Instructions:
1. Open book exam, one 8.5" × 11" page of notes.
2. Duration: 60 minutes.
3. I’m interested in the procedure you use to solve the following problems.

Calculations are important if they help illustrate your procedure. Sometimes solutions involve an iterative process, but on examinations, multiple iterations are not necessary.

<table>
<thead>
<tr>
<th>Material</th>
<th>T(K)</th>
<th>Density</th>
<th>Cp</th>
<th>k</th>
<th>Viscosity</th>
<th>Pr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K</td>
<td>kg/m³</td>
<td>J/(kg K)</td>
<td>W/(m K)</td>
<td>m²/s</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>300</td>
<td>1</td>
<td>1000</td>
<td>0.025</td>
<td>1.5(10⁻⁵)</td>
<td>0.72</td>
</tr>
<tr>
<td>Air</td>
<td>350</td>
<td>1</td>
<td>1010</td>
<td>0.030</td>
<td>2.3(10⁻⁵)</td>
<td>0.71</td>
</tr>
<tr>
<td>Air</td>
<td>400</td>
<td>1</td>
<td>1030</td>
<td>0.035</td>
<td>2.5(10⁻⁵)</td>
<td>0.70</td>
</tr>
<tr>
<td>Water</td>
<td>300</td>
<td>1000</td>
<td>4180</td>
<td>0.613</td>
<td>0.85(10⁻⁵)</td>
<td>5.83</td>
</tr>
<tr>
<td>Water</td>
<td>350</td>
<td>970</td>
<td>4190</td>
<td>0.668</td>
<td>0.37(10⁻⁵)</td>
<td>2.29</td>
</tr>
</tbody>
</table>

1. (50%) A flat-plate solar has 8-m of 10-mm diameter smooth copper tubing soldered to it. The collector is maintained at 350 K by solar irradiation. Water enters the tube at 300 K and a flow rate of 0.01 kg/s.

(a) What is the water exit temperature if fully developed flow is assumed?
(b) What is the total heat rate (W) of the collector?
(c) If the tube has rough walls maintained at 350 K, how would the exit temperature calculated in part (a) change? Explain.
(d) How good is the fully developed flow assumption? Discuss.

2. (25%) A long wire of diameter 0.5 mm is positioned across a large passage to determine air flow velocity from heat transfer characteristics. A known current is passed through the wire to heat it, and all the heat generated is dissipated to the flowing air. The resistance of the wire is determined from electrical measurements and thus its temperature and heat generation are known. Outline how to find the air velocity in terms of the wire and environment temperatures.

3. (25%) Air at 350 K flows over a flat plate at 1 m/s. What is the flow velocity parallel to the plate at a point 1 m from the leading edge and 1 cm above the plate?
Problem 1

Solution:

\[ \text{Re} = \frac{4m}{\pi Dv_p} = \frac{4 \times 0.01}{\pi (10 \times 10^{-3}) (0.85 \times 10^{-4}) (1000)} = 1500 < 2300 \quad \text{laminar flow} \]

a) \( \text{Nu} = 3.66 \)

\[ h = \frac{\text{Nu} \cdot k}{d} = 229 \frac{W}{m^2K} \]

\[ A_s = \pi d l = 0.251 m^2 \]

\[ T_e = T_s - (T_s - T_i) \exp\left(-\frac{h A_s}{m c_p}\right) = 350 - 50 \exp\left(-\frac{229 \times 0.251}{0.01 \times 9180}\right) \]

\[ T_e = 337 K \]

b) \[ \Delta T_{lm} = \frac{T_i - T_e}{\ln \frac{T_s - T_e}{T_s - T_i}} = \frac{300 - 337}{\ln \frac{350 - 337}{350 - 300}} = 27.47 K \]

\[ q = h A_s \Delta T_{lm} = 1544 W \]

c) no change (\( f \) is not a function of roughness in laminar flow)

d) \( L_t = 0.05 \text{Re} \cdot \text{Pr} \cdot d = 4.37 m \)

more than half of the pipe is entry length fully developed is not a good assumption
Problem 2

\[ V \dot{q}_{\text{gen}} = \pi d h (Tw - Ta) + \pi d l e o (Tw - T_{\text{surv}}) \]

\[ \dot{q}_V = \pi d l \left[ h (Tw - Ta) + e o (Tw - T_{\text{surv}}) \right] \]

\[ h = \frac{\dot{q}_V - \pi d l e o (Tw - T_{\text{surv}})}{\pi d l (Tw - Ta)} \]

\[ Nu = \frac{h d}{K} = \frac{\dot{q}_V - \pi d l e o (Tw - T_{\text{surv}})}{\pi d l K (Tw - Ta)} \quad \text{(known)} \]

Churchill and Bernstein:

\[ Nu = 0.3 + \frac{0.62 \text{ Re}^{0.2} \text{ Pr}^{0.1}}{\left[ 1 + (0.9 / \text{Pr})^{0.2} \right]^{0.1/3}} \rightarrow \text{Re is obtained} \]

\[ V = \frac{\text{Re} \cdot d}{d} \]
Problem 3

\[ \eta = y \sqrt{\frac{u_\infty}{v_X}} = 0.01 \times \sqrt{\frac{1}{2 \times (10^{-5})}} = 2.29 \]

Table 7.1 (interpolation)

\[ \frac{u}{u_\infty} = 0.689 \quad \Rightarrow \quad u = 1 \times 0.689 = 0.689 \text{ m/s} \]