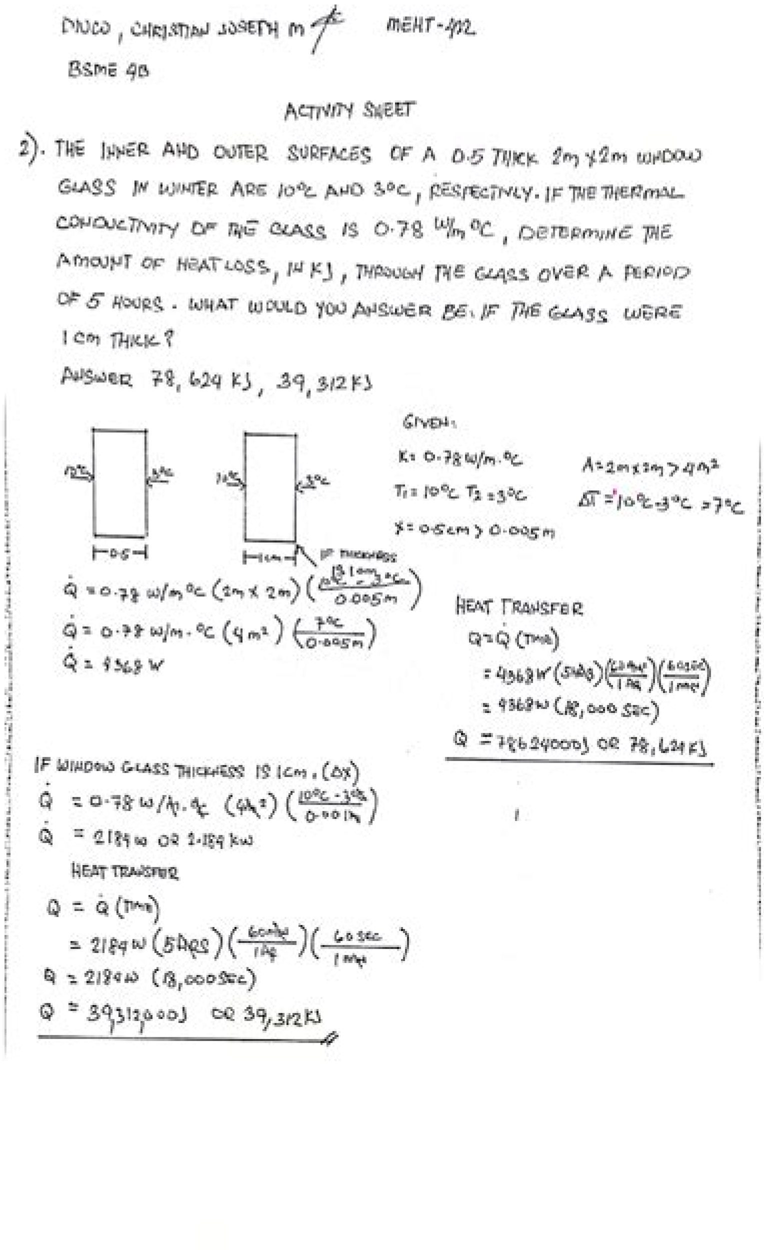
Heat Transfer Problems With Solutions



DIUCO, CHRISTIAN JOSEPH M. MEHT-412
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, RESPECTIVELY. 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 1 cm. (ΔX)
Q̇ = 0.78 W/m·°C (4m²) (10°C - 3°C / 0.01m)
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

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Heat transfer problems are common in both academic and industrial settings, often presenting significant challenges for engineers and scientists. Understanding these problems is crucial for designing efficient thermal systems and ensuring optimal performance in various applications, from HVAC systems to material processing. This article delves into various heat transfer problems, their underlying principles, and provides solutions to help clarify the concepts involved.

Understanding Heat Transfer

Before tackling specific problems, it's essential to understand the three primary modes of heat transfer: conduction, convection, and radiation. Each mode operates under different principles and contexts.

1. Conduction

Conduction is the transfer of heat through a solid material without any movement of the material itself. The rate of heat transfer by conduction can be described by Fourier's Law, which states:

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

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

2. Convection

Convection involves the transfer of heat between a solid surface and a fluid (liquid or gas) in motion. This process can be natural or forced, depending on whether the fluid motion is induced by buoyancy or external means (like a fan). The heat transfer rate through convection can be expressed as:

$$q = h \cdot A \cdot (T_s - T_{\infty})$$

Where:
- h = convective heat transfer coefficient ($W/m^2 \cdot K$)
- T_s = surface temperature (K)
- T_{∞} = fluid temperature far from the surface (K)

3. Radiation

Radiation is the transfer of heat in the form of electromagnetic waves. It does not require a medium and can occur in a vacuum. The Stefan-Boltzmann Law defines the heat transfer rate due to radiation:

$$q = \epsilon \cdot \sigma \cdot A \cdot (T_s^4 - T_{\infty}^4)$$

Where:
- ϵ = emissivity of the surface
- σ = Stefan-Boltzmann constant (5.67×10^{-8} $W/m^2 \cdot K^4$)
- T_s = surface temperature in Kelvin
- T_{∞} = ambient temperature in Kelvin

Common Heat Transfer Problems and Solutions

Now that we have a foundational understanding of heat transfer, let's explore some common problems and their solutions.

Problem 1: Heat Conduction through a Wall

Problem Statement:
A wall with a thickness of 0.2 m separates two rooms. The inner room has a temperature of 25°C, while the outer room has a temperature of 5°C. The wall is made of a material with a thermal conductivity of 0.5 W/m·K. What is the heat transfer rate through the wall?

Solution:
1. Convert temperatures to Kelvin (not necessary for this calculation but good practice).
2. Calculate the temperature gradient:

$$
\Delta T = T_{inner} - T_{outer} = 25^\circ C - 5^\circ C = 20^\circ C
$$

3. Use Fourier's Law of heat conduction:

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

Assuming a unit area (1 m^2):

$$
q = -0.5 \cdot 1 \cdot \frac{20}{0.2} = -50 \, \text{W}
$$

The negative sign indicates the direction of heat transfer, which is from the warmer to the cooler room.

Problem 2: Forced Convection over a Heated Plate

Problem Statement:
A flat plate with a surface temperature of 70°C is exposed to air at a temperature of 20°C. The air flows over the plate at a velocity of 2 m/s. The convective heat transfer coefficient is known to be 25 $W/m^2 \cdot K$. Calculate the heat loss from the plate per unit area.

Solution:
1. Calculate the temperature difference:

$$
\Delta T = T_s - T_{\infty} = 70^\circ C - 20^\circ C = 50^\circ C
$$

2. Apply the convection heat transfer equation:

$$
q = h \cdot A \cdot (T_s - T_{\infty}) = 25 \cdot 1 \cdot 50 = 1250 \, \text{W/m}^2
$$

The heat loss from the plate per unit area is 1250 W/m^2.

Problem 3: Radiation Heat Transfer

Problem Statement:
A blackbody surface (emissivity = 1) at a temperature of 100°C is surrounded by an environment at 25°C. Calculate the net radiation heat transfer from the surface.

Solution:
1. Convert temperatures to Kelvin:

$$
T_s = 100°C + 273.15 = 373.15 \, K
$$
$$
T_{\infty} = 25°C + 273.15 = 298.15 \, K
$$

2. Use the Stefan-Boltzmann Law:

$$
q = \epsilon \cdot \sigma \cdot A \cdot (T_s^4 - T_{\infty}^4)
$$

Assuming a unit area (1 m^2):

$$
q = 1 \cdot 5.67 \times 10^{-8} \cdot (373.15^4 - 298.15^4)
$$

Calculating the fourth powers:

$$
q = 5.67 \times 10^{-8} \cdot (1.946 \times 10^{10} - 7.842 \times 10^{9}) = 5.67 \times 10^{-8} \cdot 1.062 \times 10^{10}
$$
$$
q \approx 603.4 \, \text{W/m}^2
$$

The net radiation heat transfer from the surface is approximately 603.4 W/m^2.

Real-World Applications of Heat Transfer Solutions

Understanding and solving heat transfer problems is crucial in various real-world applications, including:

- HVAC Systems: Efficient heating and cooling designs rely on accurate modeling of heat transfer.
- Electronics Cooling: Proper heat dissipation ensures the reliability and longevity of electronic components.
- Building Insulation: Identifying heat loss through walls and roofs helps in designing energy-efficient buildings.
- Industrial Processes: Many manufacturing processes require precise temperature control to ensure product quality.

Conclusion

In conclusion, heat transfer problems can be effectively addressed by applying the principles of conduction, convection, and radiation. By understanding these concepts and utilizing appropriate equations, engineers and scientists can design more efficient systems, enhance safety, and optimize performance across various applications. The solutions provided in this article demonstrate the practicality of heat transfer principles and their relevance to both theoretical and practical scenarios. Whether you are an aspiring engineer, a student, or a professional in the field, mastering these concepts is essential for success in the heat transfer domain.

Frequently Asked Questions

What is conduction and how does it relate to heat transfer problems?

Conduction is the process of heat transfer through direct contact between materials, where thermal energy moves from the hotter region to the cooler region. In heat transfer problems, understanding conduction is crucial for calculating temperature changes in solid materials.

How can I calculate the rate of heat transfer through a wall?

To calculate the rate of heat transfer through a wall, you can use Fourier's Law: $Q = k A (T1 - T2) / d$, where Q is the heat transfer rate, k is the thermal conductivity, A is the area of the wall, T1 and T2 are the temperatures on either side of the wall, and d is the thickness of the wall.

What are common methods to solve convection heat transfer problems?

Common methods to solve convection heat transfer problems include using empirical correlations like the Nusselt number for forced convection, applying the heat transfer coefficient in calculations, or utilizing computational fluid dynamics (CFD) for complex systems.

What is the difference between natural and forced convection?

Natural convection occurs due to buoyancy forces resulting from temperature differences within a fluid, while forced convection involves an external force, such as a fan or pump, to enhance fluid movement and heat transfer. This distinction is important for selecting the appropriate equations in heat transfer problems.

How do I approach a heat transfer problem involving phase change?

For heat transfer problems involving phase change, use the latent heat equation: $Q = m L$, where Q is the heat transferred, m is the mass of the substance, and L is the latent heat of the phase change. Additionally, apply energy balance principles to account for temperature changes before and after the phase change.

What is the role of insulation in heat transfer problems?

Insulation reduces heat transfer by minimizing conduction, convection, and radiation. In heat transfer problems, calculating the effectiveness of insulation involves considering its thermal resistance and the temperature gradient across it, thereby optimizing energy efficiency.

How can I analyze heat exchangers in heat transfer problems?

To analyze heat exchangers, you can use the effectiveness-NTU method or the log mean temperature difference (LMTD) method. These approaches help determine the heat transfer rate and efficiency by relating the inlet and outlet temperatures of the fluids involved.

What factors affect the thermal conductivity of materials?

Factors affecting thermal conductivity include temperature, material composition, density, and moisture content. Understanding these factors is essential when solving heat transfer problems to select the right materials and predict their behavior under different conditions.

How do radiative heat transfer problems differ from conductive and convective problems?

Radiative heat transfer involves the emission and absorption of electromagnetic waves and does not require a medium, while conduction and convection rely on physical contact or fluid movement. This distinction requires different equations and considerations, particularly Stefan-Boltzmann law for radiation.

What is thermal resistance and how is it used in heat transfer calculations?

Thermal resistance is a measure of a material's ability to resist heat flow. It is calculated as R = d / (k A), where d is the material thickness, k is thermal conductivity, and A is the area. In heat transfer calculations, it helps in determining the total resistance in series or parallel systems.

[Heat Transfer Problems With Solutions]

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