ME265: Thermal Engineering & Heat Transfer

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4. Heat Transfer

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4.3.2 External Forced Convection

❑ For Parallel flow over flat plates

Flow over an isothermal flat plate

Parameter	Laminar flow $\boldsymbol{Re_x < 5 \times 10^5}$	Turbulent Flow $\boldsymbol{5 \times 10^5 \le Re_x \le 10^7}$
Local Friction Coefficient, $C_{f,x}$	$C_{f,x} = \dfrac{0.664}{Re_x^{1/2}}$	$C_{f,x} = \dfrac{0.059}{Re_x^{1/5}}$
Local Convection Coefficient, Nu_x	$Nu_x = 0.332\, Re_x^{1/2} Pr^{1/3}$ For $\mathrm{Pr} > 0.6$	$Nu_x = 0.0296\, Re_x^{0.8} Pr^{1/3}$ For $0.6 \le \mathrm{Pr} \le 60$

Parameter	Laminar flow $\boldsymbol{Re_x < 5 \times 10^5}$	Turbulent Flow $\boldsymbol{5 \times 10^5 \le Re_x \le 10^7}$
Average Friction Coefficient, C_f	$C_f = \dfrac{1.33}{Re_L^{1/2}}$	$C_f = \dfrac{0.074}{Re_L^{1/5}}$
Avg. Convection Coefficient, Nu	$Nu = 0.664\, Re_L^{1/2} Pr^{1/3}$ For $\mathrm{Pr} > 0.6$	$Nu = 0.037\, Re_L^{0.8} Pr^{1/3}$ For $0.6 \le \mathrm{Pr} \le 60$

Fluid properties are taken at film temperature: $\boldsymbol{T_f = (T_s + T_\infty)/2}$

4.3.2 External Forced Convection

❑ For Parallel flow over flat plates

Average convection coefficient for parallel flow over an **isothermal flat plate**:

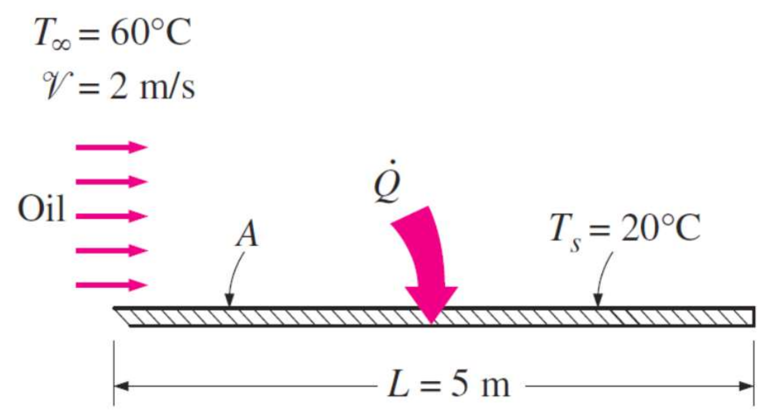
Flow situation	**Relationship** $5 \times 10^5 \le Re_L \le 10^7$
Turbulent flow with negligible laminar component	$Nu = 0.037\, Re_L^{0.8}\, Pr^{1/3}$ For $0.6 \le \mathrm{Pr} \le 60$
Turbulent and laminar components are significant	$Nu = 0.037\, (Re_L^{0.8} - 871) Pr^{1/3}$ For $0.6 \le \mathrm{Pr} \le 60$

$$5 \times 10^5 = Re_{cr} = \frac{V x_{cr}}{\nu}$$

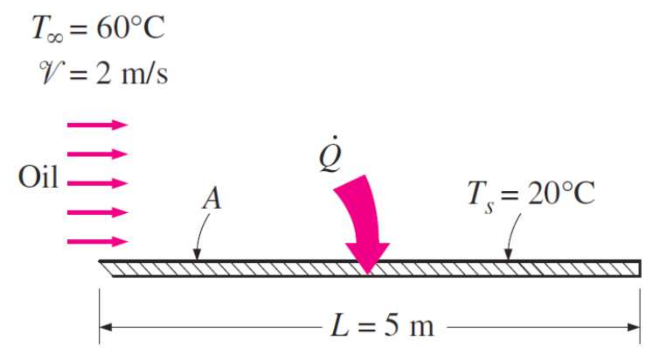
Fluid properties are taken at film temperature: $T_f = (T_s + T_\infty)/2$

EP# 3.3

Engine oil at 60°C flows over the upper surface of a 5-m-long flat plate whose temperature is 20°C with a velocity of 2 m/s. Determine the total drag force and the rate of heat transfer per unit width of the entire plate.



EP# 3.3 Solution



Assumptions

1. The flow is steady and incompressible.

2. The critical Reynolds number is $Re_{cr} = 5 \times 10^5$.

Properties

The properties of engine oil at the film temperature of $T_f = (T_s + T_\infty)/2 = (20 + 60)/2 = 40°C$ are (Table A–13):

$\rho = 876$ kg/m^3 Pr = 2962 $k = 0.1444$ W/m °C $\nu = 2.485 \times 10^{-4}$ m^2/s

4.3.2 External Forced Convection

EP# 3.4

To defrost ice accommodated on the outer surface of an automobile windshield, warm air is blown over the inner surface of the windshield. Consider an automobile windshield (k_w=1.4 W/m.K) with an overall height of 0.5 m and the thickness of 5 mm. The outside air ambient temperature is -20^{o}C and the average air flow velocity over the outer shield surface is 80 km/h, while the ambient temperature inside the automobile is 25^{o}C. Determine the convection heat transfer coefficient for the warm air blowing over the inner surface of the windshield, necessary to cause the accumulated ice to begin melting.

EP# 3.4 Solution

Assumptions

1. The flow is steady and incompressible.
2. The critical Reynolds number is $Re_{cr} = 5 \times 10^5$.

Properties

The properties of engine oil at the film temperature of $T_f = (T_s + T_\infty)/2 = (-20 + 0)/2 = -10°C$ are (Table A–15):

$\rho = 1.341 \text{ kg/m}^3$

$Pr = 0.3787$

$k = 0.02288 \text{ W/m °C}$

$\nu = 1.252 \times 10^{-5} \text{ m}^2\text{/s}$