What Is The Partial Pressure (in Atm) Of CO At 468.2 K In A 25.0 L Fuel Combustion Vessel If It Contains

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Understanding the behavior of gases within combustion systems is essential in fields such as chemical engineering, environmental science, and energy production. One key concept in this realm is partial pressure, which describes the pressure exerted by a specific gas within a mixture. In particular, calculating the partial pressure of carbon monoxide (CO) at a given temperature and volume provides insights into combustion efficiency, pollutant levels, and safety measures.

In this article, we will explore the detailed process of determining the partial pressure of CO in a 25.0-liter combustion vessel at a temperature of 468.2 K. We will introduce relevant principles, equations, and step-by-step calculations to provide a comprehensive understanding of this chemical physics problem.

Understanding Partial Pressure in Gases

What Is Partial Pressure?

Partial pressure refers to the pressure contributed by a single gas in a mixture of gases. According to Dalton's Law of Partial Pressures, the total pressure exerted by a gas mixture is the sum of the partial pressures of each individual component:

$$P_{total} = P_1 + P_2 + \dots + P_n$$

When gases behave ideally, each gas's partial pressure can be calculated using the ideal gas law, considering the amount of moles, temperature, and volume.

Fundamental Principles for Calculating Partial Pressure

The Ideal Gas Law

The ideal gas law is expressed as:

$$PV = nRT$$

Where:

- P = pressure in atmospheres (atm)
- V = volume in liters (L)
- n = number of moles (mol)

- R = ideal gas constant, 0.0821 L·atm/(mol·K)
- T = temperature in Kelvin (K)

This law describes the behavior of gases under ideal conditions, which is a good approximation at moderate pressures and temperatures.

Calculating Partial Pressure of a Gas

To find the partial pressure of CO, you need to know:

- The number of moles of CO present
- The temperature
- The volume of the vessel

Once these are known, the partial pressure PCO can be calculated using the ideal gas law:

$$P_{CO} = (n_{CO} R T) / V$$

Determining the Moles of CO in the Vessel

The calculation hinges on knowing how many moles of CO are present in the vessel at the specified conditions. Several scenarios can lead to this:

1. Given the mass of CO: If you have the mass, convert to moles using molar mass.
2. Given the total pressure and composition: If the total pressure and mole fraction of CO are known.
3. From the combustion reaction: If the initial quantities of fuel and oxidant are given, and the combustion reaction is balanced.

For this example, assume that the total number of moles of gas in the vessel is known or can be deduced from the initial conditions. Suppose the vessel contains only CO gas, or the partial pressure corresponds to a known mole fraction of CO in a mixture.

Step-by-Step Calculation of Partial Pressure of CO

Let's assume that:

- The vessel contains only CO gas.
- The number of moles of CO, nCO, is derived from initial conditions or measurements.

Sample Data for Calculation:

- Temperature, T = 468.2 K
- Volume, V = 25.0 L
- Moles of CO, nCO = 10.0 mol (hypothetical value for illustration)

Calculating PCO:

Using the ideal gas law:

$P_{CO} = (n_{CO} R T) / V$

Plugging in the values:

$P_{CO} = (10.0 \text{ mol } 0.0821 \text{ L·atm/(mol·K) } 468.2 \text{ K}) / 25.0 \text{ L}$

Calculations:

- Numerator: 10.0 0.0821 468.2 ≈ 10.0 38.43 ≈ 384.3
- Divide by volume: 384.3 / 25.0 ≈ 15.37 atm

Result:

The partial pressure of CO in this scenario is approximately 15.37 atm.

Factors Affecting Partial Pressure in Real Scenarios

While the above example assumes ideal behavior and a known number of moles, real-world situations may involve additional complexities:

- Non-ideal gas behavior: At high pressures or low temperatures, deviations from ideality occur.
- Mixtures of gases: The partial pressure depends on the mole fraction of CO relative to other gases.
- Reaction dynamics: Combustion reactions might change the amount of CO present over time.
- Leakage or contamination: External factors can alter the gas composition.

It is essential to consider these factors when designing experiments or interpreting data.

Application of Partial Pressure Calculations in Fuel Combustion Analysis

Understanding the partial pressure of CO during combustion processes has several practical applications:

- Emission control: Monitoring CO levels to ensure compliance with environmental standards.
- Efficiency optimization: Ensuring complete combustion to minimize CO formation.
- Safety protocols: Detecting high CO concentrations that could pose health hazards.
- Engine and reactor design: Calculating partial pressures to optimize combustion chamber conditions.

Additional Considerations and Advanced Topics

- Dalton's Law in Mixture Analysis: When multiple gases are present, partial pressures are proportional to their mole fractions:

$$P_i = X_i P_{total}$$

Where X_i is the mole fraction of gas i.

- Effect of Temperature Variations: As temperature increases, gas pressure tends to increase if volume and moles remain constant.

- Use of Gas Laws in Combustion Modeling: Accurate modeling of combustion systems requires integrating partial pressure calculations with thermodynamic data.

Conclusion

Calculating the partial pressure of CO at a given temperature, volume, and amount of substance is fundamental in analyzing combustion systems and gas behavior. Using the ideal gas law, one can derive the partial pressure provided the amount of CO (in moles), temperature, and volume are known or can be estimated. This calculation informs environmental monitoring, safety assessments, and efficiency improvements in energy systems.

Understanding these principles enables engineers and scientists to optimize combustion processes, reduce emissions, and design safer, more efficient energy devices. Always consider the specific conditions and potential deviations from ideal gas behavior for more precise results in practical applications.

Keywords: Partial Pressure, CO Gas, Ideal Gas Law, Combustion Vessel, Gas Law Calculations, Fuel Combustion, Gas Mixture, Thermodynamics, Environmental Science, Energy Production

Frequently Asked Questions

What is the partial pressure of CO at 468.2 K in a 25.0 L vessel during fuel combustion?

To determine the partial pressure, use the ideal gas law: $P = (nRT)/V$. You need the amount of CO (in moles) present to calculate the pressure accurately.

Which gas law is used to calculate the partial pressure of CO in the vessel?

The ideal gas law ($PV = nRT$) is used to calculate the partial pressure of CO, assuming ideal behavior.

What additional information is needed to find the partial pressure of CO in the vessel?

You need to know the number of moles (n) of CO present in the vessel at the given temperature and volume.

How does temperature affect the partial pressure of CO in the vessel?

An increase in temperature increases the partial pressure of CO, assuming the number of moles and volume remain constant, because $P \propto T$.

If the amount of CO in moles is known, how can you calculate its partial pressure?

Using $P = (nRT)/V$, where $R = 0.0821$ L·atm/(mol·K), n is moles of CO, T is 468.2 K, and V is 25.0 L.

What are typical units used for partial pressure in such calculations?

Partial pressure is commonly expressed in atmospheres (atm), but can also be in kPa or mmHg depending on context.

How does the volume of the vessel influence the partial pressure of CO?

The partial pressure is inversely proportional to volume; increasing volume decreases pressure, assuming moles and temperature stay constant.

Can Dalton's Law be applied to find the partial pressure of CO in a mixture?

Yes, Dalton's Law states that the partial pressure of a gas is proportional to its mole fraction times the total pressure in the mixture.

What assumptions are made when calculating partial pressure using the ideal gas law?

It is assumed that gases behave ideally, meaning no interactions between molecules and that the gas particles occupy negligible volume.

In a fuel combustion vessel, what factors could cause deviations from the ideal gas law when calculating partial pressure?

Factors include high pressure or temperature conditions, gas interactions, non-ideal behavior, or presence of other gases affecting the system.

Additional Resources

What Is The Partial Pressure (in Atm) Of CO At 468.2 K In A 25.0 L Fuel Combustion Vessel If It Contains

In the realm of chemical engineering and environmental science, understanding the behavior of gases during combustion processes is crucial. One fundamental concept that often emerges in such contexts is the partial pressure of individual gases within a mixture. Specifically, the partial pressure of carbon monoxide (CO) in combustion systems can have significant implications—from efficiency assessments to environmental impact evaluations. This article explores the concept of partial pressure, focusing on a practical problem: determining the partial pressure of CO at 468.2 K within a 25.0 L vessel containing combustion gases.

Understanding Partial Pressure in Gas Mixtures

What Is Partial Pressure?

Partial pressure is a term rooted in Dalton's Law of Partial Pressures. It refers to the pressure that a single component of a gas mixture would exert if it occupied the entire volume alone at the same temperature. If a mixture contains multiple gases—say, oxygen, nitrogen, carbon monoxide, and others—the total pressure is the sum of the partial pressures of each constituent. Mathematically:

$$
P_{total} = P_{O_2} + P_{N_2} + P_{CO} + \ldots
$$

Each partial pressure can be expressed as:

$$
P_{gas} = y_{gas} \times P_{total}
$$

where y_{gas} is the mole fraction of the gas in the mixture.

Why is partial pressure important? It directly relates to the rate of reactions, gas diffusion, and equilibrium states, especially in combustion and environmental modeling.

The Ideal Gas Law as a Tool

Calculating the partial pressure often involves the Ideal Gas Law:

$$
PV = nRT
$$

where:

- P is the pressure (atm),
- V is the volume (L),
- n is the number of moles,
- R is the universal gas constant (0.082057 L·atm/(mol·K)),
- T is the temperature (K).

This law provides a straightforward way to connect the amount of gas in moles with its pressure, given fixed volume and temperature.

Setting Up the Problem

Suppose we have a combustion vessel of volume 25.0 liters containing gases at 468.2 K. The question is: What is the partial pressure of CO in this vessel? To answer this, certain information must be specified or assumed:

- The total number of moles of gases in the vessel.
- The mole fraction (or amount) of CO within the mixture.

In typical combustion scenarios, the composition may vary, but for the purpose of this calculation, we will assume that the total moles of gases are known or can be estimated based on combustion chemistry.

Calculating the Partial Pressure of CO

Step 1: Determine Total Moles of Gas in the Vessel

The total pressure exerted by the gases depends on the amount of gas present. Suppose, for illustration, the total moles of gases in the vessel is n_{total}.

If this is unknown, it can be estimated based on the combustion reaction and the initial fuel and oxidizer quantities. For this example, assume that the total moles of gases in the vessel are 2.0 mol (a typical value for illustrative purposes).

Step 2: Find the Mole Fraction of CO

The mole fraction of CO, y_{CO}, is defined as:

$$
y_{CO} = \frac{n_{CO}}{n_{total}}
$$

Assuming from combustion calculations, the CO constitutes 0.3 mol out of the total 2.0 mol:

$$
y_{CO} = \frac{0.3}{2.0} = 0.15
$$

This mole fraction indicates that 15% of the total moles are CO.

Step 3: Calculate Total Pressure Using the Ideal Gas Law

Applying the Ideal Gas Law:

$$
P_{total} = \frac{n_{total} R T}{V}
$$

Plugging in the values:

$$
P_{total} = \frac{2.0 \text{ mol} \times 0.082057 \text{ L·atm/(mol·K)} \times 468.2 \text{ K}}{25.0 \text{ L}}
$$

Calculating numerator:

$$
2.0 \times 0.082057 \times 468.2 \approx 76.756 \text{ L·atm}
$$

Dividing by volume:

$$
P_{total} \approx \frac{76.756}{25.0} \approx 3.07 \text{ atm}
$$

\]

Step 4: Find Partial Pressure of CO

Using Dalton's Law:

$$
P_{CO} = y_{CO} \times P_{total} = 0.15 \times 3.07 \approx 0.4605 \text{ atm}
$$

Result: The partial pressure of CO in the vessel is approximately 0.46 atm.

Implications and Practical Considerations

Understanding such calculations helps engineers and scientists optimize combustion processes, control emissions, and develop cleaner energy solutions. The partial pressure of CO directly influences:

- Reaction kinetics: Higher partial pressures can accelerate or inhibit reactions.
- Environmental impact: CO is a toxic pollutant; knowing its partial pressure aids in emission control.
- Safety protocols: Elevated CO levels in closed systems pose health risks.

Factors affecting the calculation:

- Actual gas composition: Variations in reaction conditions alter mole fractions.
- Temperature fluctuations: Deviations from assumed temperature impact pressure.
- Incomplete combustion: Not all fuel converts to CO2; more CO might be produced under certain conditions.

Advanced Scenarios and Real-World Applications

In real-world applications, several complexities arise:

- Non-ideal gas behavior: At high pressures or low temperatures, deviations from ideality occur.
- Dynamic systems: Gas composition can shift over time, requiring real-time monitoring.
- Multi-component analysis: Advanced models incorporate partial pressures of multiple gases for comprehensive analysis.

For example, in designing catalytic converters or emission control systems, accurately measuring and predicting the partial pressure of CO enables better system performance and compliance with environmental standards.

Conclusion

Determining the partial pressure of CO at a specific temperature within a combustion vessel involves fundamental principles of gas laws and chemistry. By understanding the relationships between moles, pressure, temperature, and volume, scientists and engineers can accurately assess the behavior of gases during combustion processes. In the example provided, assuming typical values, the partial pressure of CO at 468.2 K in a 25.0 L vessel is approximately 0.46 atm. This knowledge not only advances scientific understanding but also helps in designing safer, cleaner, and more efficient combustion systems.

In the broader context, mastering such calculations is vital for environmental management, energy production, and safety protocols—underscoring the importance of gas laws in practical and industrial applications.

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