

“BLUE SMOKERS”: HYDROTHERMAL CIRCULATION IN THE LABORATORY

1 A Simple Introduction for Middle and High School Students

Deep in the oceans, near mid-ocean ridges and in certain basins, one can find black smokers. These smokers are what are known as active hydrothermal vents—in other words, high-velocity outlets of hot water rich in (blackish) metals. These hydrothermal systems play a significant role in heat extraction at mid-ocean ridges through advection. Specifically, cold water penetrates the rock, heats up at depth as it approaches reservoirs filled with magma, and then rises, following the laws of fluid mechanics. In this experiment, we will simulate these black smokers using water, a porous medium, and a blue colorant.

2 Materials

To simulate a porous medium such as rock, we will use glass beads and water as the fluid. The colorant makes it possible to visualize convection.

- Water
- Glass beads (e.g.,: diameter = 2.5 mm)
- Heat-resistant glass bowl
- Hot plate: e.g., Magnetic Stirrer Hot Plate
- Blue or dark-colored food coloring
- Optional: thermometers

3 Protocol

The first step is to build the porous medium. To do this, place the glass beads in the transparent tank and try to create a flat surface. The layer of beads should be about 5 cm thick. Next, fill the tank with water until it rises 1 to 2 cm above the beads. The next step is to place the container on the hot plate and turn it on at full power (or nearly so). The setup should look like the figure below. Then, wait until you can feel a temperature difference between the bottom and top of the container, and until the liquid appears calm (no initial turbulence), before placing a large drop of dye in the center of the container. You must then wait for convection to develop to see the desired structures appear. If you want to know the exact ΔT , you must use the probes: place one in the porous medium and one at the water's surface, with the significant risk of disturbing the system.

Note: If you hear a “pshhhht” sound, it means it's getting a little too hot! There's water under the tank: you need to turn down the “heat” slider.

3.1 Observations and Connection to the Equations

- We usually observe that the dye moves: there is material movement.
- After seeping into the porous material, the dye rises to the surface, especially along the edges.
- Once it comes back up, you can sometimes see the dye seep back in between the beads, or move across the surface of the water above and eventually disperse.

Simple explanation using hand gestures: Creating a temperature difference between the top and bottom causes the water to move. The speed of water flow “ u ” increases with the temperature difference “ ΔT .” “Blue smokers” form where it is easier for the water to rise—that is, where

permeability is higher (this is the case at the edges of the tank, since there is more space to pass between the beads). Water rises wherever its buoyancy allows it to: when it is heated, the buoyant force causes it to rise.

Mathematics Curriculum Content: Darcy's Law, the concepts of advection, convection, and diffusion.

Possible experiments: We can record videos of the rising hot water plume at different temperature gradients and set $T = 0^\circ\text{C}$ at the top using an ice cube, since we are working with water, so this is possible. We can measure the rise velocities manually or by video analysis (PIV method) to plot a line of u versus ΔT (which, at a more advanced level, should allow us to derive the relationship: $\text{Nu} \propto \text{effective Ra}$ in a porous medium). Finally, we can try using a different ball size to change the effective permeability of the medium.

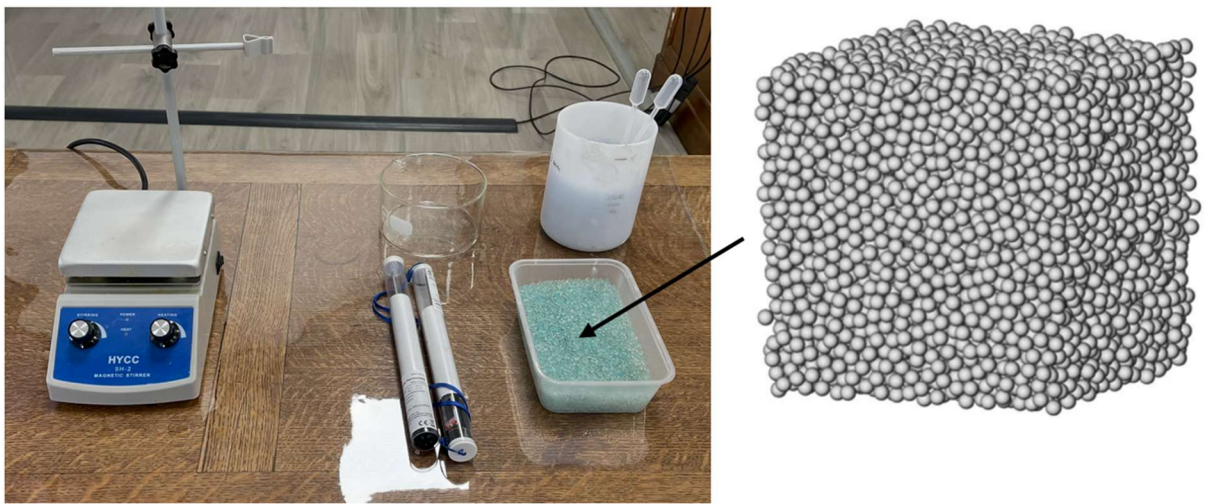


Figure 1: Experimental dispositive

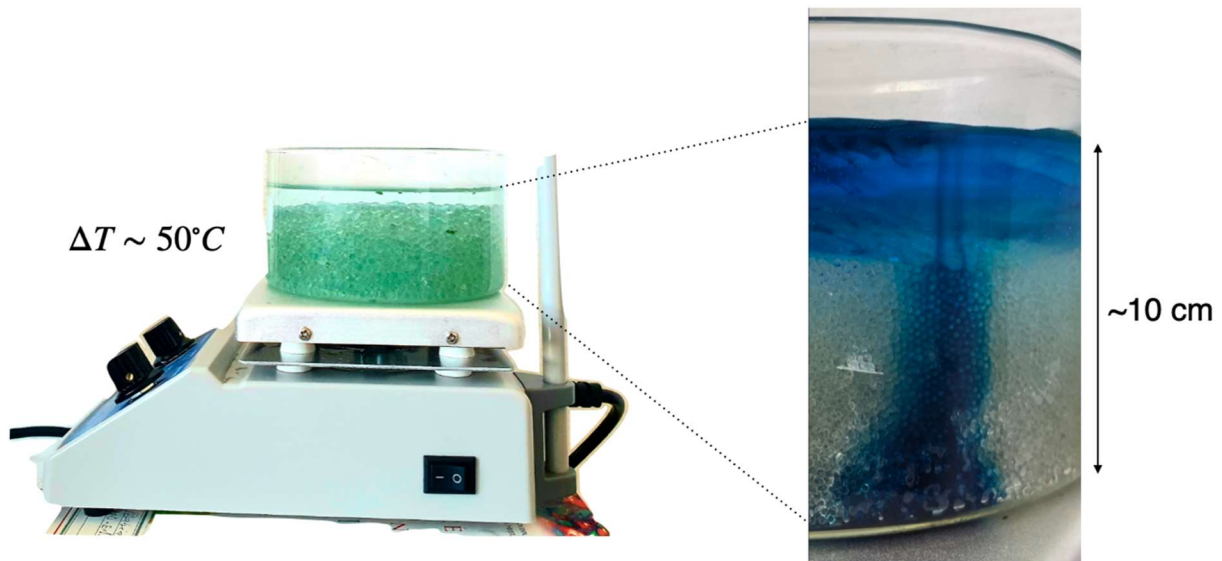


Figure 2: An experiment demonstrating the formation of an upward plume along the edge of the tank.

Credit: Kim Moutard, Paco Bacrie, J.-A. Olive, H. Rouby, L.-L. Durantet