Examination 2: Convection

Heat Transfer Ch En 3453

Rules:

- Open book and notes
- Calculators and use of software (like Excel) allowed
- Anyone caught communicating with others during the exam (via email, text, chat, in person, etc.) will receive a score of zero on the exam and will be disciplined according to university policies.
- Attempt to answer as much of each problem as possible. Partial credit may be awarded based on completing parts of the problem correctly or demonstrating the correct thought process.
- Report answers to at least 3 significant figures.

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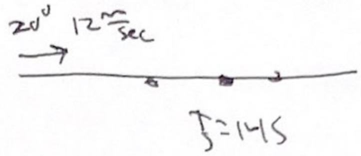
Problem 1 (25 pts)

Air at 20 °C flows parallel to a flat plate at 12 m/s. The heated plate is kept at a constant temperature (T_s) of 145 °C. If the plate is 1 m wide and 10 m long, **what is the total amount of heat (in W) that is transferred from the plate to the air?**

Use the following thermal properties for air:

ρ	1.16 kg/m³
μ	1.846×10^{-5} (N*s/m²)
k	2.63×10^{-2} (W/m*K)
Pr	.707



$Re = \frac{\rho L V}{\mu} = 7540628 >> 5 \times 10^5 \therefore$ Turbulent

$Nu = 0.0296 Re^{4/5} Pr^{1/3} = \cancel{\ldots} = 8375.76$

$h = \frac{Nu\, k}{L} = \frac{8375 \cdot 2.63 \times 10^{-2}}{10} = 22.03 \frac{W}{m^2 K}$

$q = hA(T_s - T_\infty) = 22.03 \cdot 10 \cdot 1 (145 - 20)$

$= 27535 \boxed{\approx 2.75 \times 10^4 \text{ W}}$

Problem 2 (25 pts)

Water at 30 °C enters a pipe with an inner diameter of 6 cm. The pipe's inner wall is held constant at a temperature of 110 °C. If the water's velocity is 2.3 cm/s, **what is the mean temperature of the water at x = 14 m from the pipe entrance?**

Use the following thermal properties for water:

ρ	998 kg/m^3
μ	0.000890 (N*s/m^2)
k	0.598 (W/m*K)
Pr	6.99
C_p	4180 (J/kg*K)

$$Re = \frac{\rho v D}{\mu} = 1547 < 2300$$

Laminar

$$Nu = 3.66 + \frac{0.0668\,Gz}{1+0.04\,Gz^{2/3}} \qquad Gz = \frac{D}{x}\,Re\,Pr$$

$$Nu = 5.702 \qquad h = \frac{Nu\,k}{D} = 56.8\,\frac{W}{m^2K}$$

$$\cancel{q'' = h(T_s - T_\infty)} \qquad \dot{m} = vA\rho$$

$$T_o = -\exp\left(\frac{-PLh}{\dot{m}c}\right)(T_s - T_i) + T_s = 110 - \exp\left(\frac{-2\pi r \cdot 14 \cdot 56.8}{vA\rho \cdot 4180}\right)(110-30)$$

$$\boxed{T_o = 63.98\ ^\circ C} =$$

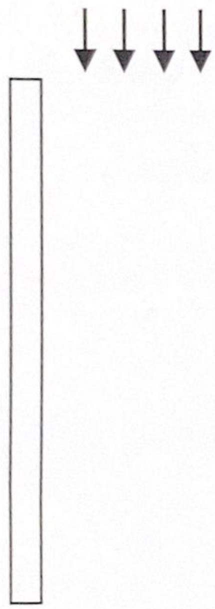
$$\cancel{\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln\left(\frac{\Delta T_o}{\Delta T_i}\right)} = \frac{(110-64) - (110-30)}{\ln\left(\frac{110-64}{110-30}\right)} = 61.5\ ^\circ C}$$

Problem 3 (25 pts)

A hot, 3 m tall wall with a constant surface temperature of 330 K causes natural convection to happen in a room. There is also forced convection due to a downward draft of cooler air at 280 K. Given the Nusselt numbers for forced and natural convection below, **what is the average rate of heat flux from the wall to the room air?**

q''

$\overline{Nu_F}$	650	
$\overline{Nu_N}$	450	
k_{air}	.0262	W/m*K
k_{wall}	20.3	W/m*K



$$(Nu_{Comb})^3 = N_F^3 + N_N^3$$

$$Nu = \sqrt[3]{650^3 + 450^3} = 715$$

$$h = \frac{Nu\, k_{air}}{L} = \frac{715 \cdot 0.0262}{3} = 6.246 \frac{W}{m^2K}$$

$$q'' = h(T_s - T_\infty) = 6.246(330 - 280)$$

$$= 312. \frac{W}{m^2}$$

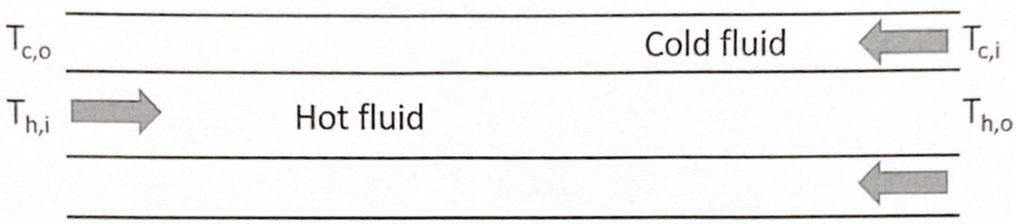
120 / 170 Cold → * 283 \ 134.51
\ 290 ← Hot 418 /

Problem 4 (25 pts)

A counterflow heat exchanger (double-pipe configuration) is used to recover heat from a hot fluid in order to heat up a cold fluid.

Assuming that the exchanger is at steady state, what is the value of the product U*A (in W/K)?

$T_{c,i}$ (cold fluid inlet temperature) = 170 K	$T_{h,i}$ (hot fluid inlet temperature) = 418 K
	$T_{h,o}$ (hot fluid outlet temperature) = 290 K
$\dot{m}_c$ (cold fluid mass flow rate) = 5 kg/s	$\dot{m}_h$ (hot fluid mass flow rate) = 3 kg/s
$C_{p,c}$ (cold fluid heat capacity) = 1,570 J/kg*K	$C_{p,h}$ (hot fluid heat capacity) = 2,320 J/kg*K



$q = \dot{m} c (T_o - T_i)$ $\qquad q = UA\,\Delta T_{lm}$ $\qquad UA = \frac{q}{\Delta T_{lm}} = \frac{\dot{m} c (T_o - T_i)}{\Delta T_{lm}}$

$\cancel{UA = 3 \cdot 2320 (290 - 418) \cdot \frac{\ln\left(\frac{290-170}{418-x}\right)}{(290-170)-(418-x)}}$ $\qquad q = 890880\ W$

$\dot{m}_c C_c (T_{oc} - T_{ic}) = \dot{m}_H C_H (T_{oH} - T_{iH})$

$T_{c,o} = \frac{\dot{m}_H C_H \Delta T_H}{\dot{m}_c C_c} + T_{ic} = 283\ K$

$UA = \frac{q}{\Delta T_{lm}} = q \cdot \frac{\ln\left(\frac{120}{134}\right)}{120 - 134} = 890880 \cdot 127 = 113246901$

$\cancel{= 1.13 \times 10^8\ W}$

$\boxed{= 1.13 \times 10^8\ \frac{W}{K}}$