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3T622 – Laboratory Internship

Convection

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The aim of our project is to carry out an experiment representative of thermal convection in the Earth's mantle.
Having divided the work into two groups, we will focus on the development of a protocol to observe a temperature gradient using thermochromic inks during convection while the second group will try to determine α parameters (thermal expansion coefficient), κ (thermal diffusivity) and ν (kinematic viscosity) of the fluid selected for this model.

Experimental protocol : colour index as a function of temperature

To define a temperature gradient, we use thermochromic ink or powder. Thermochromic ink color change when the temperature increases, so it can be a great estimation of the mantellic convection model and a great reference to follow the temperature changes

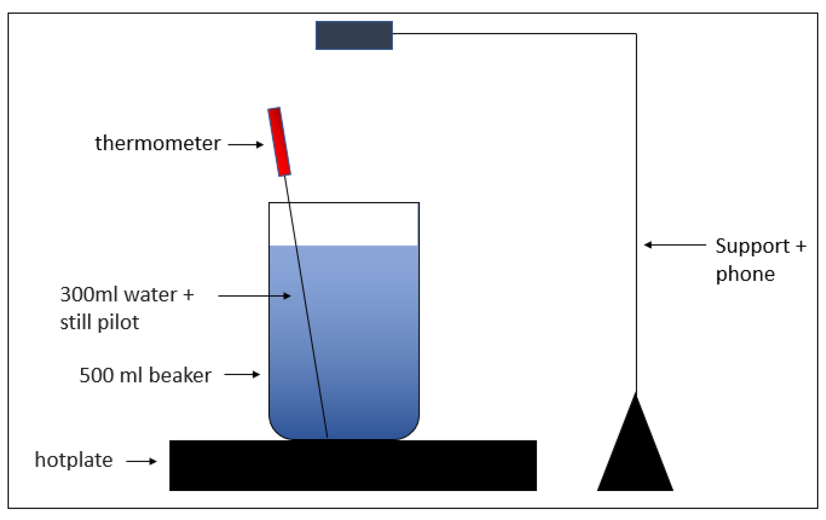
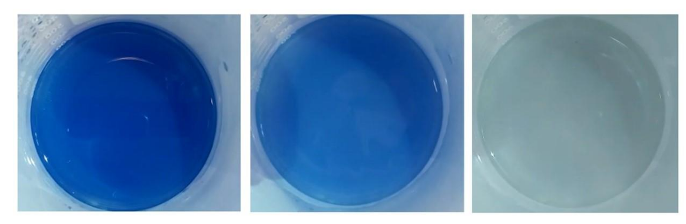


Figure 1 : Assembly

Figure 2 : color changes for a Pilot ink



Protocol: we add 300ml of water on a beaker and we add a blue Pilot ink before heating up the mixture.

Over time, the color progresses until it becomes translucid. The color change appears around 50°C.

Then, we can determine a law between the temperature and the color index with a Matlab code. We write the temperature over time with a thermometer and a chronometer then we plot the graph with Matlab. We can extract frames per seconds from a movie and we can extract the color index (RVB) in each frame for a fixed point. Lastly, we can mix the two graphs to represent the color index (RVB) as a function of temperature. We obtain the following graph :

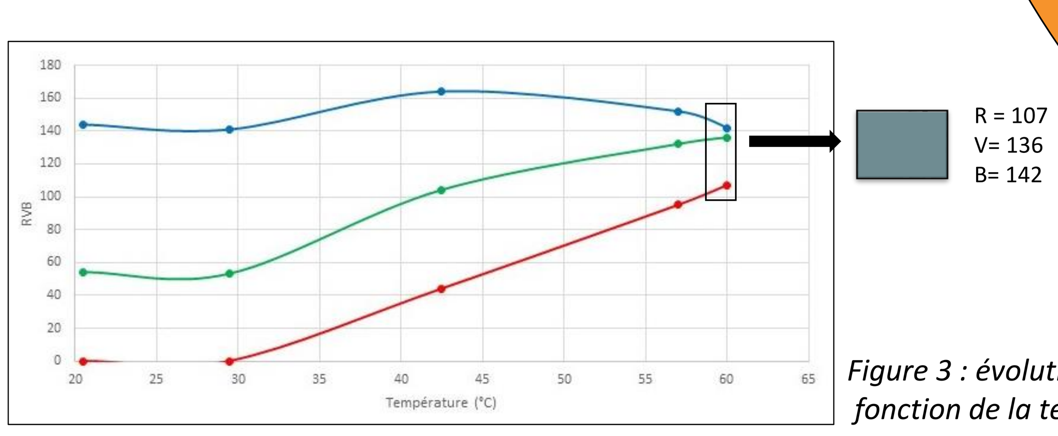


Figure 3 : évolution de la couleur RVB en fonction de la température pour l'encre bleu

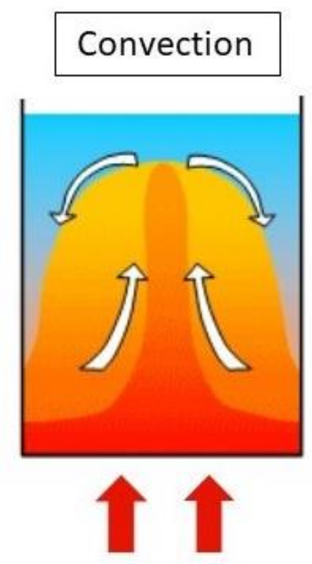
At the end of the experimentation, we found: R = 107, V = 136, B = 142.

This color composition gives us a color that is not white but grey. This can be due to the shadows or to the frame's brightness and to the fact that the color is not perfectly white.

What is convection?

If a deformable body is heated from below, it will expand, and its density will decrease [1]. Less dense areas will be close to the heat source and denser areas will be away from the heat source.

The cold material at the top - denser - will tend to go down and the hot matter - less dense - will tend to go up. These ascending and descending movements of material with heat travels define convection.



[2]

A system is convective if the Rayleigh Ra number is upper than a critical value ~10^3

The Rayleigh number :

$$R_a = \frac{\alpha g \Delta T h^3}{\kappa \nu}$$

Viscous fluid: Earth's mantle

The fluid we used to represent the terrestrial coats is too viscous, so we will have to change its viscosity. To do so, we will use a fluidizer. After several tests, we concluded that adding 10% of the total mass of fluidizer allowed us to have a more manageable and less viscous fluid.

After finding the correct properties of the fluid, a small amount of powder + ink is added.

fluid	fluidizer	ink + powder
90,4%	9,4%	0,2%

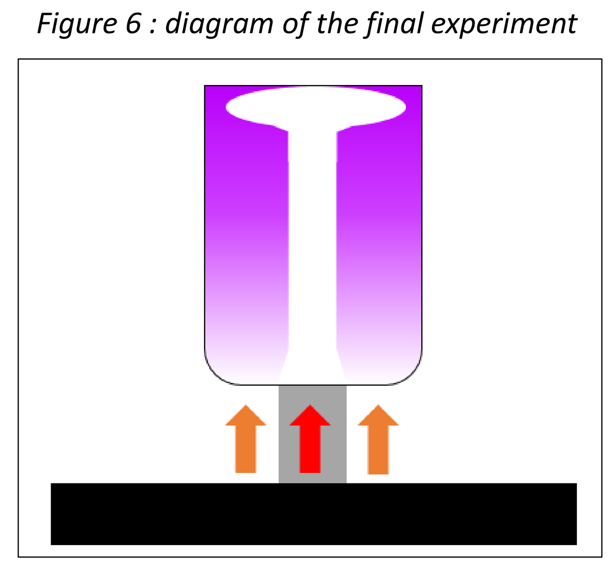
Finally, we realize a test to observe our convection. The layer heated is too thin to observe a proper convection.
On the contrary, we observe a temperature gradient that is most representative of a conduction as in the figure 4.

Figure 4: Temperature gradient (conduction)

Final experiment

To perform this experiment, we need a significant amount of fluid. Therefore, we filled a 2000ml beaker by adding the right proportions of fluidizing then powder/ink. Once the homogeneous mixture is obtained, the beaker is placed in equilibrium on a steel cylinder (which is a highly conductive component) to have a point heat source and promote the convection process.

Figure 6 : diagram of the final experiment



Unfortunately, our fluid was not translucent enough to observe the phenomenon from the side. However, we were able to observe it from above. Figure 6 corresponds to what will be observed from the side and Figure 7 corresponds to what we observed during the experiment

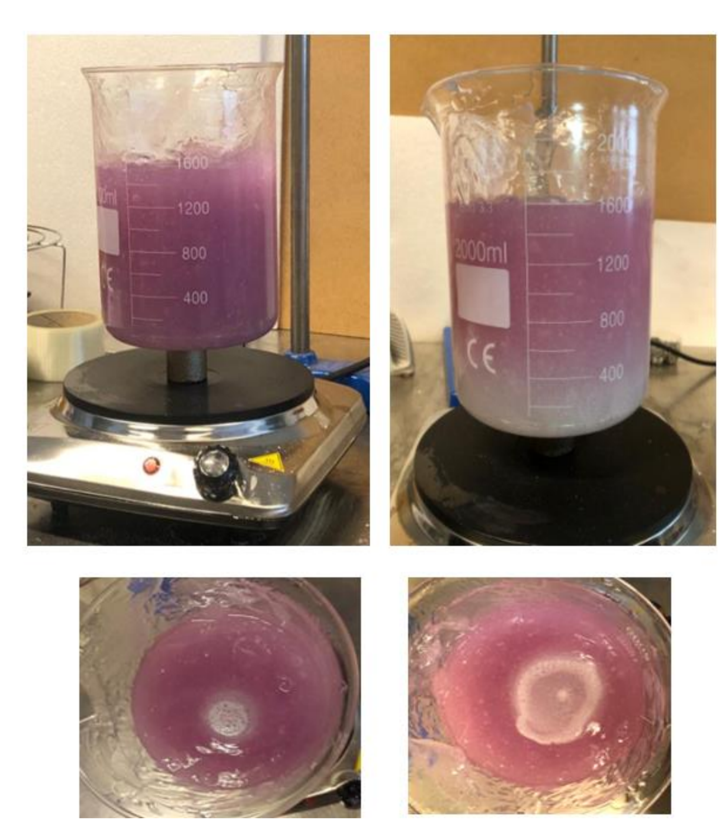


Figure 7 : Convection – Final experiment

Ink choices

	Ink			Powder			
Colour	Blue	Black	Red	Black	Yellow	Blue	Red
Temperature activation	15°C	27°C	47°C	27°C	28°C	28°C	28°C

The experiment laid out upward helped us to check the values supplied by the manufacturers. We choose between the ink and powders show on the table above. To observe a temperature gradient that is the most efficient, we choose to mix the blue powder with the red ink. At the start of the experiment, we will have a purple mixture that will change into a red mixture after 28°C and that will become colorless from 47°C.

Conclusion

We were able to perform one time only, to observe the convection with our temperature gradient, as we had restricted amounts of gloss for our experiments. The mixture remained very opaque for good views from the side, despite the fact that we made the fluid more translucent and having added the smallest amount of dye possible. We then thought of possible alternatives to observe the temperature gradient: find better proportions to obtain a much more translucent fluid and try to take an even smaller amount of dye to observe convection. We could also look for colorless thermochromic inks that changes color at a certain temperature (this is what we thought we had at first, but we had the opposite effect). The temperature gradient is made visible by conduction, but we got a dense and colorless result with the convection of the hot fluid.

Data source

[1] https://planet-terre.ens-lyon.fr/ressource/convection-mantellique-tectonique-plaques.xml#theorie-manteau
[2] https://svtlyceedevienne.files.wordpress.com/2014/02/convection-et-conduction.jpg