Newton's Law of Cooling: Analysis

PHY 2020: Physics Lab 3

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The temperature versus time graph for the cooling of water for different sized beakers is,

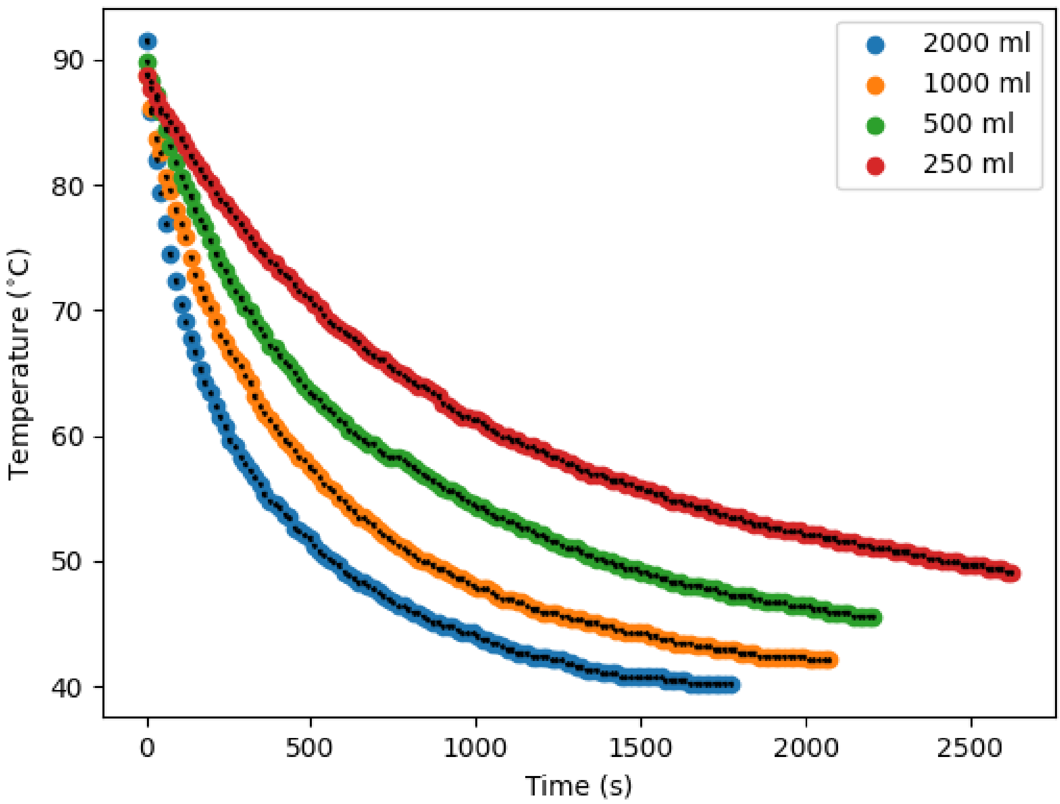

Figure 1: Temperature versus time graph for the cooling of 100 ml of water in 4 different sized beakers

The temperatures were calculated from the resistance measured by the Pt100 by using the calibration relation,

$$R = 0.37T + 107.09$$

The temperature of the surrounding when the cooling curves were drawn was 25.6 °C.

The plots follow the general trend predicted by Newton's Law of cooling, i.e., the temperature falls exponentially till it reaches a stable temperature. The plots show this general trend where it decreases rapidly at first and then the drop becomes slower and it stabilizes after a point.

To analyze this further a decaying exponential can be fitted to each curve. The equation used to create a fit is,

$$T = T_s + (T_0 - T_s)e^{-\frac{hA}{mc}}$$

Where T_s is the surrounding temperature, T_0 is the initial temperature of the object that is cooling down, A is the surface area of the object that is cooling down, m is the mass of the object, c is the specific heat capacity and h is the heat transfer coefficient.

The fits obtained are,

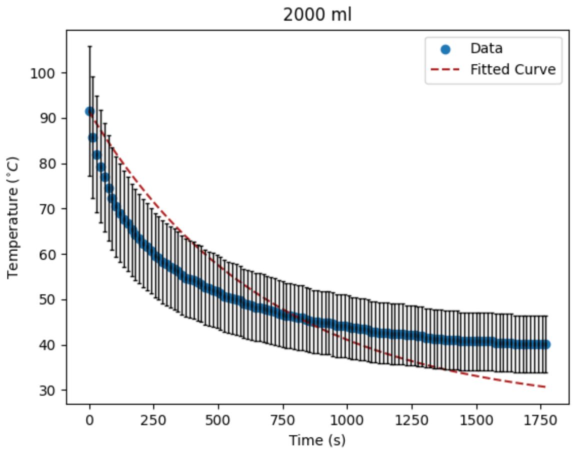

Figure 2: 2000 ml beaker

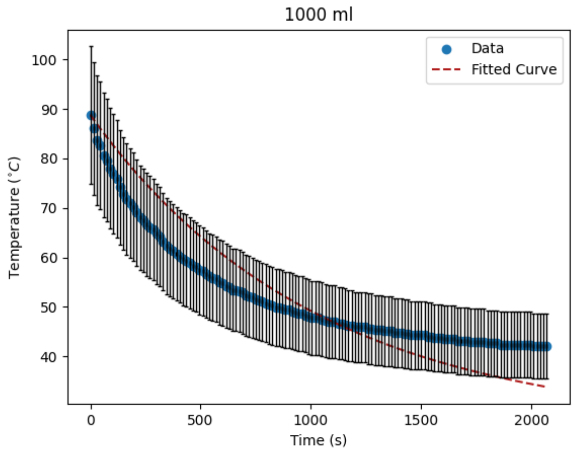

Figure 3: 1000 ml beaker

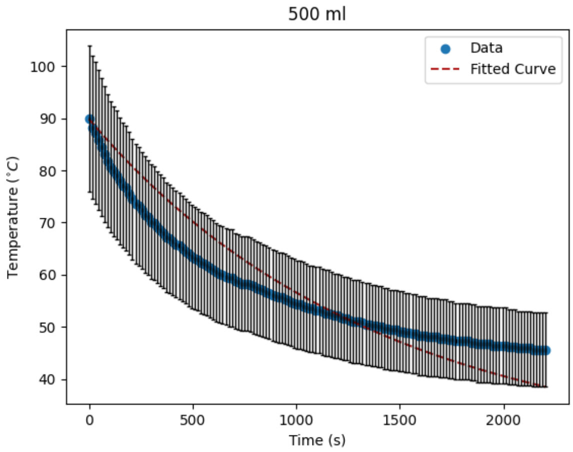

Figure 4: 500 ml beaker

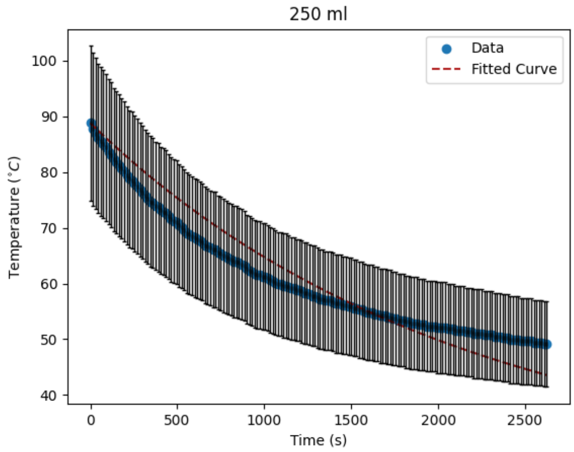

Figure 5: 250 ml beaker

The fits were performed using the `scipy.optimize.curve_fit()` function on python which takes as input the independent variable and unknown parameters. It returns the value of the unknown parameter which in this case is the heat transfer coefficient. Using these fits the heat transfer coefficients obtained are,

Surface area (m^2)	Heat Transfer Coefficient ($Wm^{-2}K^{-1}$)
0.0137	44.025
0.0089	46.522
0.0054	56.622
0.0038	52.798

Table 1: Heat transfer coefficients for the different beakers, 2000 ml, 1000 ml, 500 ml and 250 ml measured by fitting decaying exponential to the cooling curves in fig. 1

Another method to find the value of the heat transfer coefficient is to plot the following equation,

$$\ln\left(\frac{T - T_s}{T_0 - T_s}\right) = -\frac{hA}{mc}t$$

Fitting a straight line to this plot gives us a slope which is equal to,

$$\text{slope} = -\frac{hA}{mc}$$

This can be used to get the values of the heat transfer coefficents. Doing this the graphs obtained were,

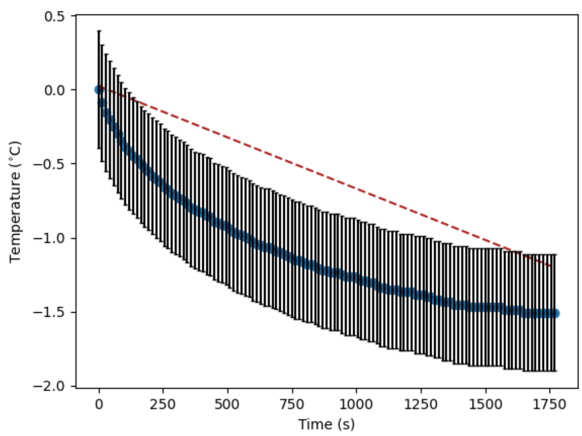

Figure 6: 2000 ml beaker

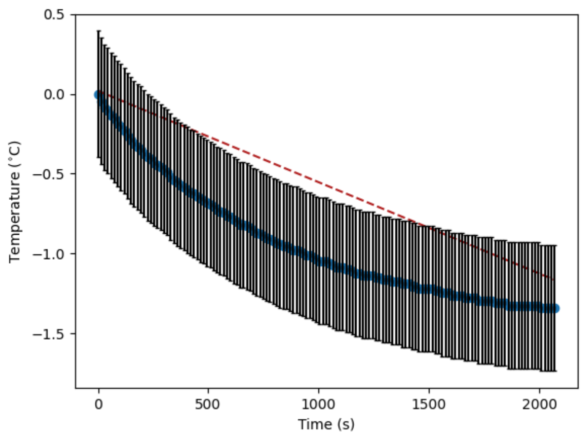

Figure 7: 1000 ml beaker

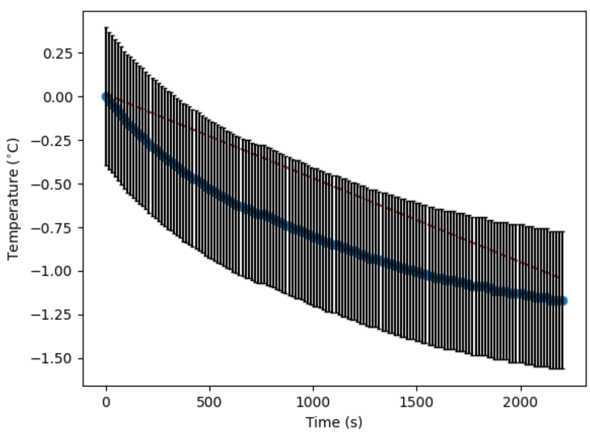

Figure 8: 500 ml beaker

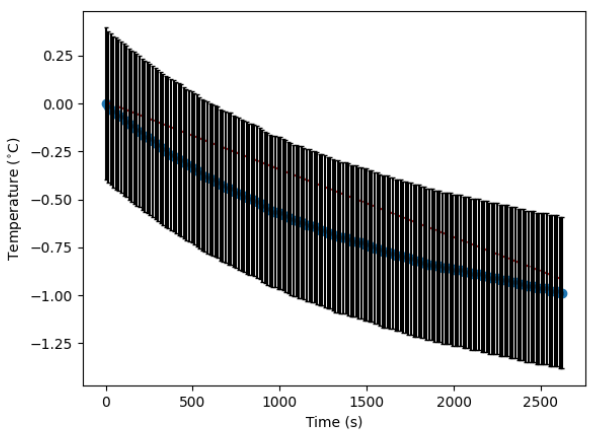

Figure 9: 250 ml beaker

From these the values of the heat transfer coefficients obtained are,

Surface area (m^2)	Heat Transfer Coefficient ($Wm^{-2}K^{-1}$)
0.0137	21.076 $\pm$ 0.00048
0.0089	27.019 $\pm$ 0.00042
0.0054	37.324 $\pm$ 0.00038
0.0038	38.936 $\pm$ 0.00022

Table 2: Heat transfer coefficients for the different beakers, 2000 ml, 1000 ml, 500 ml and 250 ml.

The 2nd method is a better one since the values obtained make more sense than what is obtained by fitting a decaying exponential to the cooling curves. This is so since according to the values obtained from the exponential fit the heat transfer coefficient for the beaker with surface area 0.0054 m^2 is greater than that of the beaker of surface area 0.0038 m^2. This is physically not possible. Thus the results obtained from fitting a straight line is a better method.