Stage fog = Water + glycerin or propylene glycol. Additive slows evaporation

Fog machine

reservoir  pump  resistance heater  vaporizes liquid  condenses to  fog  upon cooling

Small machines: heater too small to run continuously. Buy at Target, 1 month before Halloween for $35. Large machines: can run continuously. For professional stage and theaters. $1000. Mfg: Roscoe, Le Maitre. 1 gallon lasts 4 hr.

Health effects are minimal, except to asthmatics and opera singers.

For fog-on-the-ground: chillers

C) Oil aerosols

- Won't evaporate unless burned. Oil has low vapor pressure.
- Use medical or Bernoulli atomizer/nebulizer

Can be used to mark flame fronts. Illuminate fog with a laser sheet = "laser tomography" in 1980s.

Danger! Oil aerosol will coat lungs ⇒ pneumonia ⇒ death

D) Dusts
AlO$_2$ = alumina, aluminum dioxide. Polishing powder, available in submicron diameters. Inexpensive.
Won’t burn; is already fully oxidized. Good for imaging individual particles in flames.
Aerosolize in a cyclone seeder:

- Large particles centrifuge to walls. Only small particles that track the flow can exit through the center. Like a Dyson vacuum cleaner.
- Inject air tangentially
- For heavy seeding, try a fluidized bed.

Particles for Water
Hydrogen bubbles (discussed below)
Electrolytic precipitation

Rheoscopic fluids:
- Pearl Ex (art pigment, TiO$_2$ coated mica)
- Pearl Swirl (Steve Spangler Science)
Kalliroscope: expensive Pearl Swirl fish scales?

For individual particle images (PIV)
Corn starch (diluted)
Glass or polystyrene microspheres
Latex bubbles
Rust (filtered)
Alumina
Wax beads (Pine Sol)

Pine pollen (floats on surface)
Lycopodium powder (also used as flash powder)
http://vimeo.com/89491724 Cymatics

Want neutral buoyancy, but for very small particles viscous forces are high. Can use up to 100 µm particles. Good scatterers.

Van Dyke's Album of Fluid Motion

Hydrogen Bubbles

Smallest H₂ bubbles if wire is very thin. Bubbles ≈ 1/2 to 1 wire diameter
≈ 25 to 50 µm
Want small enough bubbles to track flow, and have a slow rise time, so < 100 µm needed.
Best if wire is platinum. Other wires oxidize, and don’t provide a clean sheet of bubbles.
Minute paper: Why not use O2?

For same current, get half as much O₂
- diffusivity
- relative solubility
- surface tension

Need 50 - 70 VDC, 1 amp minimum.
For long wires (200 mm) need 250 V, 2 amps
Expensive power supply.

The water must conduct well.
Add salt. Some refs say sodium sulfate is better than sodium chloride, table salt.
Weak acid or base would also conduct, but may eat wire.

Too much salt = bigger bubbles

Pt wire, tight and smooth. Big bubbles form at kinks.

Any ions in the water are attracted to the electrodes, so material plates onto the electrodes, fouls the wire.
"Cleaning" = Reverse polarity briefly now and then for a few seconds

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**Electrolytic Precipitation Technique**

* Same circuitry as H₂ bubbles, but 10VDC, 10 mA. Much more reasonable requirements but....
* Tracer is electrolytically precipitated oxide at anode, of anode material.
* Metal often used = solder = tin+lead. Two heavy metals you don’t want to put down the drain; needs 5 um filter.

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![Image](image_url)

* Electrolytic precipitation of a metal oxide on Pt wire. (Image credit: author)

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* Minute paper: Why not use O₂?

For same current, get half as much O₂
- diffusivity
- relative solubility
- surface tension

Need 50 - 70 VDC, 1 amp minimum.
For long wires (200 mm) need 250 V, 2 amps
Expensive power supply.

The water must conduct well.
Add salt. Some refs say sodium sulfate is better than sodium chloride, table salt.
Weak acid or base would also conduct, but may eat wire.

Too much salt = bigger bubbles
Latex Microbubbles.
If too dense, can be 'cooked' to expand to neutral buoyancy

Very expensive! $100 for a few grams worth.

Molecular Tagging Velocimetry

Laser beam "uncages" dye along a beam line, which then deforms with the fluid:

\[
\begin{align*}
\text{flow in a tube} & \\
\text{later:} & \\
\text{Many beams} & \\
\end{align*}
\]

Can be quantified to measure velocity field.
Dye is molecular, no seed problems.

http://www.egr.msu.edu/tmual/MTV.html

Index of Refraction Techniques
Requires no seed. Can visualize differences and gradients in temperature and chemical concentration,
as both change the index of refraction of the media.
Techniques discussed in detail: schlieren and shadowgraphy

Color schlieren
A. DAVIDHAZY (retired now),
RIT = Rochester Institute of Technology, offers engineering and BS through PhD in Imaging Science.
81. Growth of vortices on an accelerated plate. Spark shadowgraphs show the history of a 3-inch-square plate in air, accelerated from rest to 24 ft/s. The sharp edge of the plate is initially opposite the first of a series of pins spaced \( \frac{3}{4} \) inch apart. The motion is actually vertical, and the flow is visualized by painting a narrow band of benzene across the center of the balsa-wood plate, so that when the plate accelerates benzene vapor is drawn into the vortex sheet. The difference in density between the vapor and the air makes the paths of their boundaries visible. Care was taken to ensure that the undulations observed in the vortex sheet were not caused by vibrations of the model. Pierce 1961
167. **Subsonic jet becoming turbulent.** A jet of air from a nozzle of 5-cm diameter flows into ambient air at a speed of 12 m/s. The laminar interface becomes unstable as in figure 102, and the entire jet eventually becomes turbulent. Bradshaw, Ferris & Johnson 1964.

168. **Supersonic jet becoming turbulent.** At a Mach number of 1.8 a slightly over-expanded round jet of air affects the ambient air through a succession of oblique and normal shock waves. The diamond-shaped pattern persists after the jet is turbulent. Oertel 1973.
Mach 1.1, full size T-38 in flight, 1993. L. Weinstein, NASA example of Background Oriented Schlieren (BOS). Correlate patterned background from image to get schlieren

How it works:
Michael Hargather, New Mexico Tech

\[ n = \frac{C_{\text{vacuum}}}{C_{\text{medium}}} \]

\( n \) = index of refraction
Light is deflected towards more dense medium

Figure 1. Disturbance in Collimated Beam

\[
\frac{L}{U} \frac{dy}{dx} = \frac{\lambda^2}{\lambda^2_c}
\]

curve of disturbed line

**SNELL’S LAW**

\[ \eta_1 \quad \eta_2 \]

Air \quad Water

\[ \theta_1 \quad \theta_2 \]

\( \lambda \) is shorter
Beam is slowed, turns into, i.e towards the denser medium

like a caustic sunlight
Figure 2. The Refractive Index Gradient Above a Candle

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http://web.mit.edu/Edgerton/www/schlieren5.html
Minute paper: What would camera see looking at parallel light, camera lens focused at infinity?

Works the other direction too; a light source at the focal point becomes parallel light exiting the lens.