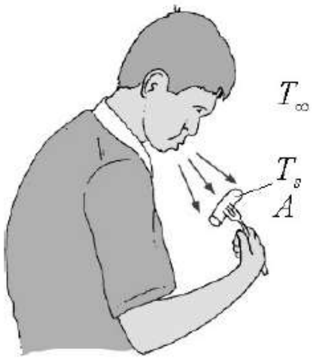
Lecture 7

7.1 Blowing man with a carrot

A perfectly cylindrical carrot with a length of 7 cm and a diameter of 2 cm is cooled by a handsome young man blowing over it. The heat transfer coefficient $h = 15\ \mathrm{W\,m^{-2}\,K^{-1}}$. The thermal conductivity of the carrot is $k = 0.80\ \mathrm{W\,m^{-1}\,K^{-1}}$, the specific heat is $c_p = 3.60\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$ and the density is $\rho = 1100\ \mathrm{kg\,m^{-3}}$. Initially, the carrot is at a uniform temperature of 100 °C and the ambient temperature is 20 °C.

a) What is the temperature of the carrot after one minute of blowing?

b) How long should the man blow to cool the carrot from 100 °C to 80 °C?



7.2 Cooling a copper sphere

A solid copper sphere of 10 cm diameter (density $\rho = 8954\ \mathrm{kg\,m^{-3}}$ and $c_p = 383\ \mathrm{J\,kg^{-1}\,K^{-1}}$ and $k = 386$ $\mathrm{W\,m^{-1}\,K^{-1}}$), initially at a uniform temperature $T_i = 250$ °C, is suddenly immersed in a well-stirred fluid maintained at a uniform temperature $T_a = 50$ °C. The heat transfer coefficient between the sphere and the fluid is $h = 200\ \mathrm{W\,m^{-2}\,K^{-1}}$. Determine the temperature of the copper block at $t = 5$ min after the immersion.

7.3 Cooling a copper sphere under forced convection conditions

One of the steps in material processing could be curing a material. Curing is a heat treatment process used to accelerate a chemical reaction.

In this case, a plastic film is wrapped around a copper sphere with a diameter of 10 mm, and is placed in an oven at 75 °C. After removal from the oven, the sphere is exposed to an air stream at 10 m/s and 23 °C.

Estimate the time taken to cool the sphere to 35 °C using Lump theory. Use the correlation

$$\mathrm{Nu} = 2 + \left[0.4(\mathrm{Re})^{0.5} + 0.06(\mathrm{Re})^{2/3}\right](\mathrm{Pr})^{0.4}\left(\frac{\mu_a}{\mu_s}\right)^{0.25}$$

for determination of correlation coefficient h. Use the following properties of air and copper:

- Copper:
  - $\rho = 8933\ \mathrm{kg\,m^{-3}}$, $k = 400\ \mathrm{W\,m^{-1}\,K^{-1}}$, $c_p = 380\ \mathrm{J\,kg^{-1}\,K^{-1}}$
- For air at 23 °C
  - $\mu = 18.16 \cdot 10^{-6}\ \mathrm{N\,s\,m^{-2}}$, $\nu = 15.36 \cdot 10^{-6}\ \mathrm{m^2\,s^{-1}}$
  - $k = 0.0258\ \mathrm{W\,m^{-1}\,K}$, Pr=0.709
  - $\mu_s = 19.78 \cdot 10^{-6}\ \mathrm{N\,s\,m^{-2}}$ at 35 °C

7.4 Marbles - Hand-in

One of the production steps of Marbles is letting the marbles cool down to room temperature. The marbles have been cooled down rapidly from a high temperature of 650 °C to 100 °C. In a further cooling chamber the marbles are cooled down to 30 °C. Calculate how long it the marbles need to be in this further cooling chamber to reach the 30 °C. In the cooling chamber there is a air stream of 13 m/s at 20 °C. First calculate the Biot number for the marble. The marble has a diameter of 13 mm.

Note: For solving this question, material properties are needed for the (glass) marbles. These are $\rho = 2200$ kg m^{-3}, $k = 6$ W m^{-1} K^{-1}, $c_p = 792$ J kg^{-1} K^{-1}

You may use the following relationship for the Nusselt number:

$$Nu = 2 + \left[0.4 \cdot Re^{1/2} + 0.06 \cdot Re^{2/3}\right] Pr^{0.4} \cdot \left(\frac{\mu_\infty}{\mu_f}\right)^{0.25}$$