Design of a high efficiency cyclone for collection of rare and low concentration airborne pathogens

Baxter, R; Johnston, I; Kaye, R; Munro, I; Tracey, M; Day, R; & McCluskey, D

¹University of Hertfordshire, MEMS research Group, Hatfield, UK
Who we are

• University of Hertfordshire’s MEMS group conducts applied research in microfluidics and micro engineering
  ➔ Concept design
  ➔ Experimental testing
  ➔ System delivery

• BBSRC project - work package 4: Airborne spore trapping networks, improving understanding of spread and development of a distributed network (spore trapping)

Research Assistant :- Richard Baxter BEng MSc
Supervisor/Chief Engineer :- Dr Dan McCluskey
Head of group :- Professor Mark Tracey
Target Pathogen is Chalara Fraxinea. This pathogen is responsible for Ash dieback that has been killing Ash trees in Europe and is now established in the UK.
Spore size
Important to know the target specification for our Airborne sampler

CF spores dyed with cotton blue at x400 magnification, courtesy of Ian Britain, FERA

<table>
<thead>
<tr>
<th>Common name</th>
<th>Pathogen</th>
<th>Particle Size (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash dieback</td>
<td>Hymenoscyphus fraxineus (Chalara Fraxinea)</td>
<td>17.6-28</td>
</tr>
<tr>
<td>Septoria leaf blotch</td>
<td>Septoria tritici</td>
<td>2x50</td>
</tr>
<tr>
<td>Yellow Rust</td>
<td>Puccina Striiformis</td>
<td>22x17</td>
</tr>
<tr>
<td>Brown Rust</td>
<td>Puccinia Triticina</td>
<td>22x27</td>
</tr>
</tbody>
</table>

Table of some economically important agricultural pathogens
Cyclone design

Two main types of Cyclone:-

1. Axial
2. Reverse flow

Main Design Specifications:-

- 7 day sampling
- High volumetric air flow (100 L/min)
- Consumable part that can disposed of for contamination purposes
- High collection efficiency for the particle size range
- Chemically resistant (Teflon, Laser sintered PA 2200, Polypropylene)
Cyclone theory

University of Hertfordshire has research licenses for:
1. STAR CCM+
2. ANSYS CFX
3. Solidworks Flow Simulation
Initial Stairmand design ratio used as follows

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Ratio</th>
<th>Stairmand</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Body diameter</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Inlet height</td>
<td>$K_H = H/D$</td>
<td>0.5</td>
</tr>
<tr>
<td>W</td>
<td>Inlet width</td>
<td>$K_W = W/D$</td>
<td>0.2</td>
</tr>
<tr>
<td>S</td>
<td>Outlet length</td>
<td>$K_S = S/D$</td>
<td>0.5</td>
</tr>
<tr>
<td>De</td>
<td>Outlet diameter</td>
<td>$K_{De} = De/D$</td>
<td>0.5</td>
</tr>
<tr>
<td>L1</td>
<td>Cylinder height</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>Cone height</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

Calculated Cyclone Collection Efficiencies

50% Cut size = 1.613 μm
Design iterations

Many different designs were designed and tested

<table>
<thead>
<tr>
<th>Centrifuge Tube</th>
<th>Inner Diameter</th>
<th>Outer Diameter</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 ml</td>
<td>27.5 mm</td>
<td>29.5 mm</td>
<td>114.2 mm</td>
</tr>
<tr>
<td>25 ml</td>
<td>21.9 mm</td>
<td>24.9 mm</td>
<td>90 mm</td>
</tr>
<tr>
<td>15 ml</td>
<td>14.5 mm</td>
<td>17.3 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>5 ml</td>
<td>14.2 mm</td>
<td>15.9 mm</td>
<td>57 mm</td>
</tr>
</tbody>
</table>

3D Printed ABS plastic

PA 2200 Laser sintered cyclone with PEEK tube
Final Design

In House Manufacturing

3D printing
3 Axis CNC

Teflon involute inlet
Aluminium Vortex finder with O-ring seal
Teflon bottom seal
Aluminium interface with test tube

3D printed Tube Adapter
Cyclone Testing

- Particle deposition on falcon tube

<table>
<thead>
<tr>
<th></th>
<th>3μm</th>
<th>5μm</th>
<th>50μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate (L/min)</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Collection Efficiency</td>
<td>96.1%</td>
<td>98.3%</td>
<td>99.1%</td>
</tr>
</tbody>
</table>

SO₂ (Silica) spheres
- Mean = 3 μm
- σ = +/- 0.8 μm

SO₂ (Silica) spheres
- Mean = 5 μm
- σ = +/- 1.9 μm
Aerosol Chamber Testing

5 μm Aerosol TSI OPC test data

PSL
Mean = 2.9 μm
Uniformity = <5%

PSL
Mean = 5 μm
Uniformity = <5%
Impellers

Main Design specifications:-

- Low power
- Flow rate of 100 L/min
- Pressure requirements

Impeller
- High rpm ~ 20,000 rpm
- Pressure ratio of 1.2

Volute
- Compact
- Good pressure recovery

Motor and Heat sink
- Brushless Motor
- Aluminium heat sink
Impeller Testing

Test rig for impellers

Air mover Performance Curve

Number of Vanes

- Impellers with Intervanes (Splitter Blades)
- No Intervanes (Splitter Blades)
Presented today was Airborne collection of spores in the Chalara Fraxinea size range

- Novel Cyclonic collector
- Energy Efficient Air mover

Further optimisation of the efficiency and operation of the cyclone is a focus of ongoing work.
Thank you for listening