Unsteady plume heads in the Earth's mantle: long-lasting effect of heat source on the ascent velocity of starting plumes

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Mantle starting plumes play a key role in heat and mass transfer in the Earth's mantle. Fluid mechanics show that their nature strongly depends on material properties and initial conditions of the heat source. In order to examine the effect of heat source on the behavior of thermal starting plumes, we systematically performed laboratory experiments by changing the heater size, fluid viscosity, and heat flux from the bottom. Our experiments are carried out in a rectangular tank filled with syrup which has a strong temperature dependence of viscosity like Earth's mantle. A thermal starting plume is generated from a circular plate heater (40 and 70 mm in diameter) placed at the bottom of the tank. The plume is visualized by using TLCs (Thermochromic Liquid Crystals) method for temperature measurements.

Thermal boundary layer grows with time after turning on the heater and eventually doming starts at the critical Ra. The unstable dome accelerates and forms a starting plume. The ascent velocity of the plume head reaches the peak velocity and decelerates with time. This unsteady nature is not observed in a point source experiments (e.g. Kaminski and Jaupart, 2003). We confirmed this deceleration was not caused by free surface effect at the top of the fluid. We identified two deceleration modes. The first mode is observed after the peak velocity. There is no heat supply from the stem into the plume head because the ascent velocity of the plume head is higher than that of the stem. The second mode occurs when the stem catches up with the plume head and the hot fluid in the stem is supplied to the plume head.

The ascent velocity of the plume head is normalized by the peak velocity and the time at the peak velocity. All the data with the same heater size are plotted on a single curve in this normalization. This universal curve and the scaling of the critical Ra number predict that the unsteady nature of the plume heads should be observed in the Earth's mantle.