Approach

The approach below gives a guideline in how to solve the problems presented during this course. Correctly applying this approach will lead to a good understanding of the concepts presented in this course.

Analysis

1. Explain the problem: which physical phenomena are important in this problem?
2. Make a sketch of the problem
3. Give the known variables (with the appropriate units!)

Approach

1. Explain the assumptions you make to solve the problem
2. Show the solution method for solving the problem

Elaboration

1. Show the calculation steps and explain the equations you use
2. Give references if values are found online or in tables

Evaluation

1. Check the units of your solution
2. Is the answer realistic/expected?
3. Did you answer all the questions asked?
4. Iterate if this is required

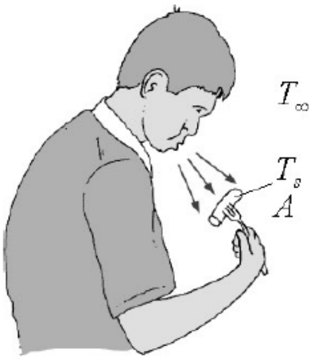
Lecture 7

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:

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