Introduction

Plumes occur when buoyancy is supplied steadily and is continuous between the source and the level of interest. The usual sources of buoyancy that drive the motion of plumes are heat, a difference in composition between the ascending fluid and its surroundings, or a combination of both. Here, we report on MRI analysis of plumes and thermals driven by a source of buoyancy unique to plumes—an autocatalytic chemical reaction. The evolution of such a chemical plume is shown in Fig.1.

Dynamic MRI

Dynamic MRI is a sequence of MRI images which may be used to study flows that are time-dependent. MRI uses a radio frequency (RF) pulse to deflect the spin of nuclei which are otherwise aligned in a strong applied magnetic field. When the RF pulse stops the spins return to their natural alignment with the magnetic field, in the process emitting energy that may be measured.

Velocity images of chemical plumes were obtained using an RF pulse sequence called the gradient echo rapid velocity and acceleration imaging sequence (GERVAIS) [2]. Velocities are calculated from the phase shift between sequential images from a velocity encoding gradient pair of RF pulses. The pulse pair impart a phase shift that is proportional to the velocity in the direction of the gradient. Gradients in the vertical direction (direction of plane ascent) were used for tracking the motion of chemical plumes as they passed through a horizontal cross section along the length of the conduit.

Results

Plume velocities in the vertical direction were measured at distances of 10 cm, 12.5 cm, and 15 cm from the outlet (the end of the capillary tube). Fig. 5 shows a typical image of the velocity profile for the conduit of a plume at 10 cm from the outlet. Each value in the 64 x 64 data matrix represents a separate velocity measurement.

In addition to measuring the velocity profiles of chemical plumes using dynamic MRI, velocity profiles of buoyant plumes (38% by volume glycerol in a 40% glycerol solution) were measured. This heat flux contributes buoyancy to the plume conduit along its length. The effect of entrainment is even more pronounced in velocity profiles for chemical plumes at 15 cm from the source, as shown in Fig. 8. Here we observe that the maximum velocity along the conduit is found to be at the conduit edge. The conduit of the plume is wider in this region (see Fig. 9(a)) than at 10 cm. Freshly reacted solution at the conduit interface, while compositionally the same as that in the interior of the plume, is warmer, and therefore more buoyant.

Conclusions

The effect of entrainment is even more pronounced in velocity profiles for chemical plumes at 15 cm from the source, as shown in Fig. 8. Here we observe that the maximum velocity along the conduit is found to be at the conduit edge. The conduit of the plume is wider in this region (see Fig. 9(a)) than at 10 cm. Freshly reacted solution at the conduit interface, while compositionally the same as that in the interior of the plume, is warmer, and therefore more buoyant.

References