81) A Sphere Of Surface Area 1.25 M2 And Emissivity 1.0 Is At A Temperature Of 100C. At What Rate Does

81) A Sphere Of Surface Area 1.25 M2 And Emissivity 1.0 Is At A Temperature Of 100°C. At What Rate Does

Understanding the rate of heat transfer from a spherical object is fundamental in various scientific and engineering applications, including thermal management, materials science, and environmental studies. In this article, we delve into the detailed calculation of the radiative heat loss from a sphere with a known surface area, emissivity, and temperature. Specifically, we analyze a sphere with a surface area of 1.25 m^2, an emissivity of 1.0 (indicating a perfect blackbody), and a temperature of 100°C, to determine the rate at which it radiates heat into its surroundings.

Understanding Radiative Heat Transfer

What is Radiative Heat Transfer?

Radiative heat transfer is the process by which energy is emitted by a body in the form of electromagnetic radiation. Unlike conduction and convection, which require a medium, radiation can occur through a vacuum, making it crucial in space physics and high-temperature applications.

Stefan-Boltzmann Law

The primary principle governing radiative heat transfer from a blackbody or a real surface is the Stefan-Boltzmann law, expressed as:

$$
Q = \varepsilon \sigma A T^4
$$

Where:
- Q = Heat radiated per unit time (W)
- ε = Emissivity of the surface (dimensionless, 0 to 1)
- σ = Stefan-Boltzmann constant ($5.670374419 \times 10^{-8} \mathrm{W\,m^{-2}\,K^{-4}}$)

- A = Surface area (m^2)
- T = Absolute temperature (K)

This law states that the radiated energy depends on the surface temperature raised to the fourth power, scaled by the emissivity, surface area, and a universal constant.

Given Data and Conversion to Kelvin

Before calculations, ensure all parameters are in consistent units, primarily Kelvin for temperature.

Parameter	Value	Conversion / Explanation
Surface Area	1.25 m^2	Given directly
Emissivity	1.0	Blackbody surface
Temperature	100°C	Convert to Kelvin: $T(K) = 100 + 273.15 = 373.15 K$

Using these values, the problem simplifies to calculating the radiative heat loss rate (Q).

Calculating the Radiative Heat Loss Rate

Step 1: Apply the Stefan-Boltzmann Law

Since the surface is a perfect blackbody ($\varepsilon = 1.0$), the formula becomes:

$$
Q = \sigma A T^4
$$

Substituting the known values:

$$
Q = (5.670374419 \times 10^{-8} \,\mathrm{W\,m^{-2}\,K^{-4}}) \times 1.25\, \mathrm{m^2} \times (373.15\, \mathrm{K})^4
$$

Step 2: Compute T^4

Calculating T^4:

$$
T^4 = (373.15)^4
$$

Using a calculator:

$$
T^4 \approx 1.938 \times 10^{10} \, \mathrm{K^4}
$$

Step 3: Final Calculation of Heat Loss

Now, multiply all the components:

$$
Q = 5.670374419 \times 10^{-8} \times 1.25 \times 1.938 \times 10^{10}
$$

Step-by-step:

- $5.670374419 \times 10^{-8} \times 1.25 = 7.088 \times 10^{-8}$
- $7.088 \times 10^{-8} \times 1.938 \times 10^{10} = 1373.3$ W

Thus,

$$
Q \approx 1373\, \mathrm{W}
$$

This indicates that the sphere radiates approximately 1373 Watts of thermal energy per second at 100°C, assuming it radiates into a vacuum or an environment with negligible incoming radiation.

Additional Considerations in Real-World Scenarios

While the calculation above provides a theoretical maximum heat loss under ideal conditions, real-world situations often involve additional factors influencing the heat transfer rate.

1. Environmental Radiation and Surroundings

- The surrounding environment's temperature influences net radiative heat transfer.
- If the surroundings are at a different temperature, the net heat transfer is given by:

$$
Q_{net} = \varepsilon \sigma A (T^4 - T_{surroundings}^4)
$$

- For example, if the surroundings are at 25°C (298.15 K), the net heat loss reduces accordingly.

2. Emissivity Variations

- Not all surfaces are perfect blackbodies; emissivity can vary based on material properties.
- For surfaces with $\varepsilon < 1.0$, the heat loss decreases proportionally.

3. Convection and Conduction

- In practical settings, heat loss occurs not only by radiation but also through convection and conduction.
- These modes can dominate, especially in environments with air movement or contact with other objects.

4. Radiation into Surroundings

- The sphere radiates energy in all directions; if enclosed or near reflective surfaces, the net radiation could be affected.

Applications of Radiative Heat Transfer Calculations

Understanding the rate at which objects radiate heat is crucial across various fields:

- Thermal Management in Spacecraft: Designing thermal control systems that radiate excess heat efficiently.
- Industrial Processes: Managing heat in furnaces and reactors where high temperatures are involved.
- Environmental Modeling: Assessing heat exchange between Earth's surface and atmosphere.
- Material Testing: Evaluating thermal properties of surfaces and coatings.

Summary and Key Takeaways

- The radiative heat loss from a sphere depends on its temperature, surface area, and emissivity.
- For a sphere of 1.25 m^2 area, emissivity 1.0, and temperature 100°C, the heat loss rate is approximately 1373 Watts.
- The Stefan-Boltzmann law provides a straightforward method for calculating radiative heat transfer for ideal blackbody surfaces.
- Real-world applications require considering environmental factors, other heat transfer modes, and material properties.

Final Thoughts

Accurate calculation of radiative heat transfer is vital for designing efficient thermal systems and understanding environmental processes. While the theoretical maximum heat loss provides a baseline, practical considerations often modify these values. Engineers and scientists must consider the context, material properties, and surroundings to accurately assess heat transfer rates and develop suitable thermal management strategies.

By understanding and applying the principles outlined above, you can effectively evaluate the radiative heat loss of spherical objects or other geometries, ensuring optimal performance and safety in various applications.

Frequently Asked Questions

What is the radiative power emitted by a sphere with a surface area of 1.25 m^2, emissivity of 1.0, at a temperature of 100°C?

Using the Stefan-Boltzmann law: Power = $\varepsilon\sigma A\ T^4$. Convert temperature to Kelvin: 100°C = 373 K. Then, Power = $1.0 \times 5.67\times10^{-8}\ W/m^2K^4 \times 1.25\ m^2 \times (373\ K)^4 \approx 1.25 \times 5.67\times10^{-8} \times 1.94\times10^{10} \approx 1.38\times10^3$ W. So, approximately 1380 watts.

How does the emissivity of a sphere affect its radiative heat loss at a given temperature?

The emissivity (ε) directly scales the radiative heat loss. With $\varepsilon = 1.0$, the sphere emits maximum radiation; lower emissivity values reduce the radiative power proportionally. Thus, a sphere with $\varepsilon < 1.0$ will radiate less heat at the same temperature.

If the temperature of the sphere increases to 150°C, what would be the new radiative heat loss?

Convert 150°C to Kelvin: 150°C = 423 K. Using the same formula: Power = $1.0 \times 5.67\times10^{-8} \times 1.25 \times (423)^4 \approx 1.25 \times 5.67\times10^{-8} \times 3.19\times10^{10} \approx 2.26\times10^3$ W. So, approximately 2260 watts.

What is the significance of a surface's emissivity in thermal radiation calculations?

Emissivity indicates how effectively a surface emits thermal radiation relative to a perfect blackbody. It ranges from 0 to 1, with 1 representing a perfect blackbody. Higher emissivity means greater radiative heat loss at a given temperature.

How does the surface area of the sphere influence its total radiative heat emission?

The total radiative heat emission is directly proportional to the surface area. Doubling the surface area doubles the power radiated, assuming temperature and emissivity remain constant.

Additional Resources

A Sphere Of Surface Area 1.25 m^2 And Emissivity 1.0 Is At A Temperature Of 100°C. At What Rate Does It Radiate Heat?

Understanding the rate at which objects radiate heat is a fundamental aspect of thermal physics, especially in engineering applications such as thermal management, environmental control, and energy systems. When dealing with a sphere of known surface area and emissivity, calculating its radiative heat loss provides insight into how objects exchange thermal energy with their surroundings. In this guide, we will delve into the principles governing thermal radiation, walk through the step-by-step calculation for a specific example—a sphere with a surface area of 1.25 m^2, emissivity of 1.0, and temperature of 100°C—and discuss broader implications and practical considerations.

Introduction to Thermal Radiation

Thermal radiation is the process by which energy is emitted by matter in the form of electromagnetic waves, primarily in the infrared spectrum for typical temperatures encountered in engineering contexts. Unlike conduction or convection, radiation does not require a medium; it can occur through the vacuum of space.

The fundamental law describing the power radiated by a blackbody (an idealized object that absorbs and emits all incident radiation) is Stefan-Boltzmann Law, expressed as:

$$ P = \sigma A T^4 $$

where:
- P = power radiated (Watts)
- σ = Stefan-Boltzmann constant ($5.670374419 \times 10^{-8} \, W\,m^{-2}\,K^{-4}$)
- A = surface area (m^2)
- T = absolute temperature (Kelvin)

However, real objects are not perfect blackbodies. Their emissivity (ε)—a measure of their efficiency in emitting thermal radiation—ranges from 0 to 1. An emissivity of 1 means the object is a perfect blackbody, while values less than 1 indicate less efficient emission.

The generalized form accounting for emissivity is:

$$ P = \varepsilon \sigma A T^4 $$

The Scenario: Analyzing the Sphere

Given:
- Surface area, $A = 1.25 \, m^2$
- Emissivity, $\varepsilon = 1.0$ (a perfect blackbody)
- Temperature, $T_{C} = 100^\circ C$

To accurately compute the radiative heat loss, we need to convert the temperature from Celsius to Kelvin:

$$ T_{K} = T_{C} + 273.15 = 100 + 273.15 = 373.15\, K $$

Step-by-Step Calculation

1. Applying the Stefan-Boltzmann Law

Since the sphere is assumed to be a perfect blackbody ($\varepsilon = 1.0$), the power radiated is:

$$P = \sigma A T^4$$

Plugging in the known values:

$$P = (5.670374419 \times 10^{-8}) \times 1.25 \times (373.15)^4$$

2. Computing T^4

Calculate T^4:

$$T^4 = (373.15)^4$$

Let's compute this step-by-step:

- First, $(373.15)^2$:

$$(373.15)^2 = 139,432.92$$

- Then, $(139,432.92)^2$:

$$(139,432.92)^2 \approx 1.945 \times 10^{10}$$

So,

$$T^4 \approx 1.945 \times 10^{10}$$

3. Final Calculation

Now, substitute all values into the equation:

\[

$$
P = 5.670374419 \times 10^{-8} \times 1.25 \times 1.945 \times 10^{10}
$$

Multiply constants:

- $5.670374419 \times 10^{-8} \times 1.25 = 7.088 \times 10^{-8}$

Then,

$$
P = 7.088 \times 10^{-8} \times 1.945 \times 10^{10}
$$

Simplify:

$$
P = 7.088 \times 1.945 \times 10^{2} \approx 13.8 \times 10^{2} = 1380\, W
$$

Result:

The sphere radiates approximately 1380 Watts of thermal energy at 100°C assuming perfect blackbody behavior.

Broader Considerations

Emissivity and Real-World Materials

In reality, most materials do not have an emissivity of 1.0. Typical values:

- Polished metals: $\varepsilon \approx 0.03 - 0.1$
- Painted or oxidized surfaces: $\varepsilon \approx 0.8 - 0.95$
- Matte surfaces: $\varepsilon \approx 0.9 - 1.0$

If the sphere's actual emissivity is less than 1.0, the radiative power would decrease proportionally. For example, with $\varepsilon = 0.8$:

$$
P_{actual} = 0.8 \times 1380 \, W = 1104\, W
$$

Impact of Surroundings and Environment

The calculation above assumes the sphere radiates into a blackbody environment at zero temperature (or effectively infinite heat sink). In real-world scenarios, the surroundings have a finite temperature and emissivity. The net radiative heat exchange considers the difference:

$$
Q_{net} = \varepsilon \sigma A (T^4 - T_{surroundings}^4)
$$

where $T_{surroundings}$ is the temperature of the environment in Kelvin.

Practical Applications

- Thermal Management: Estimating heat loss in systems like spacecraft, reactors, or industrial equipment.
- Design of Radiative Surfaces: Selecting coatings or materials with desired emissivities.
- Environmental Control: Modeling heat exchange between objects and their surroundings for climate control.

Additional Factors Influencing Radiative Heat Transfer

While the Stefan-Boltzmann law provides a fundamental estimate, several other factors can influence actual heat transfer rates:

- View factors: The geometry and surroundings affect how much radiation the sphere exchanges with other objects.
- Convection and conduction: In many practical situations, these modes of heat transfer occur alongside radiation.
- Surface coatings: Applying reflective or emissive coatings can significantly alter heat loss.
- Temperature gradients: Non-uniform temperature distributions lead to complex heat flow patterns.

Summary and Key Takeaways

- The radiative heat loss from a sphere depends on its surface area, temperature, and emissivity.
- For a sphere with a surface area of 1.25 m^2, emissivity of 1.0, and temperature of 100°C (373.15 K), the power radiated is approximately 1380 Watts.
- Real-world scenarios often involve lower emissivities, environmental interactions, and additional modes of heat transfer, all of which modify the net heat exchange.
- Understanding these principles aids in designing thermal systems, managing energy efficiency, and

predicting thermal behavior in various engineering applications.

Final Thoughts

Thermal radiation plays a vital role in many scientific and engineering contexts. By mastering the fundamental calculations—like those demonstrated here—you can better predict, control, and optimize the thermal performance of systems ranging from industrial equipment to space vehicles. Always consider material properties, environmental conditions, and real-world complexities when applying these principles to practical problems.

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