The effect of wind-induced motion on wind pollination

October 23, 2013

Julian Krick and Joe Ackerman

Physical Ecology Laboratory
Department of Integrative Biology
University of Guelph
Wind pollination (pollen release, transport, & capture) is widespread (conifers, ~18% of Angiosperm families including economically & ecologically important species).

Little is known about pollen capture mechanisms mostly from empirical study & aerosol filtration theory.

Theoretical models are based on static collectors and laminar airflow conditions.
Aerosol Filtration Theory

- Gravitational Deposition
- Direct Interception
- Inertial Impaction
- Diffusional Deposition
- Electrostatic Attraction
- Leeward Deposition
Aerosol Filtration Theory

Rigid Cylinder

\[
\eta_{\text{front}} = \frac{1}{9} s R^2 \cdot \text{Re} = \text{ability to follow flow}
\]

(Haugen & Kragset 2010)
Leeward Capture: A Controversy (!)

What is the effect of plant motion on pollen capture?

Does it enhance leeward sedimentation?

Niklas (1987):
35 – 70% leeward sedimentation for strong oscillation

Cresswell et al. (2010):
5% leeward sedimentation for non-oscillating plant
Model and Parameters:
- Input parameters were taken from published values.
- Response of flow and structure influence particle capture.

Three Components

(1) Flow
- Reynolds number
  (F inertial: F viscous)
- mass, damping, flexibility
- Stokes number (particle momentum)

(2) Structure
- spring-mass damp., free osc.
- amplitude, frequency
- capture efficiency

(3) Particles
- drag
- capture
- flow field with vortices
Modeling Domain (FVM mesh)  Methods

- **Far field**: 2,002 hexahedral cells
- **Near field**: 38,814 hexahedral cells moves with cylinder
Pollen Capture

Methods

Experiments: (1) capture on rigid cylinder (compare to literature) (2) flow-induced vibration (compare to literature) (3) capture on FIV cylinder in steady flow (4) capture on FIV cylinder in unsteady flow

Comparisons: (a) low vs. High Reynolds number (Re) (b) pollen with 5 different Stokes number (Stk)

\[ \text{Stk} = \frac{1}{9} \cdot s \cdot R^2 \cdot \text{Re} \]

\[ s = \frac{\rho_{\text{particle}}}{\rho_{\text{fluid}}} \]

\[ R = \frac{D_{\text{particle}}}{D_{\text{collector}}} \]

\[ \text{Re} = \frac{D_{\text{collector}} \cdot u_{\text{fluid}}}{\nu_{\text{fluid}}} \]

\[ \eta = \frac{N_{\text{captured}}}{N_{\text{released}}} \cdot \frac{D}{l} = f(\text{Stk}) \]
Running the Model

Results

The generated flow fields and the interaction of particles within those fields near the cylinder.

Flow field downstream of cylinder

Particles in the flow field downstream of cylinder
Verification of Model

Capture on rigid cylinder
Cylinder with flow-induced vibration
Results agree well with reference (error < 10 %)

Capture on static cylinder

Amplitude of oscillating cylinder
- Khalak & Williamson (1996)
- Guilmineau & Queutey (2004)
- Benchmark simulations

Frequency of oscillating cylinder
- Guilmineau & Queutey (2004)
- Benchmark simulations
- $f_c = f_n$
- Fixed
Effect of Oscillation (1)

Results

Direction of Oscillation

\[ \Delta \eta_{tot}^{rel} \bigg|_{y} > \Delta \eta_{tot}^{rel} \bigg|_{x} \]

- \( \text{Re3309 steady } A_{\text{large}} \)
- \( \text{Re3309 steady } A_{\text{small}} \)
- \( \text{Re662 steady } A_{\text{large}} \)
- \( \text{Re3309 unsteady } f_{\text{high}} \)
- \( \text{Re3309 unsteady } f_{\text{low}} \)

100% →
Effect of Oscillation (2)

**Results**

**Amplitude & Frequency** – strong effect in transverse oscill.
Effect of Oscillation (3)

Results

Stokes and Reynolds No. – high $\eta$ for low Re and Stk

![Graph showing the relationship between $\Delta n_{\text{rel}}$ and Stk for different regimes of flow.](image)
Leeward Deposition

Results

Stokes and Reynolds No. – high $\eta$ for low $Re$ and $Stk$

Capture by chasing
Discussion

**Capture efficiency** of oscillating collector is significantly different (- 30 → 500%) from current rigid model.

Capture efficiency **depends on** (1) **direction of oscillation**, amplitude, Reynolds and Stokes number.

A **moving collector is ecologically more relevant** and may have higher capture efficiencies than a rigid cylinder, and our models will need to be updated.

**Leeward capture** occurs under oscillation and can be extremely important (30 – 70%) depending on conditions.

Oscillation leads to a **new capture mechanisms**
Conclusion

There is **major implications** for pollen capture from the present study.

**Ecologically more relevant conditions** should be used to inform our understanding and modeling of important plant life history events.

By integrating fluid dynamics with biology (i.e., *Physical Ecology*) we can advance our understanding of complex processes.

We are currently using **physical models** to verify these findings, which will also been examined in **grasses in the field** this summer.
A/D vs. f for my cases and range for terrestrial/aquatic pollination
Boundary and Initial Conditions:

- **Steady flow**
- **Unsteady flow**

### Parameters

- **Re**
  - Steady: 3309
  - Unsteady: 662
  - Mean: 3309

- **A/D Oscillation**
  - Large: 86%
  - Small: 6%
  - Static: 73%
  - Mean: 86%

- **f_cylinder**
  - Large: 110 Hz
  - Small: 106 Hz
  - Static: 27 Hz
  - Mean: 48 Hz

- **Stk**
  - Large: 106%
  - Static: 48%
  - Mean: 47%

- **Wind pollination**
  - Stk: 0.01, 0.1, 0.3, 1.0, 5.0
  - Aquatic pollination

- **f_inlet**
  - High: 50 Hz
  - Low: 10 Hz