1. Work Text Problem 10.1

2. Work Text Problem 10.2

3. The physical properties of beef carcasses (carved up BEVO) during chilling are \( \rho = 1073 \text{ kg/m}^3 \), \( c_p = 3.48 \text{ kJ/kg K} \), and \( k = 0.498 \text{ W/m K} \). A large slab of beef 0.203 m thick initially at 37.8°C is to be cooled to an average temperature of 10°C. Chilled air at 1.7°C (assume constant) is being circulated to yield a heat transfer coefficient \( (h) \) of 39.7 W/m² K. Calculate the time required to chill the beef.

4. Work Text Problem 10.14

5. Work Text Problem 10.15
10.1 Basis: 1 m². Let A refer to fireclay brick, B to kaolin brick, and C to steel. From Appendixes 10 and 11, thermal conductivities are

<table>
<thead>
<tr>
<th>Material</th>
<th>$K, \text{ W/m} \cdot \text{K}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fireclay brick</td>
<td>1.7</td>
</tr>
<tr>
<td>Kaolin brick</td>
<td>0.11</td>
</tr>
<tr>
<td>Steel</td>
<td>45</td>
</tr>
</tbody>
</table>

Heat loss:

$$q = \frac{T_h - T_c}{\frac{x_A}{k_A} + \frac{x_B}{k_B} + \frac{x_C}{k_C} + \frac{(x_B)_{air\_equiv.} \cdot 0.11}{1.7 + 0.11 + 45 + 0.11}}$$

$300 = \frac{1150 - 30}{0.200 + 0.100 + 0.006 + \frac{(x_B)_{air\_equiv.}}{1.7 + 0.11 + 45 + 0.11}}$

$(x_B)_{air\_equiv.} = 0.298 \text{ m}$

10.2 Pipe diameters (Appendix 3):

$D_0' = 1.315 \text{ in.}$  \hspace{1cm} $D_1' = 1.049 \text{ in.}$

$\bar{D}_{L \ (pipe)} = \frac{(1.315 - 1.049)}{\ln 1.315 / 1.049}$

$= 1.177 \text{ in.}$

$\bar{D}_{L \ (magnesia)} = \frac{(5.315 - 1.315)}{\ln 5.315 / 1.315}$

$= 2.86 \text{ in.}$

$\bar{D}_{L \ (cork)} = \frac{(6.315 - 5.315)}{\ln 6.315 / 5.315}$

$= 5.80 \text{ in.}$
Thermal conductivities, in Btu/h-ft-°F,

- Cork: \( k_A = 0.03 \)
- Magnesia: \( k_B = 0.034 \)
- Steel: \( k_C = 26 \)

Thermal resistances, based on 100 ft of pipe:

\[
R_A = \frac{0.5/12}{0.03\pi(5.80/12)\times100} = 0.00915
\]

\[
R_B = \frac{2/12}{0.034\pi(2.86/12)\times100} = 0.06547
\]

\[
R_C = \frac{0.133/12}{26\pi(1.177/12)\times100} = 0.000014
\]

Heat loss:

\[
q = \frac{249 - 90}{0.00915 + 0.06547 + 0.000014} = 2130 \text{ Btu/h}
\]

Let \( T_A \) be the temperature at the boundary between cork and magnesia and \( T_B \) that at the boundary between cork and steel. The total resistance \( R_A + R_B + R_C = 0.074634 \). Then

\[
T_A = 90 + (0.00915/0.074634)(249-90) = 109.5°F
\]

\[
T_B = 249 - (0.000014/0.074634)(249-90) = 248.97°F
\]
Problem #3

\[ \alpha = \frac{0.498 \text{ W/m}^2}{1073 \frac{\text{ W}}{\text{m}^2}} \left( 3.48 \frac{\text{ kJ}}{\text{ kgK}} \right) \left( \frac{1000 \text{ J}}{1 \text{ kJ}} \right) = 1.334 \times 10^{-3} \text{ m}^2/\text{s} \]

\[ S = \frac{0.203 \text{ m} - 0.1015 \text{ m}}{2} = 0.101 \text{ m} \]

\[ P_a = \frac{59.7 \frac{\text{ W}}{\text{m}^2}}{0.498 \frac{\text{ W}}{\text{m}^2}} \left( 0.1015 \text{ m} \right) = 8.1 \]

\[ Y_{axis} = \frac{1.7 \text{ C} - 16 \text{ C}}{1.7 \text{ C} - 378 \text{ C}} = 0.23 \]

From Figure 10.7 \( F_0 = 0.70 = \frac{\alpha t}{S^2} \)

\[ 0.70 \left( 0.1015 \text{ m} \right)^2 = t \]

\[ 1.334 \times 10^{-7} \frac{\text{ m}^2}{\text{s}} \]

\[ t = 54,060 \text{ s} \quad (15 \text{ hrs}) \]
\[ \alpha = \frac{k}{\rho c_v} = \frac{0.12}{950 \times 1600} = 7.89 \times 10^{-8} \]

\[ s = \frac{1.6 \times 10^{-2}}{2} = 8 \times 10^{-3} \text{ m} \]

\[ a_i = \left( \frac{\pi}{2} \right)^2 = 2.467 \]

Use Eq. (10.19) or Figure "b" Handout

at the center, \( x = s = 8 \times 10^{-3} \)

\[ Y = \frac{T_s - T}{T_s - T_o} = \frac{70 - 60}{70 - 30} = 0.25 \]

Try \( F_0 = 0.6, \ a_i F_0 = 2.467 \times 0.6 = 1.480 \)

\[ Y = \frac{4}{\pi} \left[ e^{-1.48} \sin \frac{\pi}{2} + \frac{1}{3} e^{-0.48} \sin \frac{3\pi}{2} + \ldots \right] \]

\[ Y = \frac{4}{\pi} \left[ 0.2276(1.0) - 5.47 \times 10^{-1}(1.00) + \ldots \right] \]

\[ Y = 0.290 \]

Try \( F_0 = 0.7, \ a_i F_0 = 1.727 \)

\[ Y \approx \frac{4}{\pi} e^{-1.727} = 0.226 \]

By interpolation, for \( \frac{T_s - T}{T_s - T_o} = 0.25, \ F_0 \approx 0.663 = \alpha t/s^2 \)

\[ t = \frac{0.663(8 \times 10^{-3})^2}{7.89 \times 10^{-8}} = 538 \text{ s} \]
\( W = 1 \text{ cm} \quad h = h_0 = 10 \ \text{W/m}^2 \cdot \text{k} \)
\( \varepsilon = 0.3 \ \text{cm} \quad k_{\text{air}} = 2.49 \times 10^{-2} \ \text{W/m} \cdot \text{k} \)
\( k_{\text{fr}} = 1.68 \times 10^{-2} \ \text{W/m} \cdot \text{k} \)
\( k_{\text{glass}} = 0.7 \ \text{W/m} \cdot \text{k} \)

with air,
\[
\frac{1}{U} = \frac{2}{10} + 2 \times 3 \times 10^{-3} \left( \frac{1}{0.7} + \frac{10^{-2}}{2.49 \times 10^{-2}} \right)
\]
\( U = 1.639 \ \text{W/m}^2 \cdot \text{k} \)

with Argon,
\[
\frac{1}{U} = \frac{2}{10} + 6 \times 10^{-3} \left( \frac{1}{0.7} + \frac{10^{-2}}{1.68 \times 10^{-2}} \right)
\]
\( U = 1.244 \ \text{W/m}^2 \cdot \text{k} \quad (24\% \ \text{less}) \)