
Week 1

Lecture 1

Information provided:
Instructor: M.M. Yovanovich, CPH 3375C X3588, E3-2133A, X6181 or X4586
email: mmyov@mhtl.uwaterloo.ca

Teaching Assistants
Mirko Stevanovic, E3-2133A, X6181; email: mirko@mhtl.uwaterloo.ca

Rebecca Kaufman, E2-2354F, X5891; email: rpkaufma@engmail.uwaterloo.ca

---

Text: Fundamentals of Heat and Mass Transfer, Fourth Edition 1996
by F.P. Incropera and D.P. DeWitt

Students are requested to sign in.

Final Grade Components and Weights
Project(s): 10 points
1 Heat Transfer Lab.: 10 points
Mid Term Examination: 30 points
Final Examination: 50 points

ME 353 Website:
Course information will be placed at ME 353 Website.

Read Chapters 1 and 2.
Do Problems:
Chapter 1: 4, 11, 13, 19, 32, 46, 49, 51
Chapter 2: 2, 6, 16, 19, 29, 37
Chapter 3: 2, 10, 19, 22, 34, 43, 57, 71, 90, 101
Chapter 4: 1, 16, 20, 25, 33

Chapter 5: 5, 14, 27, 35, 46, 60, 66, 74, 77
Solutions will be available in Engineering Photocopy Center.

No Tutorial during Week 1

Modes of heat transfer: **Conduction, Convection and Radiation**
Definitions of heat transfer by conduction, convection and radiation.
Show and tell: circulate example of air cooled heat sink from pentiums.

Lecture 2

Notation used in text: $q\,[W]\,, q^{'}\,[W/m]\,, q^{''}\,[W/m^2]\,, q^{'''}\,[W/m^3]$ denote heat transfer rate, heat transfer rate per unit length, per unit area, and per unit volume respectively.
Yovanovich uses: $Q\,[W]$ for heat transfer rate and $q\,[W/m^2]$ for heat flux.

Conduction: **Fourier's Law of Conduction**: $\boxed{Q = -kA\,\vec{n}\cdot\nabla T}$ or $\boxed{\vec{q} = -k\nabla T}$; thermal conductivity k; units of Q, q, T, ∇T; Appendix A has values of thermal conductivity for solids, liquids and gases; range of values from diamond at $2300\,[W/m\cdot K]$ to air at $0.0265\,[W/m\cdot K]$; definitions of thermal resistance R and shape factor S for a wall: $R = L/(kA)$, $S = A/L$, $S = 1/(kR)$; their units; thermal circuit with temperature nodes T, thermal resistors R and throughput Q; series arrangement of resistors.

One-dimensional steady-state temperature $T(x)$ in plane wall with convection heating and cooling; film resistances: $R_{f1} = 1/(h_1 A), R_{f2} = 1/(h_2 A)$, solid resistance: $R_s = L/(kA)$; total resistance of system: $R_{\text{total}} = R_{f1} + R_s + R_{f2}$; thermal circuit: four temperature nodes: $T_{f1}, T_{s1}, T_{s2}, T_{f2}$; three resistances in series; heat flow rate through system: $Q = (T_{f1} - T_{f2})/R_{\text{total}}$; composite wall;

Discuss forced convection of a viscous fluid at temperature T_f over a smooth, isothermal plate at temperature T_s; there are 2 boundary layers which form: hydrodynamic of thickness δ and a thermal boundary layer of thickness Δ. The relative thickness of the thermal boundary layer depends on the **Prandtl number** defined as $Pr = \nu/\alpha$ where $\nu = \mu/\rho$ and $\alpha = k/(\rho c_p)$. For $Pr = 1$, (gases), $\Delta/\delta = 1$; for $Pr >> 1$, (very viscous oils) $\Delta/\delta << 1$; and for $Pr << 1$, (liquid metals) $\Delta/\delta >> 1$.

Newton's Law of Cooling: $\boxed{Q = hA(T_{\mathrm{s}} - T_f)}$; heat transfer coefficient h; its units; its complexity (depends on several parameters: geometric, thermophysical properties, type of flow, boundary condition, surface temperature, fluid temperature, etc.); $h = f(\rho, c_P, \mu, \nu = \mu/\rho, k_f, U_\infty, x,$ or $L, T_s, T_\infty)$; properties are found at film temperature: $T_{\text{film}} = (T_s + T_\infty)/2$; definitions of **Nusselt number**, **Reynolds number** and **Prandtl number** where $Nu_x = h(x)x/k_f$, $Re_x = U_\infty x/\nu$ and $Pr = \nu/\alpha$ where $\alpha = k/(\rho c_P)$; heat transfer coefficient appears in correlation equations of the form:

$$Nu_x = C Re_x^m Pr^n$$

where the parameter C, m, n depend on the type of flow (laminar or turbulent); type of fluid (high or low Prandtl number fluids); boundary condition; for example: laminar, boundary layer, forced convection over a smooth, isothermal, flat plate correlation equation is

$$Nu_x = C Re_x^{1/2} Pr^{1/3}, \quad Pr > 0.5, \quad 100 < Re < 10^5.$$

where $C = 0.332$ for local values, and $C = 0.664$ for average value over plate length L.

film resistance: $\boxed{R_{\text{film}} = (T_s - T_\infty)/Q = 1/(hA)}$;

Lecture 3

Radiation heat transfer; Stefan-Boltzmann Law of Radiation; black-body emittance: $e_b = \sigma T^4$; Stefan-Boltzmann constant: $\sigma = 5.67 \times 10^{-8} W/(m^2 \cdot K^4)$. Grey-surface radiation: $E = \epsilon E_b$; surface emissivity: $0 < \epsilon < 1$, a complex radiation parameter associated with real surfaces; determined empirically; $0 < \epsilon < 1$; smooth, polished, clean surfaces have low values: $\epsilon < .1$; rough, oxidized, dirty surfaces have high values near 1; net radiative heat transfer between two isothermal, grey surfaces: T_1, A_1, ϵ_1 and T_2, A_2, ϵ_2 with $T_1 > T_2$ and $A_1 < A_2$; $Q_{12} = (E_{b1} - E_{b2})/R_{\text{rad}}$; total radiation resistance consists of three resistances in series: $R_{\text{rad}} = R_{s1} + R_{s2} + R_{12}$; two grey-surface resistances: $R_{s1} = (1 - \epsilon_1)/(A_1\epsilon_1)$; $R_{s2} = (1 - \epsilon_2)/(A_2\epsilon_2)$; one spatial resistance: $R_{12} = 1/(A_1 F_{12})$ or $R_{12} = 1/(A_2 F_{21})$;
view factors: $0 \le F_{12} \le 1$, $0 \le F_{21} \le 1$ are dimensionless parameters which depend on geometry and orientation of surfaces; reciprocity relation: $A_1 F_{12} = A_2 F_{21}$; radiation circuit consists of four radiation nodes: E_{b1}, E_{b2}, J_1, J_2; radiosity: J_1, J_2; more about radiosity when we discuss radiation heat transfer.
