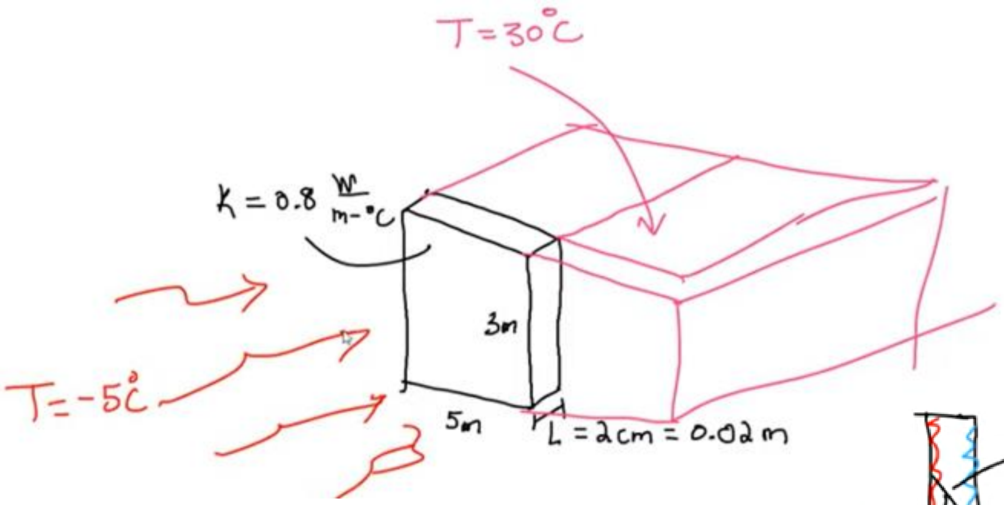
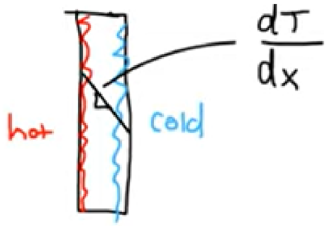
Problem 1

For a $5\text{m} \times 3\text{m}$ area concrete wall, $\text{k} = 0.8\text{W/m} -^\circ \text{C}$, the inside temperature is 30°C and the outside temperature is -5°C. What is the rate of heat transfer if the thickness L of the wall is 2cm:

(A) 15 kW
(B) 17 kW
(C) 25 kW
(D) 21 kW

Problem 1





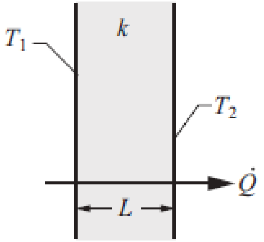
Basic Heat-Transfer Rate Equations Conduction

Fourier's Law of Conduction Page 204 of FE Handbook

$$\dot{Q} = -kA\frac{dT}{dx}$$

Conduction Through a Plane Wall

$$\dot{Q} = \frac{-kA(T_2 - T_1)}{L}$$



$$\dot{Q} = \frac{kA(T_2 - T_1)}{L}$$

$$\dot{Q} = \frac{0.8\ W/m\text{-}°C\ (3m \times 5m)(30°C + +5°C)}{(0.02m)}$$

$$\dot{Q} = 21000\ W = \boxed{21\ kW}$$

Problem 2

Air flows at a velocity of $2 \mathrm{m/s}$ in an 8 cm diameter and 7 m long tube as the tube is subjected to uniform heat flux from all surfaces. Using the air properites given below, the convection heat transfer coefficient is most nearly:

Prandtl Number, $\mathbf{Pr} = 0.7296$
Kinematic viscosity, $v = 1.562 \times 10^{-5} \mathrm{m}^2/\mathrm{s}$
Specific heat constant, $c_p = 1007 \mathrm{J/kg} \cdot \mathrm{K}$
Thermal conductivity, $k = 0.02551 \mathrm{W/m} \cdot \mathrm{K}$

(A) 7.25 $W/m^2 * K$
(B) 10.44 $W/m^2 * K$
(C) 12.44 $W/m^2 * K$
(D) 5.23 $W/m^2 * K$

Problem 2

Find: h

$$\Rightarrow h = \frac{k}{D} Nu$$ from page 248 of FE Handbook

1) $$Re = \frac{VD}{\nu} = \frac{2\ m/s\ (0.08m)}{1.562\times10^{-5}\ m^2/s}$$

$$Re = 10{,}243.27 > 10{,}000 \rightarrow \text{Turbulent}$$

Turbulent Flow in Circular Tubes (Dittus-Boelter Equation) n page 211 of FE Handbook

2) $$Nu = 0.023\ Re^{4/5}\ Pr^{n}$$

$$n = 0.4 \rightarrow \text{Heating}$$

$$Nu = 0.023(10{,}243.27)^{0.8}(0.7296)^{0.4}$$

$$Nu = 32.7576$$

Flow Over a Sphere of Diameter, D on page 210 of the FE Handbook:

3) $$h = \frac{k}{D} Nu$$

$$h = \frac{0.02551\ W/m\cdot K}{0.08\ m}(32.7576)$$

$$\boxed{h = 10.44\ W/m^2\cdot K}$$

Problem 3

A counter-flow heat exchanger is used to heat water $(C_p = 4.18\ kJ/kg - K)$ from 288 K to 348 K traveling at a mass flowrate of 65 kg/min. Heating is accomplished by oil $(C_p = 2.20\ kJ/kg - K)$ entering at 388 K and leaving at 348 K . Assume the overall heat transfer coefficient is 320 $\mathrm{W/m^2 - K}$.

The area (m^2) of the heat exchanger is most nearly:

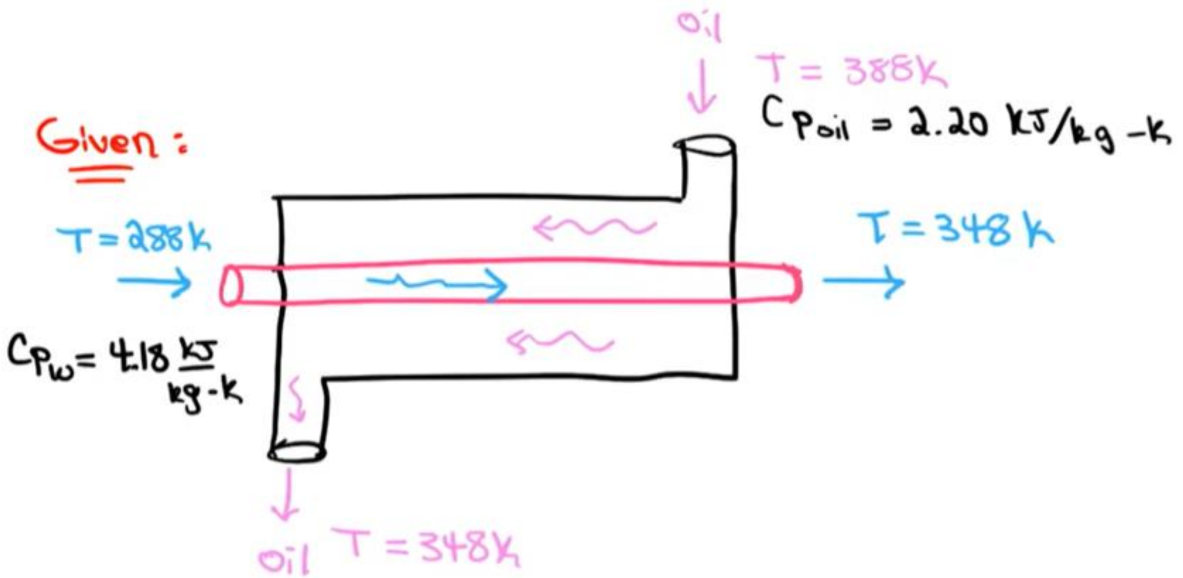
(A) 22

(B) 15

(C) 20

(D) 18

Problem 3



From page 215 of FE Handbook, the Log Mean Temperature Difference (LMTD) (for counterflow in tubular heat exchangers)

1) $$\Delta T_{lm} = \frac{(T_{Ho} - T_{ci}) - (T_{Hi} - T_{co})}{\ln\left(\frac{T_{Ho} - T_{ci}}{T_{Hi} - T_{co}}\right)} = \frac{(348K - 288K) - (388K - 348K)}{\ln\left(\frac{348K - 288K}{388K - 348K}\right)}$$

$$\Delta T_{lm} = 49.33K$$

The rate of heat transfer in a heat exchanger is:

2) $$\dot{Q} = UAF\Delta T_{lm}$$

$$271{,}700\,\frac{J}{s} = 320\,\frac{W}{m^2\text{-}K}(A)(1)(49.33K) \Rightarrow A = \boxed{17.21\ m^2}$$

The rate of heat transfer associated with either stream in a heat exchanger in which incompressible fluid or ideal gas with constant specific heats flows is:

3) $$\dot{Q} = \dot{m}_w C_{P_w}(T_{ew} - T_{iw})$$

$$\dot{Q} = \frac{65\,kg}{min}\left[\frac{1\,min}{60\,s}\right)\left(4.18\,\frac{kJ}{kg\text{-}K}\right)(348 - 288K) \Rightarrow \dot{Q} = 271.7\,\frac{kJ}{s}$$

$$\dot{Q} = 271{,}700\,\frac{J}{s}$$

Problem 4

The flowrate (kg/sec) of the oil entering is most nearly:

(A) 185

(B) 3.09

(C) 10.25

(D) 145

Problem 4

The flowrate (kg/sec) of the oil entering is most nearly:

(A) 185

(B) 3.09

(C) 10.25

(D) 145

Energy Balance

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{E} = \dot{m} c_p T$$

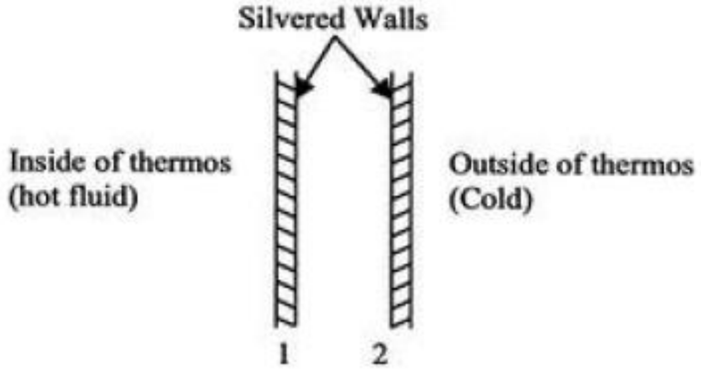
$\dot{m}_{oil}$?

$$\dot{m} = \frac{U \cdot \frac{1\,J}{W \cdot s} \cdot A \cdot \Delta T_{lm}}{c_{p \cdot oil} \cdot (T_{i \cdot oil} - T_{e \cdot oil})K}$$

$$\dot{m} = \frac{\frac{320\,W}{m^2 \cdot K} \cdot \frac{1\,J}{W \cdot s} \cdot 17.21 m^2 \cdot 49.33 K}{\frac{2200\,J}{kg \cdot K} \cdot (388 - 348)K}$$

$$\dot{m} = 3.087 \frac{kg}{s}$$

Problem 5



Silvered Walls
Inside of thermos
(hot fluid)
Outside of thermos
(Cold)
1
2

Problem 5

19.3.1 Example 1: Use of a thermos bottle to reduce heat transfer

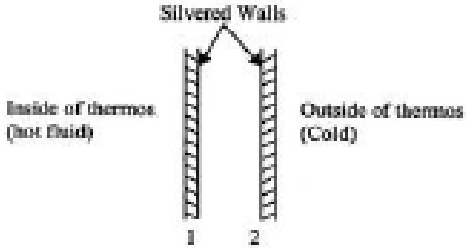


Figure 19.6: Schematic of a thermos wall

$\varepsilon_1 = \varepsilon_2 = 0.02$ for silvered walls, $T_1 = 100°\mathrm{C} = 373\ \mathrm{K}$; $T_2 = 20°\mathrm{C} = 293\ \mathrm{K}$.

$$\dot{q}_{\text{net 1 to 2}} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \dot{q}_{\text{net 1 to 2}}$$

$$= \frac{(5.67 \times 10^{-8}\ \mathrm{W/m^2K^4})((373\ \mathrm{K})^4 - (293\ \mathrm{K})^4)}{\frac{1}{0.02} + \frac{1}{0.02} - 1} = 6.9\ \mathrm{W/m^2}.$$

For the same ΔT , if we had cork insulation with $k = 0.04\ \mathrm{W/m\text{-}K}$, what thickness would be needed?

$\dot{q} = \frac{k\Delta T}{L}$ so a thickness $L = \frac{k\Delta T}{\dot{q}} = \frac{(0.04\ \mathrm{W/m\text{-}K})(80\ \mathrm{K})}{6.9\ \mathrm{W/m^2}} = 0.47\ \mathrm{m}$ would be needed! The thermos is indeed a good insulator.

Problem 6

Problem 6

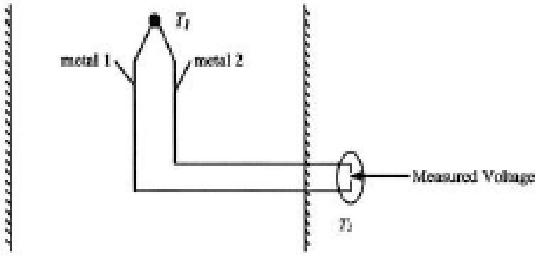


Figure 19.7: Thermocouple used to measure temperature. Note: The measured voltage is related to the difference between T_1 and T_2 (the latter is a known temperature).

Thermocouples (see Figure 19.7) are commonly used to measure temperature. There can be errors due to heat transfer by radiation. Consider a black thermocouple in a chamber with black walls.

Suppose the air is at $20°\mathrm{C}$, the walls are at $100°\mathrm{C}$, and the convective heat transfer coefficient is $h = 15\ \mathrm{W/m^2K}$.

What temperature does the thermocouple read?

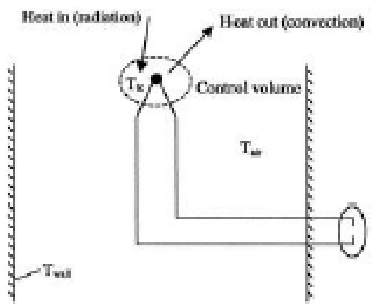


Figure 19.8: Effect of radiation heat transfer on measured temperature

We use a heat (energy) balance on the control surface shown in Figure 19.8. The heat balance states that heat convected away is equal to heat radiated into the thermocouple in steady state. (Conduction heat transfer along the thermocouple wires is neglected here, although it would be included for accurate measurements.)

The heat balance is

$$hA(T_{tc} - T_{air}) = \sigma A(T_{wall}^4 - T_{tc}^4),$$

where A is the area of the thermocouple. Substituting the numerical values gives

$$(15\ \mathrm{W/m^2\text{-}K})(T_{tc} - 293\ \mathrm{K}) = (5.67 \times 10^{-8}\ \mathrm{W/m^2K^4})((373\ \mathrm{K})^4 - T_{tc}^4),$$

from which we find $T_{tc} = 51°\mathrm{C} = 324\ \mathrm{K}$. The thermocouple thus sees a higher temperature than the air. We could reduce this error by shielding the thermocouple as shown in Figure 19.9.

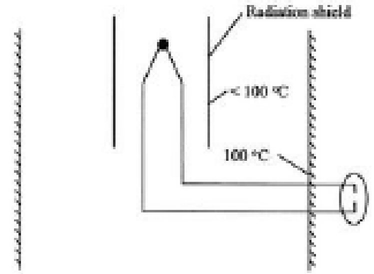


Figure 19.9: Shielding a thermocouple to reduce radiation heat transfer error

Problem 7

Problem 7

Problem 8

Problem 8

Problem 9

Problem 9

Problem 10

Problem 10

Problem 1

Problem 1

Problem 2

Problem 2

Problem 3

Problem 3

Problem 4

Problem 4

Problem 5

Problem 5

Problem 6

Problem 6

Problem 7

Problem 7

Problem 8

Problem 8

Problem 9

Problem 9

Problem 10

Problem 10