An Integrated Two-Stage Circumferential Slot Virtual Impactor (CSVI) for Concentrating Bioaerosols

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Roadmap

• CSV1 Description
• CSV1 System and function
• 2nd stage performance
• 1st stage development and performance
• Sheath flow in the transportation
• Performance of the entire system
• Summary
Fractionation Stages of the 100 L/min CSVI Unit

- 1st Stage
- 2nd Stage
Airflow in a CSVI Stage

Flow Inlet

Major Flow
~45%
Low-Inertial Particles

Exhaust Tube

Minor Flow, ~10%
High-Inertial Particles

Major Flow
~45%
Low-Inertial Particles

Flow Separation in Critical Zone

Axis
Integrated Two-Stage CSVI System

- Two CSVI stages in series.
- Inlet flow rate of 100 L/min, ideal concentration ratio of 100X.
- Cutpoint of 2.3 μm AD. Minor flow transmission efficiency >80% for 3 - 10 μm particles;
- Small pressure drop so power requirement will be low.
2nd Stage Performance

Minor Flow Transmission Efficiency

Particle Stokes Number, Stk
Results for 2\textsuperscript{nd} Stage

- Transmission efficiency is over 90\% for particles size range of 3-20 μm AD.
- At a flow rate of 10 L/min, cutpoint is about 2.2 μm AD and the pressure drop is about 125 Pa (0.5 inches of water);
- Robust performance
  - Can be operated up to 40 L/min, cutpoint is about 1 μm AD;
  - Imbalance between major flow exhaust ports of as large as 10\% does not change the minor flow transmission efficiency.
Design of the 1st Stage

- Unstable flow in an earlier 1st stage; manifested by pulsating noise and low efficiency

- Stable flow in 2nd stage; high efficiency
Unstable Flow in Early Version of 1st Stage
Revised 1\textsuperscript{st} Stage Design: Stable Flow but Losses in Wakes of Support Posts

- Wake flow downstream of posts;
- CFD analysis and solution: Move posts outward to eliminate problem.
Final 1st Stage Prototype Performance

![Graph showing the relationship between Particle Stokes Number, Stk, and Minor Flow Transmission Efficiency. The graph includes a line for Simulation and dots for Experiment data points.]
Results and Conclusions from Efforts on Modifying the 1st Stage

• Minor flow transmission efficiency is > 90% for particles size in the range of 3-11 \( \mu m \) AD.
• At a flow rate of 100 L/min, cutpoint is about 2.2 \( \mu m \) AD and the pressure drop is about 500 Pa (2.0 inches of water).
• CFD accommodated analysis of flow patterns and particle behavior in such a device.
• Upstream disturbances, such as wakes from posts, can propagate into the CSVI and degrade performance.
CSVI System with Sheath Flow

- Minor flow jet from 1st CSVI stage has a velocity of about 4 m/s;
- Inertia and gravity have same direction and cause loss of large particles on body of second stage;
- Without sheath flow, total transmission of 10 μm AD particle was only about 5%;
- Solution: sheath flow
CSVI System: Sheath Flow

- Sheath flow can form a stagnation region above the cone and displace the boundary layer;
- Sheath flow must be properly introduced.
CSVI System: Sheath Flow
Performance of the Complete 100 L/min System. With sheath flow, transmission efficiency for the integrated two-stage system is >80% for the size range of 2.5 to 10.5 µm AD. Cutpoint is about 2.3 µm AD.
Summary

• An integrated two-stage Circumferential Slot Virtual Impactor (CSVI) bioaerosol concentrator is described that has stable flow and performance.

• The two-stage system has a high transmission efficiency (>80%) for 2.5-10.5 μm AD particles; and, >90% for 3 – 8 μm AD particles.

• The system has a dynamic range of 35. Dynamic range is the ratio of the upper limit of Stokes number for which the transmission efficiency is at least 50% to the Stokes number of the cutpoint size.

• Sheath air flow, introduced at a fraction of 1% of the main flow, is effective in achieving suitable aerosol transmission from the 1st to the 2nd stage.
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