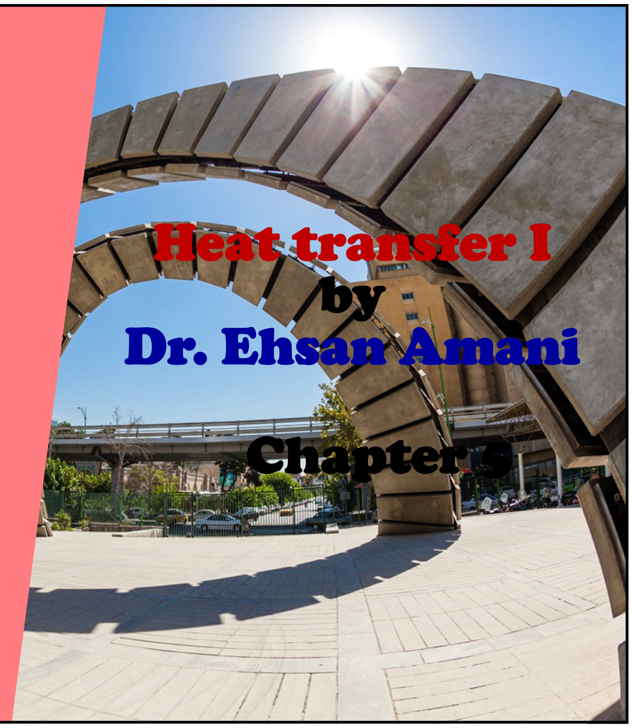


Heat transfer I

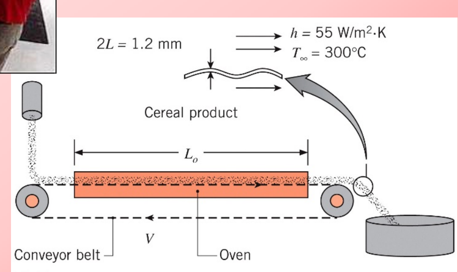
by

Dr. Ehsan Amani

Chapter 5

Transient heat conduction: Applications

- **Food industry**



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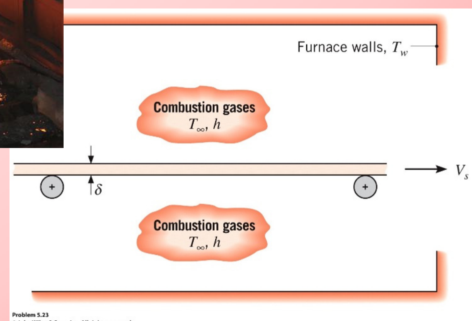
Transient heat conduction: Applications

- Annealing



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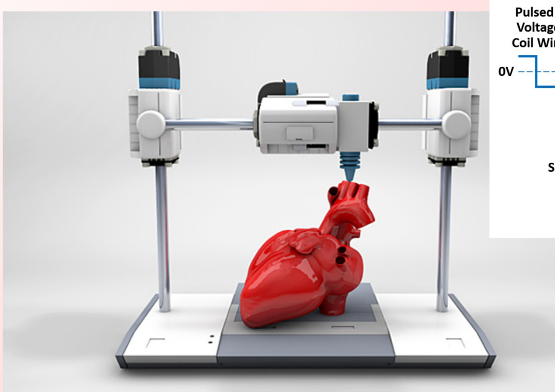
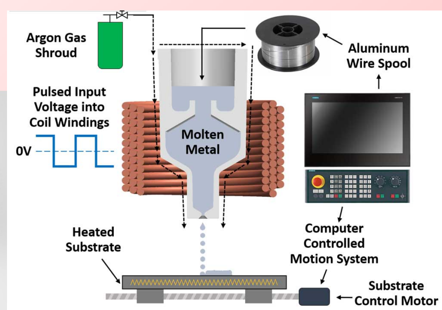
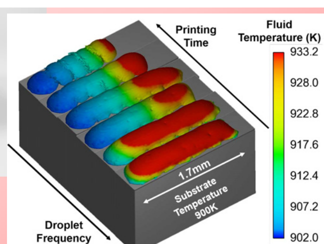
Transient heat conduction: Applications

- 3D printing







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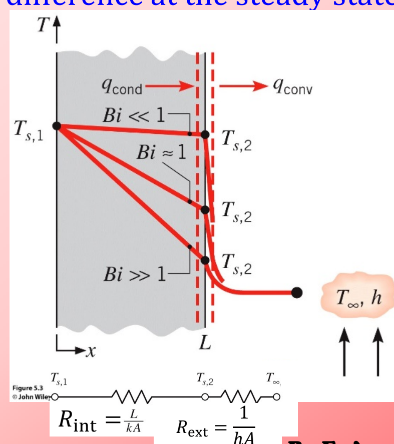
1.5 Lumped capacitance method

- **Spatially-uniform (homogeneous) temperature?**
- **Example**
  - ➢ The maximum temperature difference at the steady state

$$\frac{T_{s,1}-T_{s,2}}{R_{\text{int}}}=\frac{T_{s,2}-T_\infty}{R_{\text{ext}}}$$

$$\frac{T_{s,1}-T_{s,2}}{T_{s,2}-T_\infty}=\frac{R_{\text{int}}}{R_{\text{ext}}}=\frac{L/kA}{1/hA}=\frac{hL}{k}\equiv Bi$$



- **Biot number:**

Characteristic length

$$Bi\equiv\frac{hL_c}{k}\propto\frac{R_{\text{int}}}{R_{\text{ext}}}=\frac{R_{\text{cond(int)}}}{R_{\text{conv}}}\qquad(1.5)$$

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1.5 Lumped capacitance method

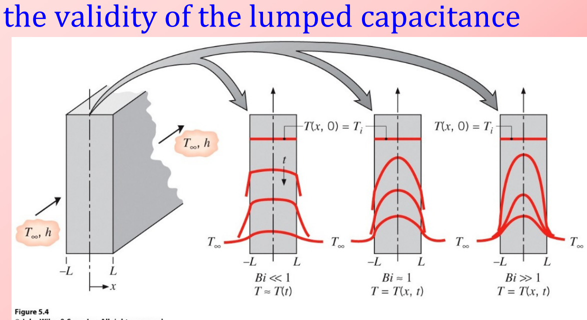
- **Biot number:**
  - ➢ For the lumped capacitance method

Body volume **Convective surface area**

$$L_c\equiv\frac{V}{A_s}\qquad(2.5)\qquad \text{e.g., } L_c\equiv\frac{LA}{A}=L$$

  - ➢ The criterion of the validity of the lumped capacitance method

$$\boxed{Bi<0.1}$$



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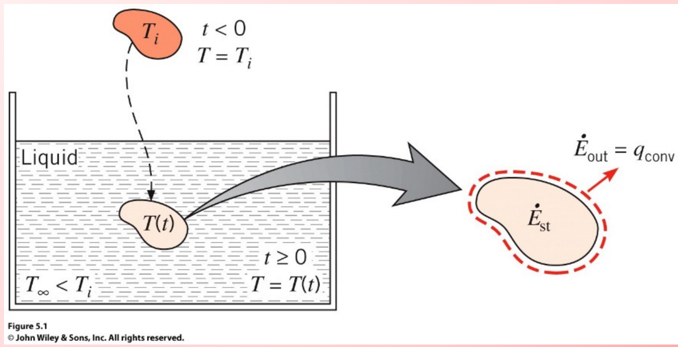
1.5 Lumped capacitance method

- **Convective condition:**



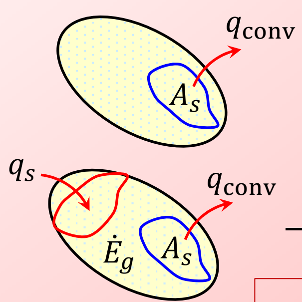
⇨ **Lecture Notes**

1.5 Lumped capacitance method

- **Other conditions:**
  - General equation: see Eq. (5.15) [1]
  - Analytical solutions:
    1. Pure radiation: Eq. (5.18) [1]
    2. Convection with variable heat transfer coefficient ($h = c(T - T_\infty)^n$) for application in natural convection or boiling: Eq. (5.28) [1]
    3. Convection ($h = cte$) + surface heat transfer ($q_s = cte$) + heat generation ($\dot{E}_g = cte$): The equivalent convection

1.5 Lumped capacitance method

- **Other conditions:**
  - General equation: see Eq. (5.15) [1]
  - Analytical solutions:
    3. Convection ($h = cte$) + surface heat transfer ($q_s = cte$) + heat generation ($\dot{E}_g = cte$): The equivalent convection



$$-hA_s(T - T_\infty) = \rho c V \frac{dT}{dt}$$

$$q_s - hA_s(T - T_\infty) + \dot{E}_g = \rho c V \frac{dT}{dt}$$

$$-hA_s\left[T - \left(T_\infty + \frac{q_s + \dot{E}_g}{hA_s}\right)\right] = \rho c V \frac{dT}{dt}$$

$$\boxed{(h, T_\infty) \rightarrow \left(h, T_\infty + \frac{q_s + \dot{E}_g}{hA_s}\right)}$$

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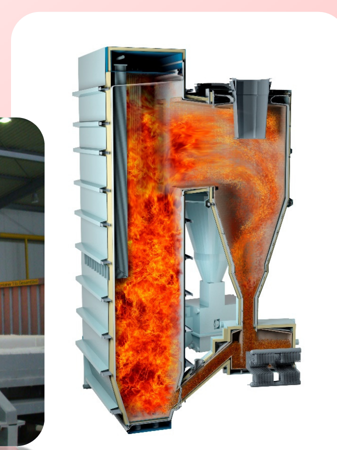
2.5 Sample problems

Furnace start-up



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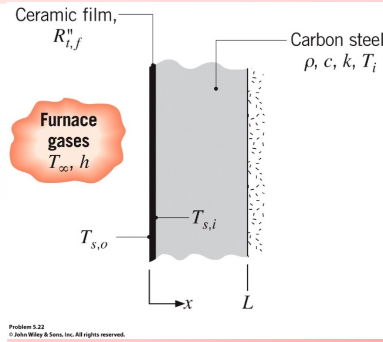
2.5 Sample problems

Furnace start-up

5.22 A plane wall of a furnace is fabricated from plain carbon steel ($k = 60\ \mathrm{W/m \cdot K}$, $\rho = 7850\ \mathrm{kg/m^3}$, $c = 430\ \mathrm{J/kg \cdot K}$) and is of thickness $L = 10\ \mathrm{mm}$. To protect it from the corrosive effects of the furnace combustion gases, one surface of the wall is coated with a thin ceramic film that, for a unit surface area, has a thermal resistance of $R''_{t,f} = 0.01\ \mathrm{m^2 \cdot K/W}$. The opposite surface is well insulated from the surroundings.

A surface heat flux of $q''_s = 1000\ W/m^2$ is absorbed by the outer surface of the film due to the radiation.

At furnace start-up the wall is at an initial temperature of $T_i = 300\ \mathrm{K}$, and combustion gases at $T_\infty = 1300\ \mathrm{K}$ enter the furnace, providing a convection coefficient of $h = 25\ \mathrm{W/m^2 \cdot K}$ at the ceramic film. Assuming the film to have negligible thermal capacitance, how long will it take for the inner surface of the steel to achieve a temperature of $T_{s,i} = 1200\ \mathrm{K}$? What is the temperature $T_{s,o}$ of the exposed surface of the ceramic film at this time?



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The end of chapter 5

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