Heat Transfer by Convection

Fluid motion driven by buoyancy forces in a gravitational field is called a *convection current*. When the buoyancy forces are due to thermal expansion convection currents carry heat energy from one place to another. Convection is the dominant heat transfer mechanism in fluids that are poor thermal conductors such as water and air. Convection is the ‘pump’ that circulates water in passive solar water heaters, distributes heat in air conditioned rooms, and sustains hurricanes.

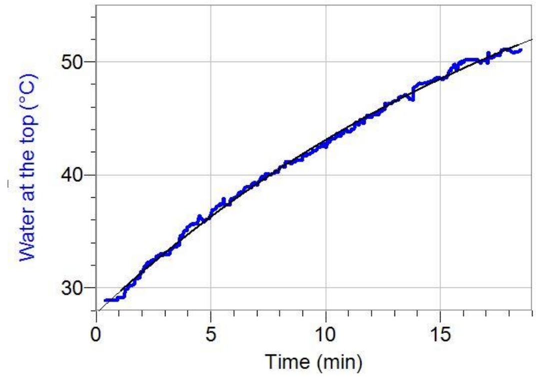
Demonstrations

1 A bottle filled with salt water and suspended plastic chips is very instructive and well worth the effort to make. The chips in this example were cut from Walls ice cream pots that are made of thinner more dense plastic than yoghurt and similar pots. The salt concentration is adjusted to suspend chips in solution for several minutes.

When the bottle is gently heated at the base with warm hands the flow is turbulent. Text-book diagrams of convection with laminar flow owe more to imagination than observation. If a class enters a cold room and sits close to the bottle slow convection currents are driven by radiated body heat.

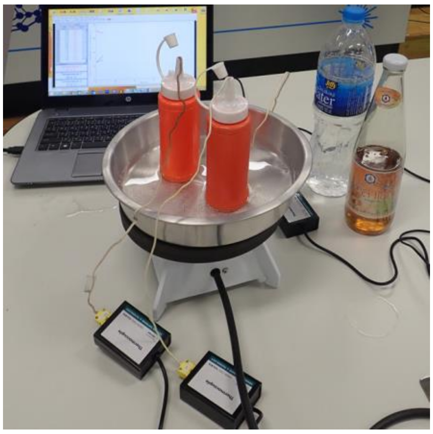
2 Exponential heating curves

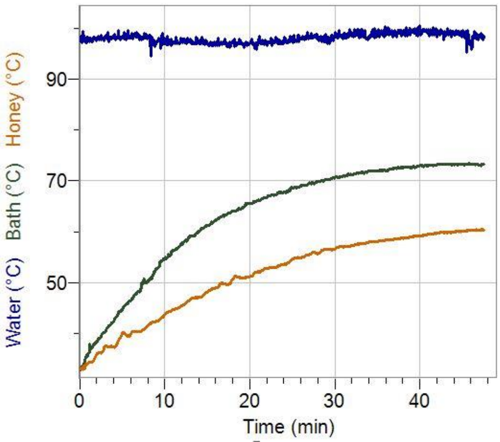
Placing the bottle with the chip suspension in a shallow water-bath with a thermocouple near the top shows the convection currents and upward heat transfer in real time.



The rise in temperature near the top of the water column is exponential as shown by the curve fit. Almost all heating curves without a change of state have this form.

Plastic sauce bottles (poor conductors) are placed in a water bath, one is filled with water and the other with honey. Both heating curves are displayed in real time.





Temperature rise with time is shown in the tops of the bottles when the water bath was held at 95°C.

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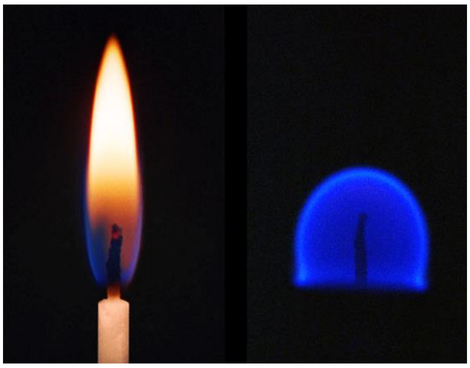
The rate of heat transfer by convection is governed by the speed of convection currents. The viscosity of honey (and of water) reduces with increasing temperature but the viscosity of honey remains higher than that of water at all temperatures. The vertical heat transfer rate in the honey is lower than in the water. Heat losses to the room reduce the upper temperatures more in the honey than in the water. *Adding a third bottle of water solidified with agar shows that the thermal conductivity of water is not zero but is very low.*

3 Convection in the atmosphere

The release of latent heat by condensation in cumulus clouds raises the local air temperature and the clouds expand upwards. At 10000 m (the tropopause) regular reduction of temperature with altitude (average 6.6ºC per 1000 m) ceases. Upward convection stops and towering cumulus clouds spread into anvil clouds. This typical anvil cloud at 10000 m was photographed off Jomtien beach, Thailand.

4 Candle flames

A candle flame becomes hemispherical in free fall due to the absence of buoyancy forces. Normal burning (left) and on the Space Station (right).



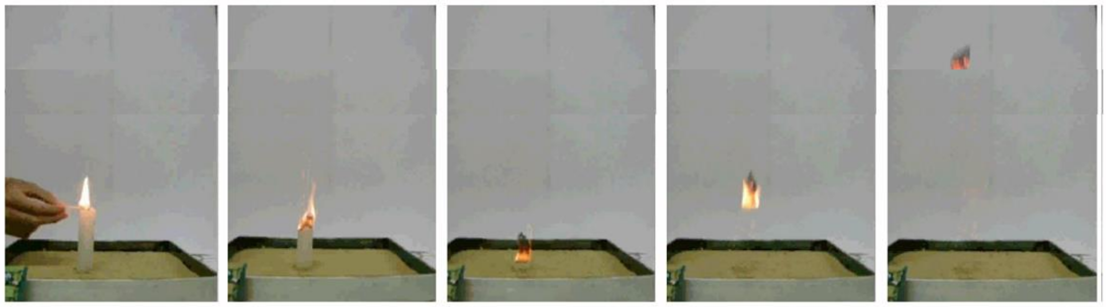
With no convection a candle burns more slowly with a hotter flame. Reference … http://www.webexhibits.org/causesofcolor/3BB.html

5 Flying tea-bags

Convection currents in air are normally not visible because ordinary objects are too heavy to be affected. Smoke particles are an exception but we are so accustomed to seeing smoke rise that it causes no comment. A simple demonstration of convection in air is provided by burning an empty tea-bag on the bench (in a tray of sand). Ash and the remaining ring of paper are light enough to give the impression of a material object rising unexpectedly

Different tea–bags behave differently.

We find that peppermint tea bags fly, Dilmah bags with more unburnt paper than Stassen bags.



Twinings English breakfast bags fly with one mm of unburnt paper and Liptons bags fail to fly at all.

Adding an accelerant (CRC) to Liptons bags increases the burn rate and fixes the problem. It appears that peppermint oil that stains Dilmah bags acts as an accelerant.

Calculations

It is not possible to write an equation that accurately predicts heat transfer rates due to turbulent convection currents in all situations for a given temperature gradient and surface area, because the rate depends on the geometry of each particular situation. Fluid flow rates also depend on viscosity that is strongly temperature dependent, but as a general principle, convection in a fluid with high specific heat (water) is a more effective heat transfer mechanism than convection with similar temperature differences in a fluid of low specific heat (air).

If someone is unfortunate enough to fall into very cold water, survival time is increased if they can keep at least part of their body above the water. They can reduce the heat loss rate under water due to convection by remaining still (not thrashing about) and by keeping the surface area exposed to the water as small as possible by curling up.