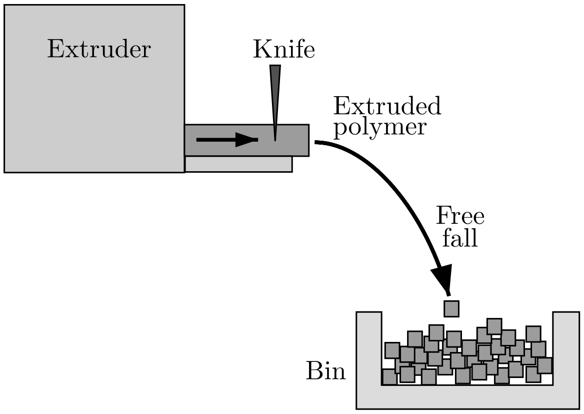
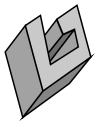
1. Cooling of a little plastic widget

Little plastic widgets are made by extruding a polymer through a shaped die and slicing it off with a knife every time it reaches a certain length. These widgets then fall through the air and cool off as they do so, hopefully reaching an acceptable temperature when they land in the bin.

The process



The widget



Each widget has a maximum dimension of 5 mm (0.005 m), surface area of 2 cm^2 ($2 \times 10^{-4} \text{m}^2$), and volume of 0.05 cm^3 ($5 \times 10^{-8} \text{m}^3$).

Thermal data:

- Widget initial temperature: 160° C
- Ambient air temperature: 20° C
- Polymer thermal conductivity: $k = 2.0 \frac{\text{W}}{\text{m}\cdot\text{K}}$
- Polymer density: $\rho = 900 \frac{\text{kg}}{\text{m}^3}$
- Polymer heat capacity: $c_p = 2500 \frac{\text{J}}{\text{kg}\cdot\text{K}}$
- Heat transfer coefficient: $h = 40 \frac{\text{W}}{\text{m}^2\cdot\text{K}}$

(a) Calculate the heat transfer Biot number of the widget, using the maximum dimension as the lengthscale. What assumption can you make about the cooling behavior?

(b) The widget takes 10 seconds to fall (it's dropped from quite a height, and reaches its terminal velocity quickly). Calculate the Fourier number at the end of this fall, again using the maximum dimension as the lengthscale.

(c) After that much time (10 seconds), calculate the temperature in the "center" of the widget (its maximum temperature). If possible, do not use the Biot and Fourier numbers with the maximum dimension, but calculate the temperature more exactly.

(d) How will your answer to part 1c change if a different polymer is used with half the thermal conductivity, but approximately the same density and heat capacity?