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Group E
Flow Visualization

Convection in Color

This Schlieren image shows a moving ice cube in warm water. It was created for the third group project in Flow Visualization at the University of Colorado. Capturing convective heat flow through thermally induced gradients in the refractive index was our goal. Our largest challenge was properly focusing the image.

The ice cube and water sat in a vase with a width of 3 inches and length of 6 inches where the ice cube moves along the length of the vas. The Reynolds number, defined

$$Re = v\rho D/\mu \quad (1)$$

where v is the velocity, ρ is the density, D is the diameter, and μ is the viscosity, describes the ratio of inertial to viscous forces in the fluid. A high Re gives to turbulent flow, low Re to laminar. The Reynolds number for the flow can be easily determined if the ice is assumed to be completely submerged (instead of accounting for the 10% of the ice above the water which interacts with air). This assumption will overestimate the viscous effects because the ice-air interaction has negligible shear compared to ice-water. Overestimated viscous effects will give a lower Re so that we expect our system to be more turbulent than predicted. Assuming an ice cube velocity of 4 inches/second (0.1 m/s), a length scale of 3 inches (0.076m) equal to the width of the vase, and water properties [1] at a film temperature of 10°C (a bulk water temperature of 20°C), the Reynolds number,

$$Re= (.1m/s)(0.076m)/(1.307 * 10^{-6}\ m^2/s)= 5815$$

Shows the flow is in the turbulent regime.

We utilized a Schlieren imaging technique, shown in figure 1, to visualize the small differences in the refractive index of the water caused by heat flow to the ice cube.

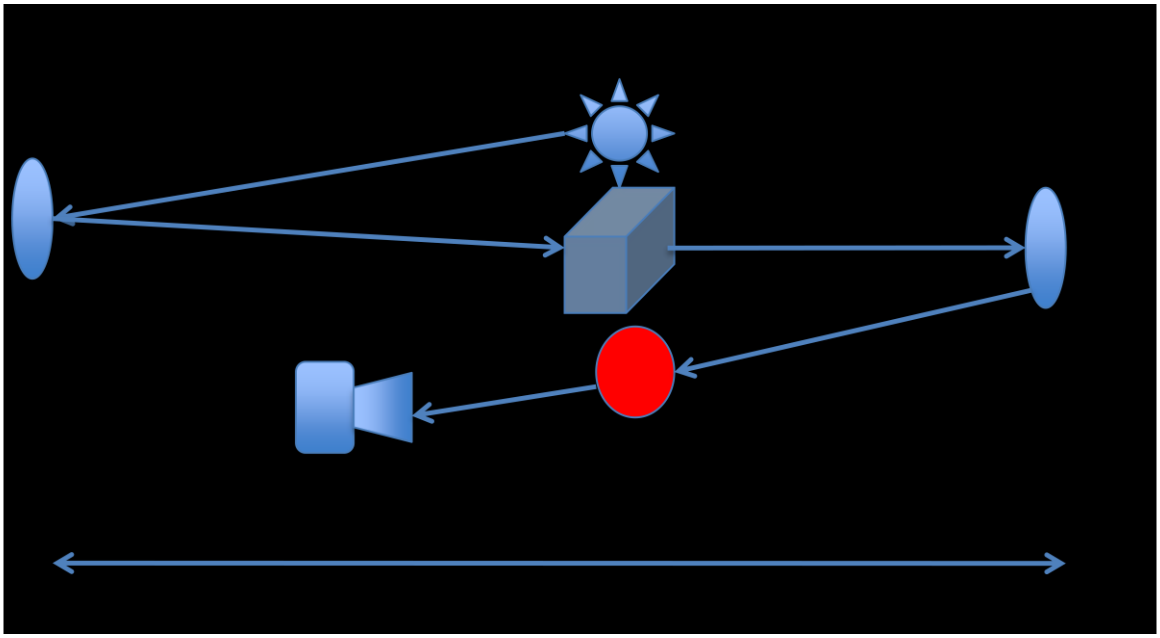

Figure 1. A flow diagram of light projected by a LED light source. The vase contains an ice cube and warm water. The vase and filter are placed at the focal length of the mirrors. The distance from mirror to mirror is approximately six feet.

A light-emitting diode provides the only light in the system. The light reflects of one mirror, interacts with the vase, reflects of another, and passes through the schlieren filter which enhances the differences in refractive index[2]. This technique is an inexpensive method of exploring material properties, such as refractive index distributions, thickness variation, and flatness[2], in additional to the ability to explore heat flow and the obvious artistic value.

The picture was taken about 1 foot from the filter(~7 feet from the vase). The image field of view is about 20 square inches. Additional camera information is given in table 1. The image was initially 1966 × 1466 pixels and was cropped down to 1629 × 1501 pixels to place the ice cube in the corner and emphasize its motion.

Table 1. Camera Specs

Camera type	Canon EOS Digital Rebel XSi
Focal length	250 mm
F-number	5.6
Exposure time	1/25 s

This image displays the convective flow caused by motion of the ice and density gradients around the ice cube. Cold (more dense) water appears to sink below the ice cube. The physics are well-revealed, but higher resolution would improve the image. Developing deeper flow complexity or inducing refractive index gradients through an electric field (for optically-active materials) may improve the image and add interesting effects.

Reference:

1. The Engineering Toolbox. www.engineeringtoolbox.com/ water-dynamic-kinematic-viscosity-d_596.html (2005).

2. Howes, W.L., *Rainbow Schlieren and its Applications.* Applied Optics: Vol 23, No. 14 (1984), 2449- 2460.