Today: Critique catch up
Particles
News: research independent study opportunities; see me

Particles
Last time, talked about where heavy or light particles will go
  Heavier than fluid, to outside of curve
  Lighter than fluid, to inside of curve.

For particles to accurately track the fluid we have

Rules of thumb:
  • In water or other liquids, 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 or effects. Avoid:
    o soluble particles
    o surface tension
    o chemical reactions
    o significant change of density
    o 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 λ.
   Scattering = ∑ of reflection, refraction, diffraction & absorption
   d ~ O(λ) : Mie scattering regime.
   e.g. visible light = 0.7 - 0.4µm, so diameters of 1 µm to 0.1µm (100 nm, 1000 Å).
   o Scattering efficiency drops as particles get smaller. Better tracking, but less light.
   o Independent of wavelength; no colors from particles this small. Makes clouds
      white.
   o Particles large enough to have color are too big to track well.
Light is not scattered uniformly:

- **Fraunhofer scattering**
  \[ \lambda > \varnothing \]

- **Mie scattering**
  \[ \varnothing = \lambda \]

- **Rayleigh scattering**
  \[ \lambda < \varnothing \]


- **Mie regime, small particles:**
  - Back scatter < Forward scatter

- **Mie regime, larger particles:**
  - Back scatter < Forward scatter

*Often a strong lobe at 120 degrees to incoming light. **SWEET SPOT**

Best to play with camera-light angles.

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.

http://www.youtube.com/watch?v=DOUfyDHxkYQ&feature=related
NCFMF film ‘Flow Visualization’
Hydrogen bubble technique

In air: smoke and fog
solids liquids

A) Smoke = soot usually, carbon particles

Smoke wire.

NiChrome wire electrically heated stretched across flow

Drip oil onto wire droplets or continuous

Flow

Caution, heat = buoyancy

Van Dyke, Milton. 
*Album of Fluid Motion*. 
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

2.1. Visualization of Flow Direction and Flow Contours

Fig. 2.6 Smoke generator designed at the University of Notre Dame. (From Mueller, 1983. Published by Hemisphere Publishing Corporation.)

Chemically generated particles:

TiO₂: Titanium dioxide particles from

\[ \text{titanium tetrachloride} + \text{water vapor} \rightarrow \text{dense TiO}_2 \text{smoke} + \text{HCl} \]

\[ \text{HCl} + \text{water vapor} \rightarrow \text{hydrochloric acid vapor} \]

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

B) Fog = aerosols of liquids

Water fog: Safe, but evaporates quickly

- ultrasonic humidifier [http://www.youtube.com/watch?v=rN-OcM5wS2I&feature=youtube_gdata_player](http://www.youtube.com/watch?v=rN-OcM5wS2I&feature=youtube_gdata_player)
- [http://www.youtube.com/watch?v=rkrLl7tJOIg&feature=youtube_gdata_player](http://www.youtube.com/watch?v=rkrLl7tJOIg&feature=youtube_gdata_player) with acoustic streaming
- medical nebulizer
- dry ice (solid CO₂)
Bernoulli atomizer
Jet nebulizer
Small Volume Nebulizer (SMN)

Inexpensive: $3
Makes 1 μm to 100μm droplets
Larger droplets impact on surfaces, can't exit device.

Liquid is delivered to jet exit by capillary action

Dry Ice Vapor: Dry ice = solid CO2
Sublimes (solid to gas) at 1 atm, -78 C (-109 F)
http://www.dryiceinfo.com/fog.htm
Submerge in hot water: much water fog created.
Fog production drops for water temperature < 50 F