$R^2 = 0.0004$
Diameter v Ventilation

Median diameter (nm)

Filter Ventilation (%)

\[ y = 1.24x + 181.03 \]

\[ R^2 = 0.87 \]
Particle Number $v$ Ventilation

$y = -8 \times 10^8 x + 8 \times 10^{10}$

$R^2 = 0.8823$
Measured v Predicted Tar Mass

\[ y = 0.96x + 0.63 \]

\[ R^2 = 0.88 \]
Summary

• Electrical mobility techniques have shown value in real-time smoke measurement with respect to sensitivity & time resolution at minimal transit time & dilution ratios

• Strong relationship observed for cigarette filter ventilation versus NFDPM and specific PM associated chemicals, particle diameter, number concentration

• Calculated particle mass in good agreement with ISO machine smoking

• Aerosol changes consistent with residence time changes in rod & filter, that is coagulation drives particle growth and reduction in particle number