Test 1
MET 440 Heat Transfer
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Problem 1

Problem Statement:

A solar flux is incident on a flat-plate solar collector used to heat water. Most of the radiation passes through the cover glass and air and is absorbed directly by the absorber plate. The remaining heat is reflected away from the collector. Water flows through tubes on the backside of the absorber plate and is heated. The tubes the water flows through are made of copper and are buried in a slab of silver which is well insulated on the back.

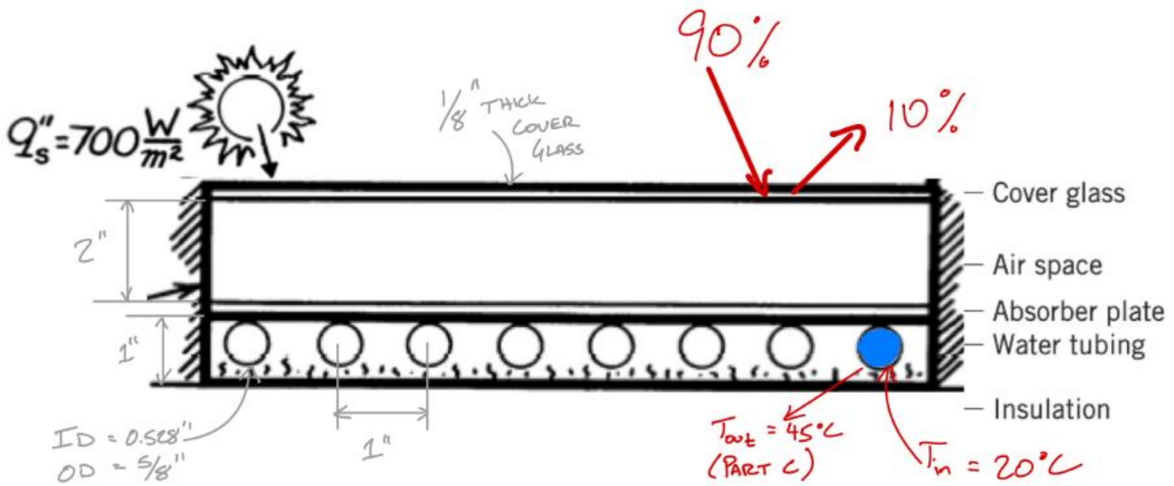
Purpose:

a) What is the amount of heat collected by the water in one of the tubes?
b) What is the air space temperature?
c) If the outlet temperature of the water is 45°C, what is the flow rate? Assume the specific heat of the water to be 4179 J/kg. K
d) The collector efficiency η is defined as the useful heat collected to the rate at which solar energy is incident on the collector. What is the value of η?

Sources:

A Textbook for Heat Transfer Fundamentals

Drawing:



Design Considerations:

- The absorber plate is very thin and highly conductive
- The silver slab loses no heat through the insulation

- Each layer is in perfect thermal contact
- There is no radiation of heat happening with the atmosphere

Data and Variables:

- The physical dimensions of the solar plate are on the drawing
- 90% of the radiation is absorbed by the plate, 10% is reflected
- The initial solar flux is 700 W/m^2
- Initial temperature of the water is 20°C
- The convection coefficient of the water is 1000 W/m^2 K
- The convection coefficient between the cover glass and the ambient air is 50 W/m^2 K
    - The air temperature is 25°C
- The convection coefficient of the air space is 10 @/m^2 K
- For air at 300K, k=0.02624 W/mK (Table B-1)

Procedure:

- The purpose of the problem is to calculate the amount of heat collected through the glass plate and absorbed by the water
- Conservation of energy results in all of the heat absorbed by the plate is being absorbed by the water as well. In this case:
    - $q_{solar} = q_{total} \cdot 0.9 = \left(700 W/_{m^2}\right) \cdot 0.9 = 630 W/_{m^2}$
- For part a) the total absorbed by a single tube over the length of one meter is calculated by finding the area of that tube and applying q_{solar} to that area
- For part b) the air space temperature is calculated by first finding the temperature of the glass plate and the resistance of the glass plate using the supplied value for the convection coefficient of air and a value from a table for the conduction coefficient of the plate glass
    - $q_{solar} = \frac{\Delta T}{R_T} \;\; \therefore \;\; T_{air\ gap} = q_{solar} \cdot R_T + T_{glass}$
    - R_T is calculated using the coefficients for heat transfer listed above
        - $R_{\infty\ air} = \frac{1}{Ah_{\infty}} \qquad R_{glass} = \frac{L}{Ak_{glass}}$
- For part c) the flow rate of the water can be calculated using:
    - $Q = \dot{m} c_p \Delta T$ where Q is the total heat over 1m^2 as determined by part a)
- For part d) the efficiency is calculated by finding the ratio of the useful heat as compared to the incident heat. Because all of the heat not reflected from the initial glass plate is stored within the system, that is the useful heat applied.
    - $\eta = \frac{q_{solar}}{q_{total}}$

Calculations:

Part a)

$$A_{\text{single tube}} = D_{OD} \cdot L = (0.01588m)(1m) = 0.01588m^2$$

$$Q = q_{solar} \cdot A_{\text{single tube}} = \left(630\ W/_{m^2}\right)\left(0.01588m^2\right) = \boxed{10.0044\ W}$$

Part b)

$$T_{glass,\ surf} = q_{solar} \cdot R_{air} + T_{air} = \left(630\ {}^{W}\!/_{m^2}\right) \cdot \left(\frac{1}{\left(1m^2\right)\left(50\ {}^{W}\!/_{m^2K}\right)} \right) + 25°\,C$$

$$= 37.6°\,C$$

$$T_{air\ gap} = \left(630\ {}^{W}\!/_{m^2}\right)\left(\frac{0.003175m}{\left(1m^2\right)\left(1.4{}^{W}\!/_{m°\,C}\right)} \right) + (37.6°\,C)$$

$$= \boxed{39.03°\,C}$$

Part c)

$$\dot{m} = \frac{Q}{c_{water}\,\Delta T} = \frac{630W}{\left(4179{}^{J}\!/_{kg\,\cdot\,K}\right)(45°\,C - 20°\,C)} = \boxed{.006\ {}^{kg}\!/_{s}}$$

Part d)

$$\eta = \frac{630{}^{W}\!/_{m^2}}{700\ {}^{W}\!/_{m^2}} = 0.9 = \boxed{90\%}$$

Summary:

By neglecting any form of heat loss to the system other than via reflection, the overall efficiency is incredibly high. For part c) the flow rate is quite low. This is due to the large temperature difference being achieved, and the small area being used in this problem. It is assumed that the solar plate is only $1m^2$ which limits the ability to heat the water significantly.

Materials:

Materials are listed in the problem statement and data sections.

Analysis:

The small footprint of the solar panel results in a slow heating process for the water in the tubes.

<u>Problem 2</u>

Problem Statement:

Brazing is a metal-joining operation where a base metal is heated to a high temperature and a brazing material is applied to the heated joint. The brazing material melts into the joint and solidifies as it is allowed to cool. This operation is performed using a brazing rod of a given material.

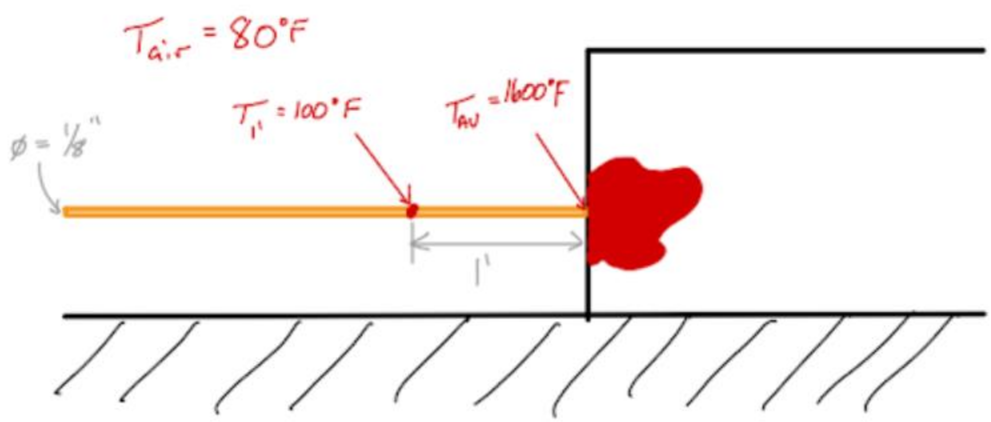
Purpose:

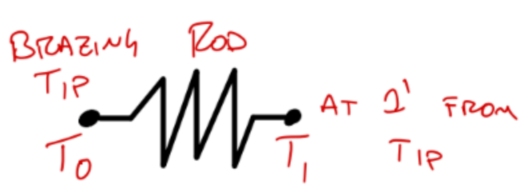
What is the conductivity of the brazing material under the given specific circumstances?

Sources:

See problem 1

Drawing:





Design Considerations:

- The system is steady-state

Data and Variables:

- The dimensions of the system are given in the drawing
- The temperature at the end of the brazing rod reaches an average temperature of 1600°F
- The temperature at a distance of 1 foot up the rod is 100°F
- Ambient air temperature is 80°F
- The convection coefficient is 0.9 BTU/hr ft^2 °R

Procedure:

- The purpose of the problem is to determine the conductivity of the unknown brazing material.
- The given information can be used to determine this value by calculating the heat loss of the rod to the ambient air over the 1-foot distance from the tip of the rod to the point under inspection
- The rod can be treated as a fin with a constant cross sectional area, and θ_x and θ_b are known
  - $\theta_x = T_{(x)} - T_\infty = (100°\,F) - (80°\,F) = 20°\,F$
    $\theta_b = T_b - T_\infty = (1600°\,F) - (80°\,F) = 1520°\,F$
- Using the fin equation solve for *k*

Calculations:

$$\frac{\theta_x}{\theta_b} = \frac{\cosh m(L-x) + \left(h/mk\right)\sinh m(L-x)}{\cosh m(L) + \left(h/mk\right)\sinh m(L)}$$

$$m^2 = \frac{hP}{Ak} \quad \therefore \quad k = \frac{hP}{Am^2}$$

Summary:

Solving for *k* will produce the thermal conductivity of the brazing material.