Drag Characteristics of Non-Spherical Particles in Transitional Flow

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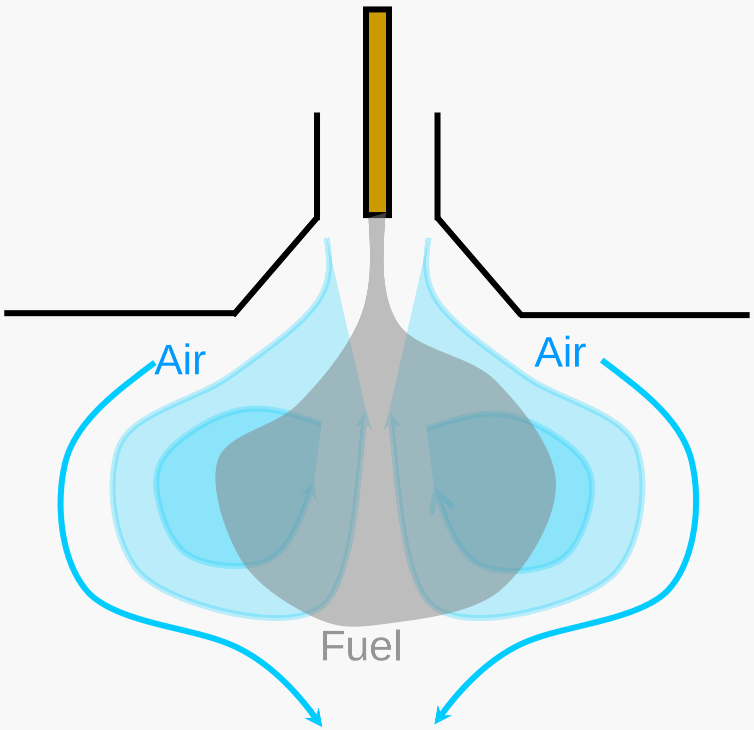
Background

Example:
Swirl Stabilized Burner



Swirl Stabilize burners involve two-phase flows.

The solid phase velocity differs from the gas phase velocity in regions of high acceleration.

The difference between the particle and gas phase velocity is call velocity slip.

Penetration of fuel relative to recirculation influences particle burnout and NO_x formation.

Relative velocities do not produce turbulence but the flow is already turbulent.

There are no measurements of drag coefficients for non spherical particles in this type of flow

Background

Typically drag coefficients are correlated with Reynolds number

$$Re = \frac{\rho V D}{\mu}$$

$$V = V_{gas} - V_{particle} = V_{slip}$$

For combustion applications

$$\rho \approx 1.0 \text{ kg/m}^3$$

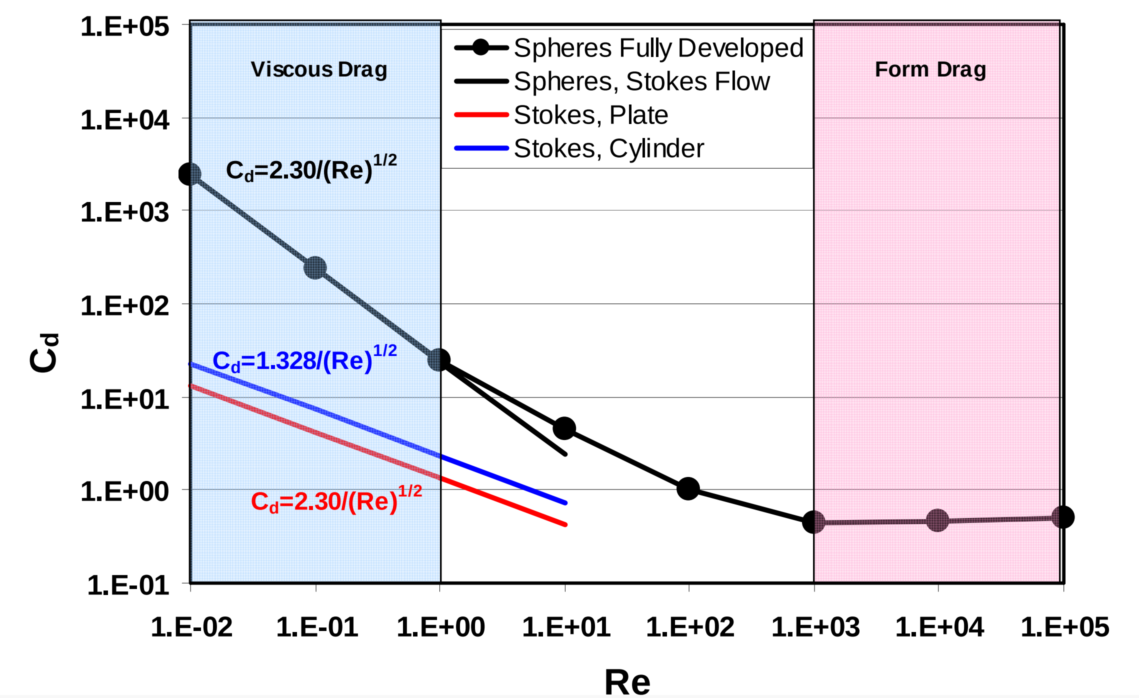
$$V_{slip} \approx 1.0 \text{ m/s}$$

$$D \approx 100 \times 10^{-6} \text{ m}$$

$$\mu \approx 20 \times 10^{-6} \text{ Ns/m}^2$$

$$Re \approx 5$$

- Re = 5 is in the transition region between stokes flow and fully developed turbulent flow
- C_d is a function of Re for small Re
- C_d is form drag dominated, not function of Re for Large Re



Objectives

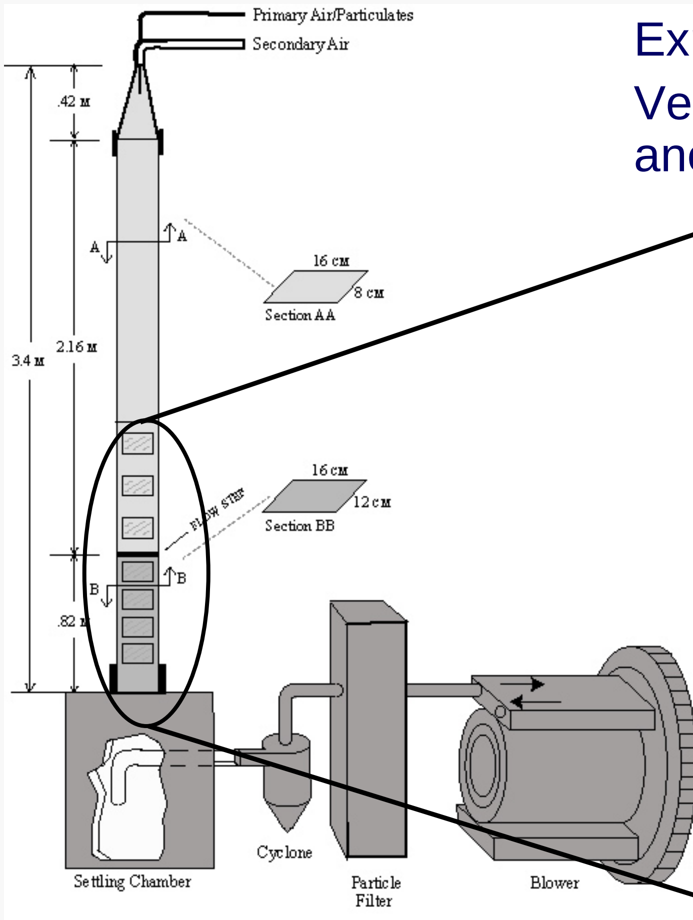
- Measure velocity of gas phase, spherical, and non-spherical particles in a backward facing step
- Compare gas phase velocity to published values and CFD predictions
- Use particle and gas phase measurements to determine the drag coefficient of the particles

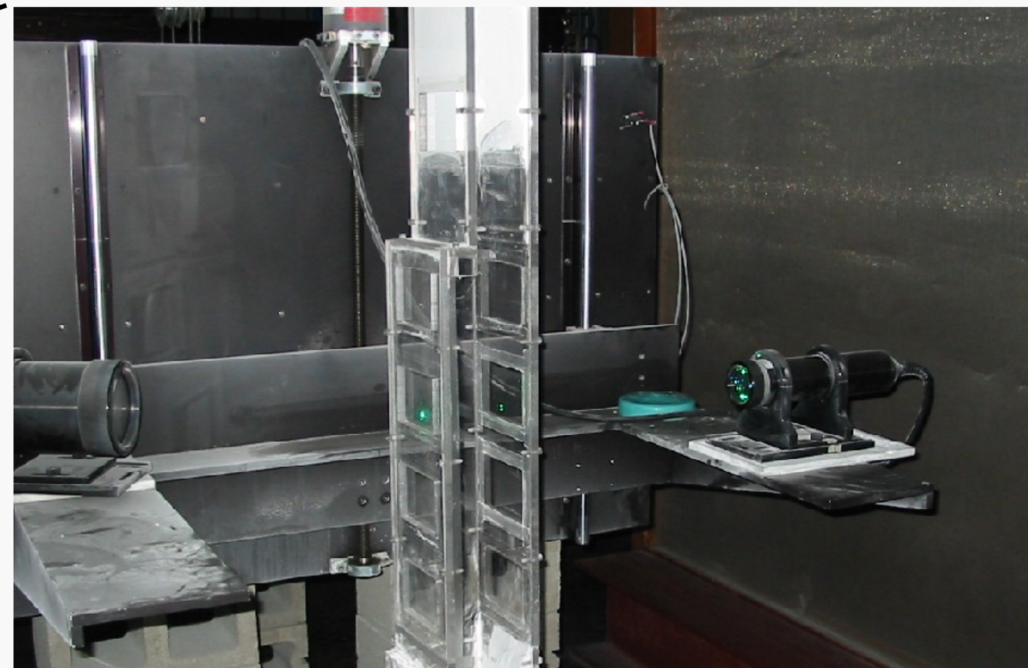
Experimental Setup

Backward facing step flow facility:

Expansion is from 2.54 to 5.08 cm

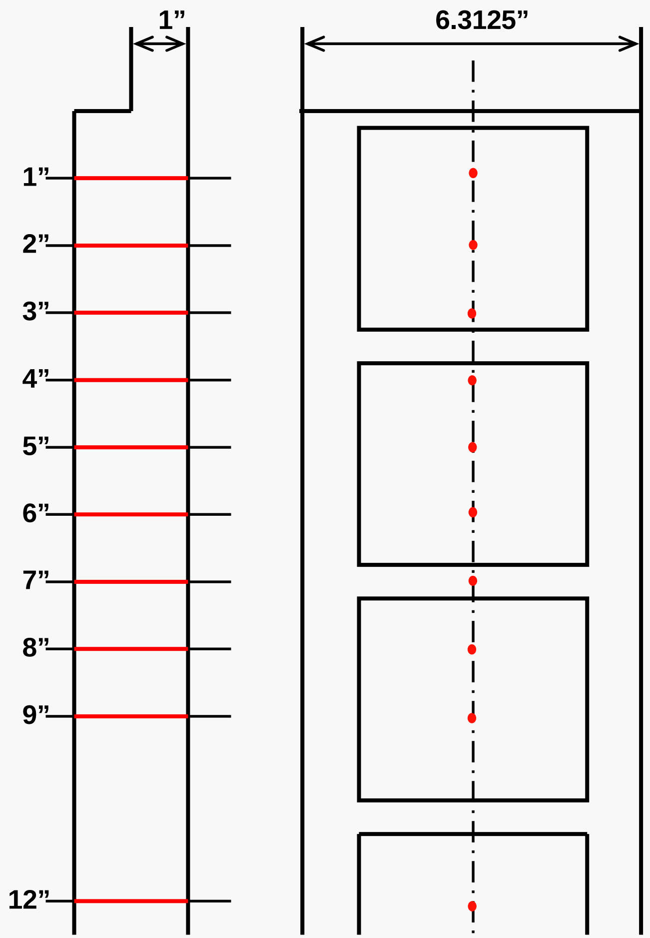
Velocity measured with a phase doppler particle anemometer (PDPA)





Inlet flow Re = 50,000

Experimental Matrix



Complete Map: 19 points at each axial location (10), total of 190 points

Gas Phase: 1-10 μm particles, 3 maps taken and repeated points when a particle velocity was taken

Spheres: 3 Sizes 41, 49, 57 μm, Three complete maps for each size

Gravel Shaped Particles: 3 sizes 50 – 150 μm, ground glass, At least one map for each size.

Flakes: 3 sizes: 96, 183, 310 μm, 5μm thick; 4 locations

Cylinders: 3 lengths 99, 151, 219 μm, 16 μm diameter; 4 locations

Terminal Velocity: 1 location for each particle size

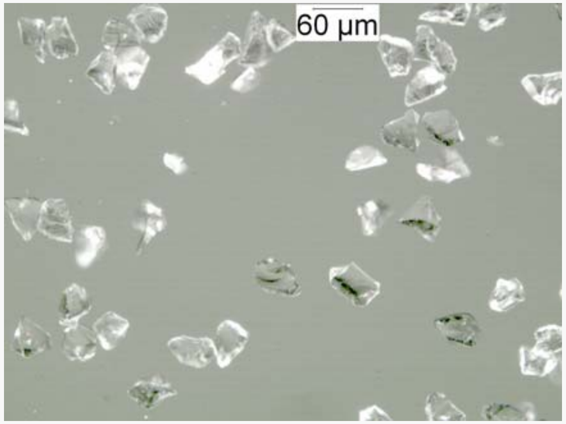
Experimental Setup

Particle Preparation

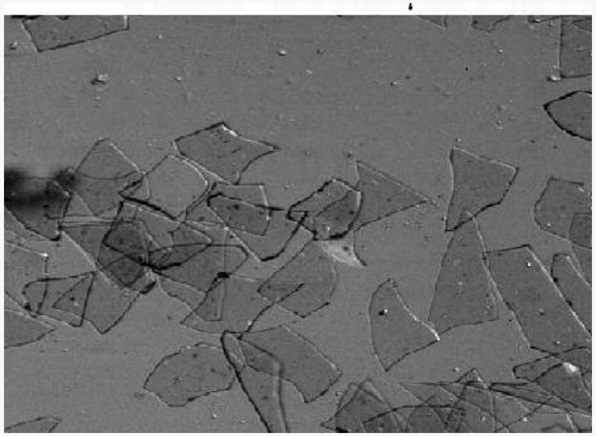
Particles were classified in a shaker, usually sieved 5 – 10 times

Small particles were a problem, they could not be physically removed

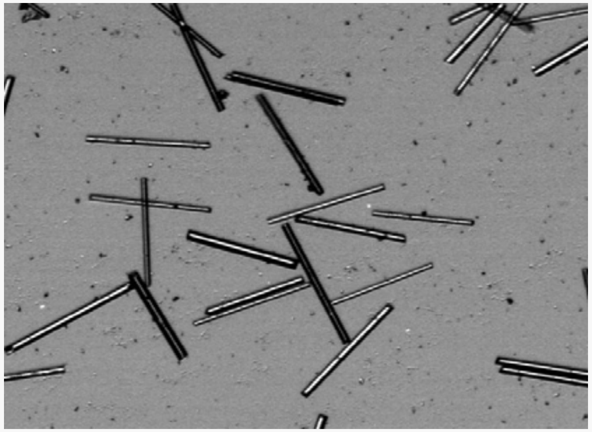
Examples of Particles



Gravel, 57µm

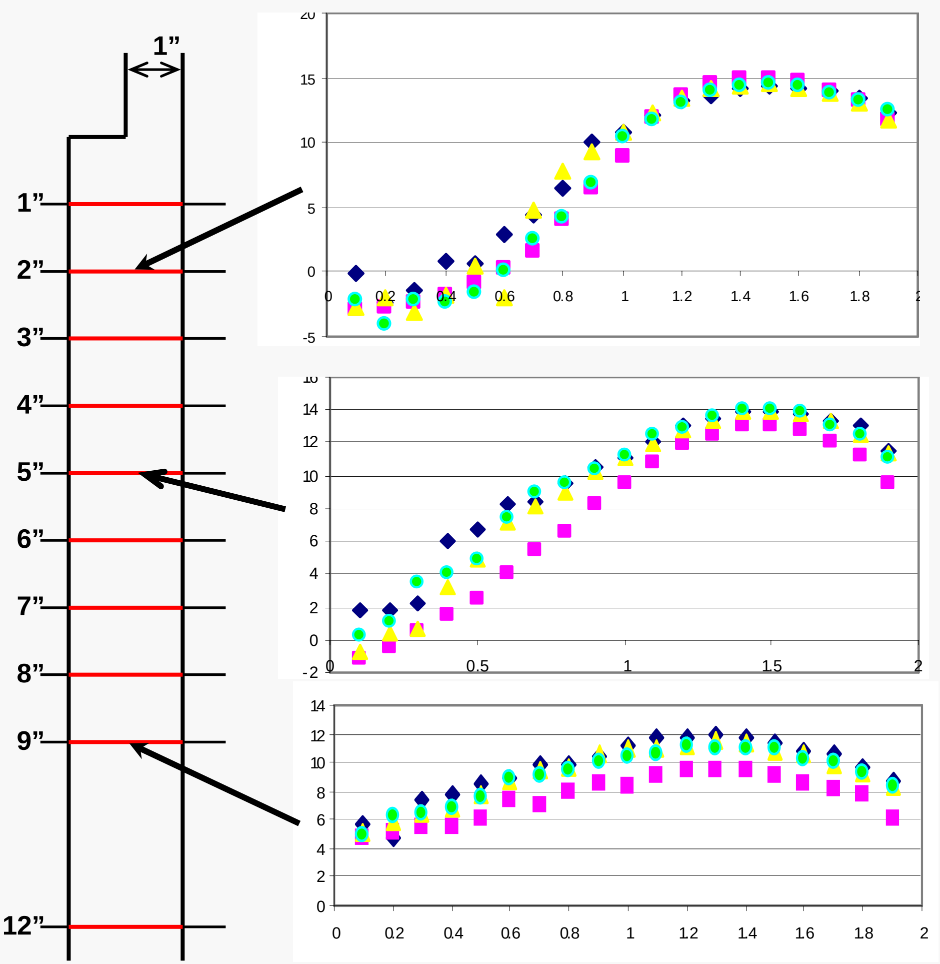


Flakes, 115µm



Cylinders, 115µm

Results - Spheres

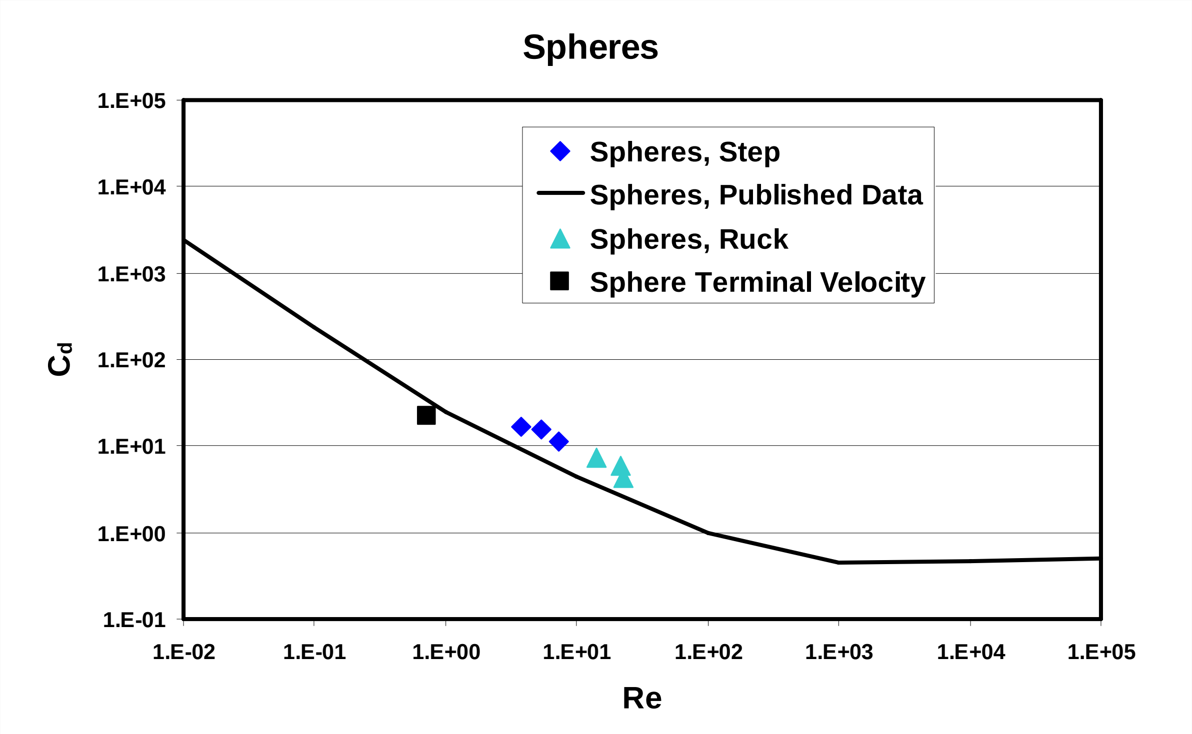


- ■ Gas Phase:
- ● Sphere 41 μm:
- ▲ Sphere 49 μm:
- ◆ Sphere 57 μm:

Flow Characteristics

- **Flow is negative or recirculates behind the step.**
- **Recirculation zones ends at about 6 step lengths below the step.**
- **Peak velocity moves from the center of the upstream geometry to center of chamber by 12 steps**
- **Particles do not decelerate as fast as the gas phase**
- **The larger the particle, the larger the velocity slip**

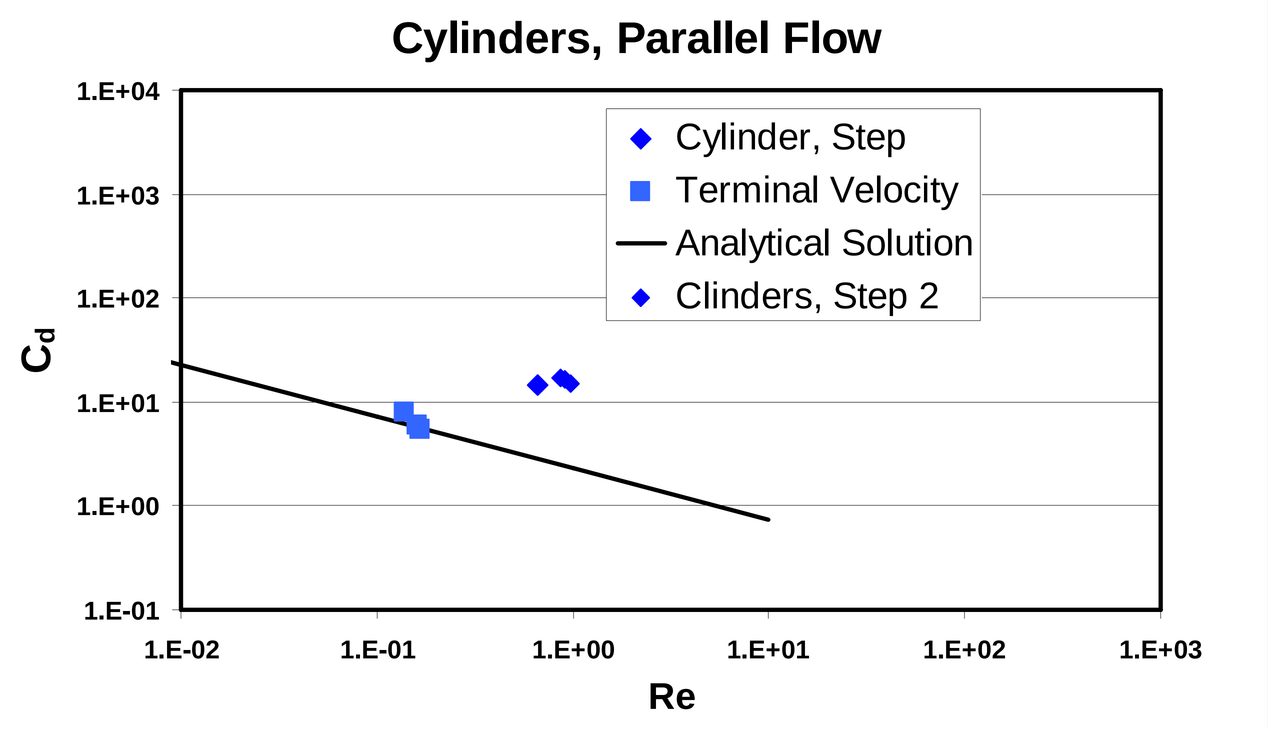
Results – Spheres, C_d



$$C_d = \frac{\frac{1}{2}\rho V_2}{m(V_2 - V_1)}$$

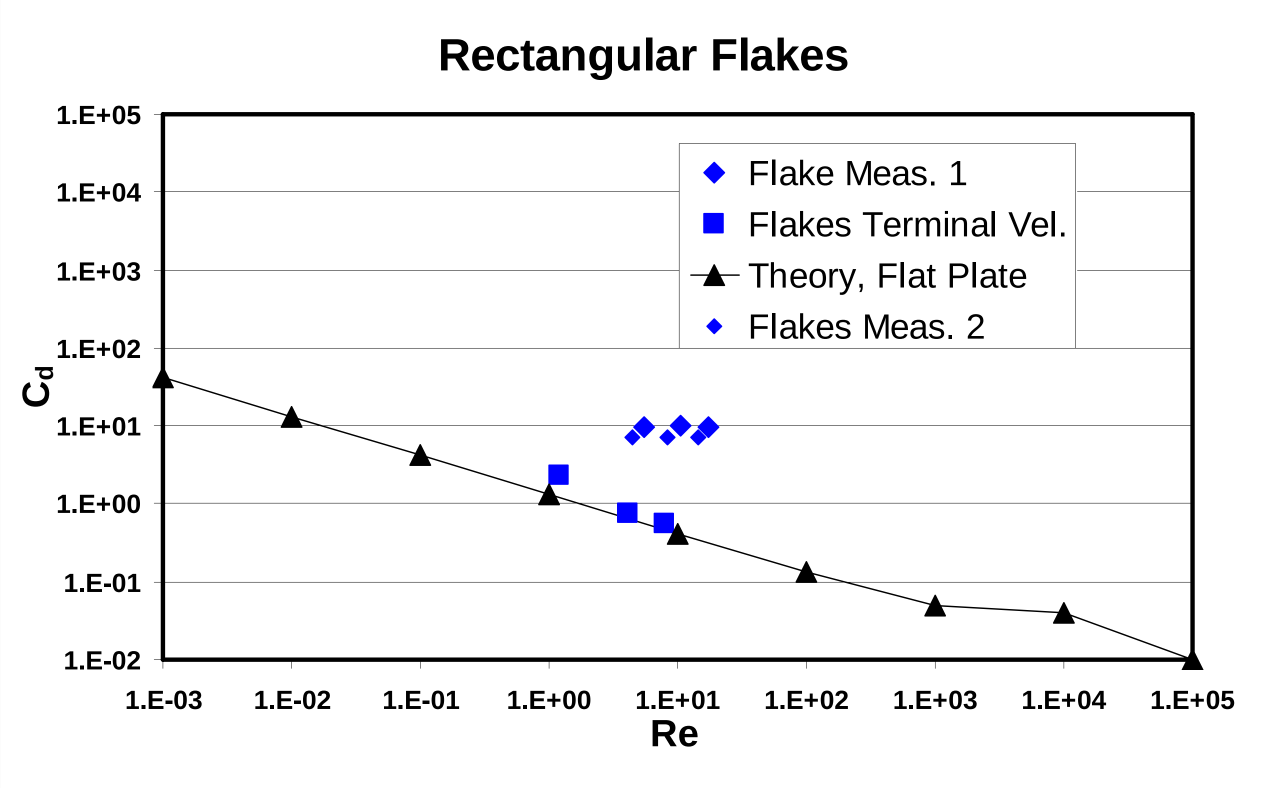
- Terminal velocity produced C_d slightly below published values.
- Both our data and data from Ruck, backward facing step flows produce C_d slightly above published value.
- C_d shows same slope and functional dependence on Re suggesting viscous friction effects, Stokes flow

Results – Cylinders, C_d



- **Terminal velocity produced C_d almost the same as flow theory.**
- **Measured C_d for the turbulent flow below the step is much higher (6 times) than theoretical value.**
- **C_d is not a function of Re as is the case for form drag only**

Results – Cylinders, C_d



- **Terminal velocity produced C_d almost the same as flow theory.**
- **Measured C_d for the turbulent flow below the step is much higher (29.5 times) than theoretical value.**
- **C_d is not a function of Re as is the case for form drag only**

Summary and Conclusions

- Velocity measurements have been obtained for non-spherical particles (gravel, flake and cylindrical shaped) in a backward facing step
- The step produces a turbulent gas phase flow that decelerates producing velocity slip for solid particles.
- Velocity slip was found to increase as particle size increased, and for a given mass, increased in the following order: flake, cylinder, gravel, and sphere.

Summary and Conclusions

- When the air was quescent, the drag coefficient measured on the particles matched published theoretical values.
- In the backward facing step, the drag coefficients were significantly higher than theoretical values, increasing with increasing asphericity.
- The aspherical drag coefficients for aspherical particles were insensitive to reynolds number suggesting drag is dominated by form drag, not viscous surface drag.

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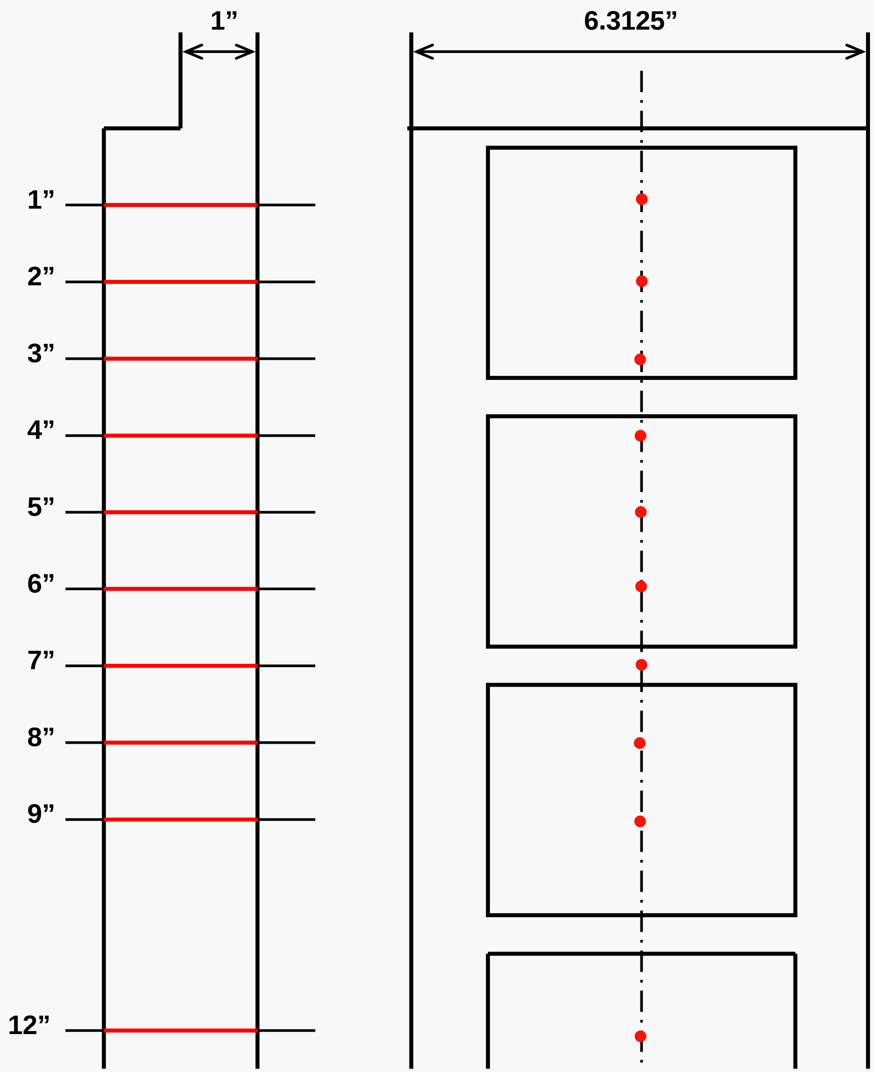
Questions

Experimental Matrix



Experimental Matrix