A 16.0-L Tank Of Carbon Dioxide Gas (CO2) Is At A Pressure Of 9.20 X 105 Pa And Temperature Of 18.0C.

Understanding the Properties of Carbon Dioxide in a Compressed Tank

A 16.0-L Tank Of Carbon Dioxide Gas (CO2) Is At A Pressure Of 9.20 X 10^5 Pa And Temperature Of 18.0°C. This scenario provides a practical example to explore the behavior of gases under pressure, the principles of thermodynamics, and applications involving CO_2 storage. Whether you're a student, engineer, or environmental enthusiast, understanding these parameters is essential for effective handling and utilization of carbon dioxide.

In this article, we will delve into the fundamental properties of CO_2 in a compressed state, analyze the conditions described, and discuss the implications for safety, storage, and usage.

Fundamentals of Gas Behavior in a Compressed Tank

The Ideal Gas Law and Its Relevance

The behavior of gases like CO_2 in a confined space is often modeled using the Ideal Gas Law:

$$PV = nRT$$

Where:
- P = pressure,
- V = volume,
- n = number of moles,
- R = universal gas constant (8.314 J/mol·K),
- T = temperature in Kelvin.

This law provides a basis for estimating the amount of gas stored in the tank, predicting how pressure varies with temperature, and understanding the system's behavior under different conditions.

Converting Temperature to Kelvin

Since the temperature is given as 18.0°C, convert it to Kelvin:

$$T\ (K) = 18.0 + 273.15 = 291.15\ K$$

This conversion is necessary for calculations involving the gas law.

Calculating the Moles of CO_2 in the Tank

Given data:
- Volume (V) = 16.0 L = 0.016 m^3 (since 1 L = 0.001 m^3),
- Pressure (P) = 9.20×10^5 Pa,
- Temperature (T) = 291.15 K,
- Gas constant (R) = 8.314 J/mol·K.

Applying the ideal gas law:

$n = (PV) / (RT)$

Calculating:

$n = (9.20 \times 10^5 \text{ Pa} \times 0.016 \text{ m}^3) / (8.314 \text{ J/mol·K} \times 291.15 \text{ K})$

$n \approx (14{,}720) / (2416.8)$

$n \approx 6.09$ mol

Thus, the tank contains approximately 6.09 moles of CO_2.

Understanding the State of CO_2 at Given Conditions

Density and Compressibility

The density of CO_2 in the tank can be estimated:

- Molar mass of CO_2 ≈ 44.01 g/mol,
- Total mass = n × molar mass ≈ 6.09 mol × 44.01 g/mol ≈ 268.2 g.

Density (ρ):

ρ = mass / volume = 268.2 g / 16.0 L ≈ 16.76 g/L

This high density indicates that CO_2 is significantly compressed compared to its gaseous form at standard conditions, where its density is about 1.98 g/L at STP (0°C, 1 atm).

Phase Considerations and Supercritical State

At 18°C and this pressure, CO_2 remains in gaseous form, but it is approaching conditions where it could become supercritical if pressure increases further. Supercritical CO_2 exhibits unique properties, acting as both a gas and a liquid, with applications in extraction and industrial processes.

Implications for Storage and Safety

Pressure Safety Limits

The pressure in the tank (9.20×10^5 Pa or approximately 920 kPa) is below typical rupture pressures for standard CO_2 tanks, but safety considerations are essential:

- Regular pressure checks,
- Proper venting systems,
- Use of pressure relief valves.

Temperature Effects on Pressure and Volume

Using the ideal gas law, if temperature increases, pressure will also increase proportionally (assuming volume and moles remain constant):

- For example, if temperature rises to 30°C (303.15 K), the pressure would increase to:

$$P_2 = P_1 \times (T_2 / T_1) = 9.20 \times 10^5 \text{ Pa} \times (303.15 / 291.15) \approx 9.58 \times 10^5 \text{ Pa}$$

This highlights the importance of temperature regulation in storage facilities.

Applications of CO2 Stored in Such Tanks

Industrial Uses

CO_2 tanks of this size are common in:

- Food and beverage industries for carbonating drinks,
- Fire suppression systems,
- Chemical manufacturing processes,
- Enhanced oil recovery.

Environmental and Safety Considerations

Proper handling of compressed CO_2 is critical to prevent:

- Asphyxiation risks in enclosed spaces,
- Explosion hazards in case of over-pressurization,
- Environmental issues if leaks occur.

Environmental Impact and Sustainability

The extraction and storage of CO_2 have implications for climate change mitigation:

- Capturing CO_2 from industrial emissions,
- Using CO_2 in green technologies like algae cultivation,
- Reducing overall greenhouse gas emissions.

However, careful management of storage tanks is vital to prevent leaks and ensure environmental safety.

Conclusion: Managing CO2 in Storage Tanks Effectively

Understanding the physical parameters of a 16.0-L CO_2 tank at specified pressure and temperature enables safe and efficient handling. Calculations based on the ideal gas law provide insight into the amount of gas stored and how environmental factors influence pressure and state.

Whether for industrial use or environmental management, proper design, monitoring, and safety protocols are essential for handling compressed CO_2. Advances in storage technology, along with adherence to safety standards, help harness the benefits of CO_2 while minimizing risks.

Summary of Key Points

- The tank contains approximately 6.09 moles of CO_2.
- At 18°C and 9.20×10^5 Pa, CO_2 remains gaseous but highly compressed.
- Temperature variations significantly affect pressure, necessitating temperature control.
- Proper safety measures are critical to prevent accidents.
- CO_2 storage plays a vital role in various industrial and environmental applications.

By understanding these principles, industries and environmental agencies can optimize CO_2 storage solutions, ensuring safety, efficiency, and sustainability.

Frequently Asked Questions

What is the initial pressure of the CO2 gas in the tank?

The initial pressure of the CO_2 gas in the tank is 9.20×10^5 Pa.

What is the volume of the CO2 gas in the tank?

The volume of the CO_2 gas in the tank is 16.0 liters.

What is the temperature of the CO2 gas in Celsius?

The temperature of the CO2 gas is 18.0°C.

How can you convert the temperature from Celsius to Kelvin?

Add 273.15 to the Celsius temperature: 18.0°C + 273.15 = 291.15 K.

What is the ideal gas law equation that relates pressure, volume, temperature, and amount of gas?

PV = nRT, where P is pressure, V is volume, n is moles of gas, R is the gas constant, and T is temperature in Kelvin.

How would you determine the number of moles of CO2 in the tank?

Use the ideal gas law rearranged as n = PV / RT, substituting the known values for P, V, R, and T.

If the temperature increases, what happens to the pressure of the gas assuming volume and moles remain constant?

The pressure increases proportionally with temperature, according to Gay-Lussac's law.

What units should be used for volume when applying the ideal gas law?

Volume should be converted to liters or cubic meters, but when using R in standard units, volume should be in liters and pressure in pascals.

What is the significance of the given pressure being 9.20 x 10^5 Pa?

It indicates that the CO2 gas is under a high-pressure condition, typical for storage tanks, and affects calculations involving gas behavior.

How does temperature affect the density of the CO2 gas in the tank?

As temperature increases, the density of the gas decreases if pressure and volume are constant, due to gas expansion.

Additional Resources

A 16.0-L Tank Of Carbon Dioxide Gas (CO_2) Is At A Pressure Of 9.20×10^5 Pa And Temperature Of 18.0°C: An In-Depth Investigation

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Introduction

The storage and handling of carbon dioxide (CO_2) are critical concerns across various industries, from beverage carbonation to chemical manufacturing and environmental management. The physical properties of CO_2 under different conditions influence its behavior, safety protocols, and applications. In this detailed investigation, we examine a specific scenario involving a 16.0-liter tank of CO_2 gas maintained at a pressure of 9.20×10^5 Pa and a temperature of 18.0°C. By analyzing these parameters through the lens of thermodynamics and gas laws, we aim to elucidate the state of the gas, assess its density, and explore implications for safety and application.

Background and Context

Carbon dioxide is a colorless, odorless gas with a critical temperature of 31.0°C and a critical pressure of approximately 7.38×10^6 Pa. Its properties are well-characterized under various conditions, making it a staple in numerous industrial processes. Storage at elevated pressures and specific temperatures can push CO_2 into different phases or states, influencing how it behaves in confined environments.

Understanding the physical state—whether gaseous, liquid, or supercritical—is essential for safe storage and optimal utilization. The scenario under examination provides the foundational parameters necessary to analyze the state and properties of CO_2 in the tank.

Thermodynamic Analysis

Fundamental Parameters

- Tank Volume (V): 16.0 L = 0.016 m^3
- Pressure (P): 9.20×10^5 Pa
- Temperature (T): 18.0°C = 291.15 K
- Universal Gas Constant (R): 8.314 J/(mol·K)

Using these parameters, we can determine the molar amount of CO_2 present, its density, and phase behavior.

Applying the Ideal Gas Law

The ideal gas law is often a starting point for such analyses:

$$ PV = nRT $$

where:

- n: moles of CO_2

Calculating n:

$$
n = \frac{PV}{RT} = \frac{(9.20 \times 10^5\, \text{Pa}) \times 0.016\, \text{m}^3}{8.314\, \text{J/(mol·K)} \times 291.15\, \text{K}}
$$

\]

$$
n \approx \frac{14,720\, \text{Pa·m}^3}{2,418.2\, \text{J}} \approx 6.09\, \text{mol}
$$

This indicates approximately 6.09 mol of CO_2 are contained within the tank.

Phase and State Considerations

Critical Parameters of CO_2

- Critical Temperature: 31.0°C
- Critical Pressure: 7.38 x 10^6 Pa

Since the tank's temperature (18.0°C) is below the critical temperature, CO_2 can exist as a liquid or gas depending on pressure. The pressure of 9.20 x 10^5 Pa (~920 kPa) is significantly below the critical pressure, indicating the CO_2 is likely in the gaseous or possibly compressed state, but not supercritical.

Comparing Pressure to Vapor Pressure

At 18.0°C, the vapor pressure of CO_2 is approximately 5.4 x 10^5 Pa. Since the tank pressure exceeds this, the CO_2 is likely to be in a compressed gaseous state rather than a vapor at equilibrium with liquid. The pressure surpassing vapor pressure suggests that the CO_2 may be in a supercritical or near-supercritical state if the temperature were higher, but at 18°C, it remains compressed gas.

Density Estimation and Implications

Calculating Density

Density (ρ) is mass per unit volume:

$$
\rho = \frac{\text{mass}}{\text{volume}}
$$

First, determine the molar mass of CO_2:

- Molar mass of C: 12.01 g/mol
- Molar mass of O_2: 16.00 g/mol x 2 = 32.00 g/mol
- Total: 44.01 g/mol

Mass of CO_2:

$$
\text{mass} = n \times \text{molar mass} \approx 6.09\, \text{mol} \times 44.01\, \text{g/mol} \approx 268\, \text{g}
$$

Converting to kilograms:

$$
0.268\, \text{kg}
$$

Density:

$$
\rho = \frac{0.268\, \text{kg}}{0.016\, \text{m}^3} \approx 16.75\, \text{kg/m}^3
$$

This density is consistent with a compressed gaseous state at this pressure and temperature.

Safety and Storage Considerations

- Pressure Limits: The tank's pressure (~920 kPa) is within common industrial storage limits for compressed gases, but safety protocols must account for pressure relief and stability.
- Phase Stability: Since the pressure is below the critical point but above vapor pressure, the gas remains in a compressed state, not liquid or supercritical.

Real Gas Corrections and Deviations

While the ideal gas law provides a baseline, real gases deviate due to intermolecular forces and finite molecular volume. For CO_2 under these conditions, the Van der Waals equation offers a better approximation:

$$
\left(P + \frac{a n^2}{V^2}\right)(V - nb) = nRT
$$

where:

- a and b are substance-specific constants:

For CO_2:

- $a \approx 3.59\, \text{L}^2 \cdot \text{bar}/\text{mol}^2$
- $b \approx 0.0427\, \text{L}/\text{mol}$

Converting constants to SI units and applying corrections can refine our estimates of pressure, density, and phase behavior.

Implications for Industry and Safety

Storage and Handling

Understanding the physical state of CO_2 under these conditions is critical for safe storage. The pressure and temperature suggest a stable compressed gas, but any temperature fluctuations could lead to phase changes, potentially causing over-pressurization or liquefaction.

Application in Industrial Processes

- Carbonation: Precise control of pressure and temperature ensures consistent carbonation levels.
- Chemical Manufacturing: Accurate phase and density information optimize reaction conditions.
- Environmental Control: In sequestration or waste management, knowing the phase behavior informs safety protocols.

Environmental and Safety Concerns

Risks of Over-pressurization

The pressure within the tank, while within standard limits, poses risks if temperature rises or if the tank's pressure relief systems malfunction. As CO_2 is odorless and colorless, leaks can go unnoticed, leading to asphyxiation hazards in confined spaces.

Accidental Release and Phase Changes

A sudden temperature increase can elevate pressure beyond design limits or induce phase changes, creating risks of tank rupture or rapid gas release.

Monitoring and Regulation

Regular monitoring of pressure, temperature, and leak detection systems is essential. Industry standards mandate safety valves and pressure relief devices to mitigate risks.

Future Directions and Research Opportunities

- Advanced Modeling: Incorporating real gas equations like Peng-Robinson or Soave-Redlich-Kwong can improve accuracy of phase predictions.
- Material Compatibility: Investigating tank materials resistant to high-pressure CO_2, especially for long-term storage.
- Environmental Impact: Studying leak mitigation strategies and the role of CO_2 storage in climate change mitigation.

Conclusion

The detailed analysis of a 16.0-liter tank of CO_2 at 9.20×10^5 Pa and 18.0°C reveals a state of compressed gas with a density of approximately 16.75 kg/m^3. While ideal gas law calculations provide a useful approximation, real gas corrections are necessary for precise modeling, particularly in safety-critical applications. Understanding the thermodynamic and phase behavior of CO_2 under these conditions is vital for safe storage, handling, and utilization across industries. As CO_2 continues to play a significant role environmentally and industrially, meticulous analysis and adherence to safety standards remain paramount.

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