II Particles

Heavy seeding

Number density high enough to look like a dye

Similar considerations to dyes:

1) Particles must track with the flow
   - Dyes are molecules, track with the flow just fine.

2) Want particles to NOT disturb flow
3) Want particles to show up - HIGH VISIBILITY

1) When will particles track well, be good tracers?

Minute paper: Consider a curved streamline. Consider a small particle, much denser than the fluid, BUT small enough that gravity is negligible compared to forces of the fluid on the particle. (diameter ~ 100µm in water)

What will the particle path look like compared to the fluid path?

For particles (or bubbles) to track with the surrounding fluid, they must accelerate the same as the neighboring fluid

Forces on particle:

Body: gravity, neglect

Surface:
- normal = pressure
- parallel = shear

from fluid
In water, particles of 100 µm diameter or less, any density, will track most flows.

In air, particles of 1 µm diameter or less, any density, will track most flows.

Rules of thumb:
- In water, particles of 100 µm diameter or less, any density, will track most flows.
- In air, particles of 1 µm diameter or less, any density, will track most flows.

Similar considerations to dyes:
1) Particles must track with the flow
2) Want particles to NOT disturb flow
3) Want particles to show up - HIGH VISIBILITY
2) Want particles to NOT disturb flow

- As with dyes, minimize injection differential velocity; inject at local flow speed.
- Want particles to not introduce new forces. Avoid:
  - soluble particles
  - surface tension
  - chemical reactions
  - significant change of density
  - particle-particle interaction

- Number density of particles = # of particles / unit volume. (Contrast to mass/volume of solid alone). Keep low enough to avoid interactions.
- Particle-particle interaction (collisions, drag) lead to non-Newtonian effects. Slurries, oobleck, blood, shampoo, silly putty, other polymers. Gets into 'complex fluid' categories. Interesting field.

3) High visibility

Particles only scatter light. Interaction depends on size (d) compared to \( \lambda \).

Scattering \( \propto \sum \) of reflection, refraction, diffraction & absorption

\( d \sim O(\lambda) \): Mie scattering regime.

- e.g. visible light \( =0.7 - 0.4 \ \mu m \), so diameters of \( 1 \ \mu m \) to \( 0.1 \ \mu m \) (100 nm, 1000 Å).
- Scattering efficiency drops as particles get smaller. Better tracking, but less light.
- Independent of wavelength; no colors from particles this small. Makes clouds white.
- Particles large enough to have color are too big to track well.

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Light is not scattered uniformly:

Fraunhofer scattering

\[ \lambda < \phi \]

Mie scattering

\[ \lambda = \phi \]

Rayleigh scattering

\[ \lambda > \phi \]

Often a strong lobe at 120 degrees to incoming light. **Sweet spot**
Best to play with camera-light angles.

Smaller particles, \( d \ll \lambda \), **Rayleigh scattering regime**. Elastic collision of photons with particles. No energy exchange. Blue sky is Rayleigh scattering; sunlight scattered by molecules of air, preferentially blue. Longer wavelengths are too long to interact much; are only seen at sunset due to long passage through atmosphere, and when scattered by larger molecules of pollutants or dust.

Next: How to make or get particles

http://www.youtube.com/watch?v=DOUfyDHzkYQ&feature=related

NCFMF film 'Flow Visualization'

Hydrogen bubble technique

In air: smoke and fog
   solids    liquids

A) Smoke = soot usually, carbon particles

Smoke wire.

Drip oil onto wire
   droplets or continuous

[Flow]

\[\text{Smoke}\]

[Caution, heat = buoyancy]

NiChrome wire
   electrically heated
   stretched across flow
Most oils work. Veg is less toxic.
Generates 1μm particles. Penetrates into lungs, causes cancer, regardless of composition.

Alt technique:
pressurized air

cigarette or incense

to wind tunnel
Chemically generated particles:

TiO$_2$: Titanium dioxide particles from
titanium tetrachloride + water vapor = dense TiO$_2$ smoke + HCl
HCl + water vapor = hydrochloric acid vapor

Spectacular smoke, but toxic, and hard on equipment, corrosive