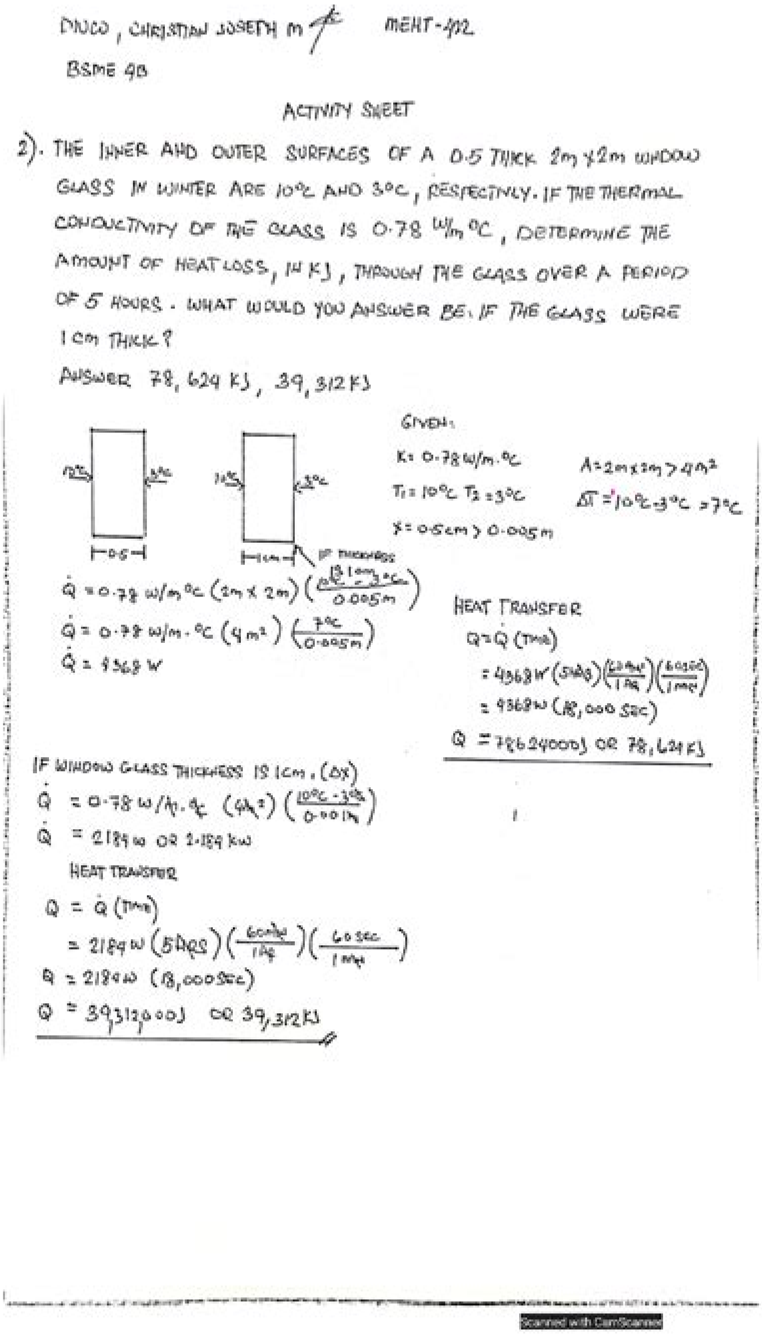
Heat Transfer Sample Problems With Solutions



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BSME 4B

ACTIVITY SHEET

2). THE INNER AND OUTER SURFACES OF A 0.5 THICK 2m x 2m WINDOW GLASS IN WINTER ARE 10°C AND 3°C, RESPECTIVLY. IF THE THERMAL CONDUCTIVITY OF THE GLASS IS 0.78 W/m °C, DETERMINE THE AMOUNT OF HEAT LOSS, IN KJ, THROUGH THE GLASS OVER A PERIOD OF 5 HOURS. WHAT WOULD YOU ANSWER BE, IF THE GLASS WERE 1 cm THICK?

ANSWER 78,624 KJ, 39,312 KJ

GIVEN:

K = 0.78 W/m·°C   A = 2m x 2m = 4m²

T₁ = 10°C T₂ = 3°C   ΔT = 10°C − 3°C = 7°C

x = 0.5cm = 0.005m

Q̇ = 0.78 W/m °C (2m x 2m) (10°C − 3°C / 0.005m)

Q̇ = 0.78 W/m·°C (4m²) (7°C / 0.005m)

Q̇ = 4368 W

HEAT TRANSFER

Q = Q̇ (TIME)

= 4368 W (5 HRS) (60 min / 1 HR) (60 sec / 1 min)

= 4368 W (18,000 sec)

Q = 78624000 J OR 78,624 KJ

IF WINDOW GLASS THICKNESS IS 1cm. (Δx)

Q̇ = 0.78 W/m·°C (4m²) (10°C − 3°C / 0.001m)

Q̇ = 2184 W OR 2.184 kW

HEAT TRANSFER

Q = Q̇ (TIME)

= 2184 W (5 HRS) (60 min / 1 HR) (60 sec / 1 min)

Q = 2184 W (18,000 sec)

Q = 39312000 J OR 39,312 KJ

Heat transfer sample problems with solutions are essential for understanding the principles of thermodynamics and energy transfer. Heat transfer is a fundamental concept in various fields, including engineering, meteorology, and environmental science. This article will explore various types of heat transfer problems, including conduction, convection, and radiation, and provide detailed solutions to enhance comprehension.

Understanding Heat Transfer

Heat transfer occurs through three primary mechanisms: conduction, convection, and radiation. Each of these processes has unique characteristics and applications.

1. Conduction

Conduction is the transfer of heat through a solid material without the movement of the material itself. It occurs when there is a temperature difference within a substance, causing energy to flow from the hotter to the cooler area. The rate of heat transfer by conduction is described by Fourier's law, which states:

$$ Q = -k \cdot A \cdot \frac{dT}{dx} $$

where:
- Q = heat transfer rate (W)
- k = thermal conductivity of the material (W/m·K)
- A = cross-sectional area (m^2)
- $\frac{dT}{dx}$ = temperature gradient (K/m)

Sample Problem 1: Conductive Heat Transfer

Problem Statement: A metal rod of length 2 m and cross-sectional area 0.01 m^2 has one end at a temperature of 100 °C and the other end at 25 °C. The thermal conductivity of the metal is 50 W/m·K. Calculate the rate of heat transfer through the rod.

Solution:

1. Identify the known values:
- Length of the rod (L) = 2 m
- Cross-sectional area (A) = 0.01 m^2
- Temperature difference (ΔT) = 100 °C - 25 °C = 75 °C
- Thermal conductivity (k) = 50 W/m·K

2. Calculate the temperature gradient:
$$
\frac{dT}{dx} = \frac{\Delta T}{L} = \frac{75}{2} = 37.5 \, K/m
$$

3. Apply Fourier's law to find Q:
$$
Q = -k \cdot A \cdot \frac{dT}{dx} = -50 \cdot 0.01 \cdot 37.5
$$
$$
Q = -18.75 \, W
$$

\]

Thus, the rate of heat transfer through the rod is 18.75 W.

2. Convection

Convection is the transfer of heat by the physical movement of a fluid (liquid or gas) caused by the fluid's temperature differences. Heat transfer by convection can be categorized into natural and forced convection. The rate of heat transfer can be expressed by Newton’s law of cooling:

$$ Q = h \cdot A \cdot (T_s - T_\infty) $$

where:
- h = convective heat transfer coefficient ($W/m^2 \cdot K$)
- A = surface area (m^2)
- T_s = surface temperature (°C)
- T_∞ = fluid temperature (°C)

Sample Problem 2: Convective Heat Transfer

Problem Statement: A flat plate with a surface temperature of 80 °C is placed in a fluid with a temperature of 25 °C. The convective heat transfer coefficient is 15 $W/m^2 \cdot K$, and the area of the plate is 0.5 m^2. Calculate the rate of heat loss from the plate to the fluid.

Solution:

1. Identify the known values:
- Surface temperature (T_s) = 80 °C
- Fluid temperature (T_∞) = 25 °C
- Convective heat transfer coefficient (h) = 15 $W/m^2 \cdot K$
- Area (A) = 0.5 m^2

2. Apply Newton’s law of cooling:

$$ Q = h \cdot A \cdot (T_s - T_\infty) = 15 \cdot 0.5 \cdot (80 - 25) $$

$$ Q = 15 \cdot 0.5 \cdot 55 = 412.5 \, W $$

Therefore, the rate of heat loss from the plate to the fluid is 412.5 W.

3. Radiation

Radiation is the transfer of heat in the form of electromagnetic waves, primarily infrared radiation. Unlike conduction and convection, it does not require a medium to transfer energy. The Stefan-Boltzmann law describes the rate of heat transfer by radiation:

$$ Q = \epsilon \cdot \sigma \cdot A \cdot (T^4 - T_{sur}^4) $$

where:
- ϵ = emissivity of the surface (dimensionless)
- σ = Stefan-Boltzmann constant (5.67×10^{-8} $W/m^2 \cdot K^4$)
- A = surface area (m^2)
- T = absolute temperature of the surface in Kelvin (K)
- T_{sur} = absolute temperature of the surroundings in Kelvin (K)

Sample Problem 3: Radiative Heat Transfer

Problem Statement: A black body surface with an emissivity of 1 is at a temperature of 100 °C. The surrounding environment is at a temperature of 20 °C. Calculate the rate of heat loss due to radiation if the surface area is 2 m^2.

Solution:

1. Convert temperatures to Kelvin:
- Surface temperature (T) = 100 °C + 273.15 = 373.15 K
- Surrounding temperature (T_{sur}) = 20 °C + 273.15 = 293.15 K

2. Identify the known values:
- Emissivity (ϵ) = 1
- Stefan-Boltzmann constant (σ) = 5.67×10^{-8} $W/m^2 \cdot K^4$
- Area (A) = 2 m^2

3. Apply the Stefan-Boltzmann law:
$$
Q = \epsilon \cdot \sigma \cdot A \cdot (T^4 - T_{sur}^4)
$$
$$
Q = 1 \cdot 5.67 \times 10^{-8} \cdot 2 \cdot (373.15^4 - 293.15^4)
$$
$$
Q = 5.67 \times 10^{-8} \cdot 2 \cdot (1.941 \times 10^{10} - 7.655 \times 10^{9})
$$
$$
Q \approx 5.67 \times 10^{-8} \cdot 2 \cdot 1.275 \times 10^{10}
$$
$$
Q \approx 144.4 \, W
$$

Hence, the rate of heat loss due to radiation is approximately 144.4 W.

Conclusion

Understanding heat transfer sample problems with solutions is crucial for students and professionals working in fields related to thermodynamics. Through the examples provided, we have explored the three primary modes of heat transfer: conduction, convection, and radiation. Each problem illustrates how to apply relevant formulas, identify known data, and derive solutions step-by-step. Mastery of these concepts is key to solving real-world thermal problems effectively and efficiently.

Frequently Asked Questions

What is the basic principle of conduction in heat transfer?

Conduction is the process of heat transfer through a solid material without any movement of the material itself, occurring due to temperature differences. The heat flows from regions of higher temperature to lower temperature until thermal equilibrium is reached.

How do you calculate the rate of heat transfer by conduction using Fourier's Law?

Fourier's Law states that the rate of heat transfer (Q) through a material is proportional to the negative gradient of temperature and the area through which heat is being transferred. It is given by the formula: $Q = -k A (dT/dx)$, where k is the thermal conductivity, A is the area, dT is the temperature difference, and dx is the thickness of the material.

What is the difference between convection and conduction?

Conduction is the transfer of heat through direct contact between materials, while convection involves the transfer of heat by the movement of fluids (liquids or gases). In convection, warmer parts of the fluid rise while cooler parts sink, creating a circulation pattern.

How can you solve a heat transfer problem involving a composite wall?

To solve a heat transfer problem involving a composite wall, you can use the concept of thermal resistance. Calculate the thermal resistance for each layer in the wall using $R = L/(kA)$, where L is the thickness, k is the thermal conductivity, and A is the area. The total thermal resistance is the sum of individual resistances, and then you can use it to find the heat transfer rate using $Q = (T1 - T2) / R_{total}$.

What is the significance of the Nusselt number in heat transfer problems?

The Nusselt number (Nu) is a dimensionless number that expresses the ratio of convective to conductive heat transfer across a boundary. It helps to determine the effectiveness of convection in heat transfer problems. A higher Nusselt number indicates enhanced heat transfer due to convection.

What is a common example of a heat transfer problem involving phase change?

A common example is the melting of ice. When ice at 0°C is heated, it absorbs heat energy (latent heat of fusion) without changing temperature until it completely melts into water. The amount of heat required can be calculated using $Q = m L_f$, where m is the mass of the ice and L_f is the latent heat of fusion for ice.

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