Calculate The SO2 Concentration In Flue Gas When 100 Moles Of C7H13 Containing 5% Sulphur Is Burnt In

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Understanding how to calculate sulfur dioxide (SO_2) concentration in flue gases is essential for environmental engineers, combustion specialists, and pollution control professionals. When hydrocarbons containing sulfur are burned, sulfur compounds are converted into SO_2, which can contribute to acid rain and atmospheric pollution. This article provides a comprehensive guide to calculating the SO_2 concentration in flue gases resulting from the combustion of 100 moles of C7H13 containing 5% sulfur. Through step-by-step analysis, relevant chemical reactions, and calculation methods, readers will gain a thorough understanding of the process involved.

Introduction to Sulfur in Hydrocarbon Combustion

Sulfur is a common impurity found in various fuels and hydrocarbons. When these fuels are burned, sulfur oxidizes to form sulfur oxides, primarily SO_2 and SO_3, with SO_2 being the predominant form under typical combustion conditions. The concentration of SO_2 in flue gases depends on:
- The amount of sulfur present in the fuel.
- The combustion process conditions.
- The extent of oxidation during combustion.

Recognizing these factors helps in designing emission control systems and complying with environmental standards.

Understanding the Composition of the Fuel (C7H13) Containing Sulfur

Before calculating SO_2 emissions, it is crucial to understand the composition of the hydrocarbon fuel:

Details of the Fuel

- The hydrocarbon is C7H13.
- It contains 5% sulfur by weight.

Key points:
- The sulfur is present as an impurity within the hydrocarbon.
- The total moles of hydrocarbon burned are 100 moles.

Calculating the Amount of Sulfur in the Fuel

To determine the sulfur content:
1. Find the molar mass of C7H13.
2. Calculate the total weight of 100 moles of C7H13.
3. Use the 5% sulfur content to find the mass of sulfur.

Step-by-step Calculation:

- Molar mass of C7H13:
- Carbon (C): 12.01 g/mol
- Hydrogen (H): 1.008 g/mol

$$
M_{C7H13} = (7 \times 12.01) + (13 \times 1.008) = 84.07 + 13.104 = 97.174\, \text{g/mol}
$$

- Total mass of 100 moles:

$$
100 \times 97.174 = 9717.4\, \text{g}
$$

- Mass of sulfur in the fuel:
- Since sulfur is 5% by weight:

$$
\text{Mass of sulfur} = 0.05 \times 9717.4 = 485.87\, \text{g}
$$

- Convert sulfur mass to moles:

- Atomic mass of sulfur (S): 32.06 g/mol

$$
\text{Moles of S} = \frac{485.87}{32.06} \approx 15.17\, \text{moles}
$$

Thus, the total sulfur present in the 100 moles of fuel is approximately 15.17 moles.

Combustion Reaction of C7H13 with Sulfur

The combustion process of hydrocarbons involves reacting with oxygen, producing CO_2 and H_2O. The sulfur impurity combusts to form SO_2.

General Combustion Reactions:

- Hydrocarbon:

$$
C_xH_y + \left(x + \frac{y}{4} \right) O_2 \rightarrow x CO_2 + \frac{y}{2} H_2O
$$

\]

- Sulfur:

$$
S + O_2 \rightarrow SO_2
$$

Note: Under complete combustion conditions, all sulfur converts to SO_2.

Specific Reaction for C7H13 with Sulfur

- Combustion of hydrocarbon:

$$
C_7H_{13} + \text{O}_2 \rightarrow 7 CO_2 + \frac{13}{2} H_2O
$$

- Combustion of sulfur:

$$
S + O_2 \rightarrow SO_2
$$

Since the sulfur content is known, the total amount of sulfur combusted is approximately 15.17 moles, producing an equal number of moles of SO_2.

Calculating the Total Moles of Flue Gas Produced

To determine the SO_2 concentration, we need to find the total moles of gases emitted during combustion.

Step 1: Moles of Hydrocarbon Consumed

- Given: 100 moles of C7H13.
- Since each mole of hydrocarbon burns completely, the total moles of gases produced from hydrocarbon combustion are:

$$
\text{CO}_2: 7 \times 100 = 700\, \text{moles}
$$
$$
\text{H}_2O: \frac{13}{2} \times 100 = 650\, \text{moles}
$$

Note: In flue gases, water vapor may condense depending on temperature, but for this calculation, we assume all gases remain in the vapor phase.

Step 2: Moles of SO_2 Produced

- Since 15.17 moles of sulfur are burned:

$$
\text{SO}_2: 15.17\, \text{moles}
$$

Step 3: Total Moles of Flue Gas

- Total moles:

$$
\text{Total} = 700\, (\text{CO}_2) + 650\, (\text{H}_2O) + 15.17\, (\text{SO}_2) = 1365.17\, \text{moles}
$$

Additional gases: Depending on excess air and combustion efficiency, nitrogen and excess oxygen may also be present, but in this simplified calculation, we focus on the primary combustion products.

Calculating SO_2 Concentration in Flue Gas

The concentration of SO_2 in the flue gas is typically expressed in parts per million (ppm) by volume or as a percentage.

Method 1: Part per Million (ppm)

- The molar concentration of SO_2:

$$
\text{SO}_2\, \text{ppm} = \frac{\text{Moles of SO}_2}{\text{Total moles of gases}} \times 10^6
$$

- Substituting the values:

$$
\text{SO}_2\, \text{ppm} = \frac{15.17}{1365.17} \times 10^6 \approx 11,100\, \text{ppm}
$$

Interpretation: The SO_2 concentration is approximately 11,100 ppm by volume.

Method 2: Percentage Concentration

- Percentage by volume:

$$
\text{SO}_2\, \% = \frac{\text{Moles of SO}_2}{\text{Total moles of gases}} \times 100

\]

- Calculation:

$$
\text{SO}_2\, \% = \frac{15.17}{1365.17} \times 100 \approx 1.11\%
$$

Conclusion: The SO_2 concentration in the flue gas is approximately 1.11% by volume.

Additional Factors Influencing SO_2 Concentration

While the above calculation provides a baseline estimate, real-world scenarios involve several additional factors:

1. Excess Air and Combustion Efficiency

- Excess air can dilute SO_2 concentrations.
- Incomplete combustion may alter the amount of SO_2 produced.

2. Temperature and Flue Gas Composition

- Temperature affects water vapor condensation.
- Flue gases may contain other nitrogen oxides, CO, unburned hydrocarbons, etc.

3. Pollution Control Devices

- Scrubbers and catalytic converters can reduce SO_2 emissions before release.

Environmental Implications and Compliance

Knowing the SO_2 concentration in flue gases is vital for environmental compliance:

- Regulatory agencies set limits on SO_2 emissions (e.g., EPA standards).
- Proper calculation helps in designing emission control systems.
- Monitoring SO_2 levels prevents environmental damage such as acid rain and respiratory issues.

Summary and Key Takeaways

- Burning 100 moles of C7H13 with 5% sulfur results in approximately 15.17 moles of sulfur.
- Complete combustion converts sulfur to SO_2, totaling around 15.17 moles of SO_2.
- Total moles of flue gases are roughly 1365.17.
- The SO_2 concentration in flue gas is estimated at about 1.11% by volume or 11,100 ppm.

Final Remarks

Calculating SO

Frequently Asked Questions

How do you determine the SO_2 concentration in flue gas when burning C7H13 containing sulfur?

First, calculate the amount of sulfur in the fuel, then determine the amount of SO_2 formed during combustion, and finally, express the SO_2 amount as a concentration in the flue gas, typically in parts per million (ppm).

What is the process to find the amount of sulfur in 100 moles of C7H13 with 5% sulfur content?

Multiply the total moles of fuel (100 mol) by the sulfur percentage (5%), resulting in 5 moles of sulfur present in the fuel.

How is the amount of SO_2 produced related to the sulfur content in the fuel?

Since each mole of sulfur forms one mole of SO_2 upon combustion, 5 moles of sulfur produce 5 moles of SO_2 gas.

What is the total moles of flue gas produced during combustion of 100 moles of C7H13?

This depends on the complete combustion reaction, but typically, combustion produces CO_2 and H_2O; the total moles can be calculated based on stoichiometry, adding the moles of gases produced.

How do you calculate SO_2 concentration in ppm in the flue gas?

Use the formula: (moles of SO_2 / total moles of flue gases) × 10^6 to get the concentration in ppm.

If 5 moles of SO_2 are produced in the combustion process, how do you find its concentration in the flue gases?

Divide 5 moles of SO_2 by the total moles of flue gases produced, then multiply by 10^6 to convert to ppm.

What assumptions are typically made in calculating SO_2 concentration for such combustion processes?

Assumptions include complete combustion, no formation of other sulfur compounds, and that all sulfur in the fuel converts to SO_2 without losses or side reactions.

Why is understanding SO_2 concentration in flue gases important?

Monitoring SO_2 levels is crucial for environmental protection, regulatory compliance, and designing pollution control systems like scrubbers to reduce sulfur emissions.

Additional Resources

Calculate The SO_2 Concentration In Flue Gas When 100 Moles Of C_7H_{13} Containing 5% Sulphur Is Burnt In

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Introduction

Understanding the formation and concentration of sulfur dioxide (SO_2) in flue gases is crucial for environmental monitoring and pollution control. When hydrocarbons containing sulfur are combusted, sulfur is oxidized to form SO_2, a significant pollutant responsible for acid rain and respiratory issues. This article provides a comprehensive analysis of calculating the SO_2 concentration in the flue gases produced from burning a specific hydrocarbon—C_7H_{13}—with a known sulfur content. The focus is on the step-by-step calculation process, including chemical reactions, molar considerations, and implications for environmental standards.

Fundamental Concepts and Background

Understanding Hydrocarbon Composition and Sulfur Content

The hydrocarbon in question, C_7H_{13}, is a heptane derivative with an empirical formula indicating a mixture of alkanes or branched hydrocarbons. The critical detail here is that the compound contains 5% sulfur by weight. This percentage directly influences the amount of sulfur available during combustion and consequently the amount of SO_2 produced.

Combustion Process Overview

Combustion of hydrocarbons is a chemical oxidation process where the hydrocarbon reacts with oxygen (O_2) to produce carbon dioxide (CO_2) and water (H_2O). When sulfur is present, it is oxidized to sulfur oxides, primarily SO_2, under typical combustion conditions. The general combustion reactions involve:

- Hydrocarbon oxidation: $C_nH_m + O_2 \rightarrow CO_2 + H_2O$
- Sulfur oxidation: $S + O_2 \rightarrow SO_2$

The combustion temperature, oxygen availability, and other operational parameters influence the extent of sulfur oxidation and the formation of SO_2.

Calculating the Total Sulfur Content in the Hydrocarbon Mixture

Step 1: Determine the Mass of Sulfur in 100 Moles of C_7H_{13}

Given:

- Total moles of hydrocarbon = 100 mol
- Sulfur content = 5% by weight

Calculating molar masses:

- Molar mass of C_7H_{13}:

$$
(7 \times 12.01) + (13 \times 1.008) = 84.07 + 13.104 = 97.174\, \text{g/mol}
$$

- Total mass of 100 mol of C_7H_{13}:

$$
100 \times 97.174 = 9717.4\, \text{g}
$$

Determining sulfur mass:

Since sulfur constitutes 5% by weight:

$$
\text{Mass of sulfur} = 0.05 \times 9717.4 = 485.87\, \text{g}
$$

\]

Number of moles of sulfur:

- Atomic mass of sulfur (S) ≈ 32.06 g/mol

\[
\text{Moles of sulfur} = \frac{485.87}{32.06} \approx 15.16\, \text{mol}
\]

Conclusion:

- Total sulfur present in the hydrocarbon mixture = approximately 15.16 mol

---

Stoichiometry of Combustion and SO_2 Formation

Step 2: Establishing the Combustion Reaction

The combustion of C_7H_{13} with sulfur content, assuming complete oxidation, can be represented as:

\[
\text{C}_7\text{H}_{13} + a\, \text{O}_2 \rightarrow 7\, \text{CO}_2 + 6\, \text{H}_2\text{O} + \text{Sulfur Oxides}
\]

The exact amount of oxygen required depends on the hydrocarbon's composition, but for sulfur, the oxidation is straightforward:

\[
\text{S} + \text{O}_2 \rightarrow \text{SO}_2
\]

Given complete oxidation, all sulfur is converted to SO_2.

Note: The combustion process may produce some SO_3, but under typical conditions, SO_2 is the primary sulfur oxide formed.

Step 3: Moles of SO_2 Produced

Since 15.16 mol of sulfur are present, and each mol of sulfur yields one mol of SO_2:

\[
\text{Moles of SO}_2 = 15.16\, \text{mol}

\]

This is the theoretical maximum amount of SO_2 generated assuming complete oxidation.

Calculating Flue Gas Composition and SO_2 Concentration

Step 4: Estimating the Total Moles of Flue Gas

The total moles of flue gases depend on the combustion process, specifically:

- The amount of oxygen supplied
- The amount of excess air (if any)
- Combustion of hydrocarbons producing CO_2 and H_2O
- The oxidation of sulfur producing SO_2

Assumption: Complete combustion with excess oxygen is typical for safety and efficiency. For calculation simplicity, assume a theoretical stoichiometric combustion with no excess air, and consider the oxygen supplied as part of the combustion.

Molar calculations:

- Moles of hydrocarbon burned = 100 mol
- Moles of sulfur burned = 15.16 mol
- Oxygen required for hydrocarbon oxidation (for C_7H_{13}):

The combustion of C_7H_{13}:

$$
\text{C}_7\text{H}_{13} + 10.5\, \text{O}_2 \rightarrow 7\, \text{CO}_2 + 6.5\, \text{H}_2\text{O}
$$

(Derived from balancing: 7 carbons require 14 O, 13 hydrogens require 6.5 O, total 20.5 O atoms, or 10.25 mol O_2 per mol hydrocarbon. For simplicity, approximate as 10.5 mol O_2 per mol C_7H_{13}.)

- Moles of oxygen required for 100 mol hydrocarbon:

$$
100 \times 10.5 = 1050\, \text{mol}
$$

- Moles of oxygen for sulfur oxidation:

\[

$$
15.16\, \text{mol S} \rightarrow 15.16\, \text{mol SO}_2
$$

Each mol SO_2 formation consumes 1 mol O_2:

$$
15.16\, \text{mol O}_2
$$

- Total oxygen consumption:

$$
1050 + 15.16 \approx 1065.16\, \text{mol}
$$

- Total moles of gases produced:

- From hydrocarbon:
- 100 mol C_7H_{13} produces:
- 7 mol CO_2 per mol hydrocarbon: $100 \times 7 = 700\, \text{mol}$
- 6.5 mol H_2O per mol hydrocarbon: $100 \times 6.5 = 650\, \text{mol}$

- From sulfur oxidation:
- 15.16 mol SO_2

- Remaining oxygen in flue gas:
- Moles of excess O_2:

$$
\text{Oxygen supplied} - \text{Oxygen consumed} = 1065.16 - (1050 + 15.16) = 0\, \text{mol}
$$

Assuming stoichiometric combustion, all oxygen is consumed.

Total moles of flue gases:

$$
700\, (\text{CO}_2) + 650\, (\text{H}_2\text{O}) + 15.16\, (\text{SO}_2) = 1365.16\, \text{mol}
$$

Step 5: Calculating SO_2 Concentration in the Flue Gas

The concentration of SO_2 in the flue gas can be expressed as a volume percentage or molar fraction.

Molar fraction of SO_2:

\[

$$
\text{Mole fraction of SO}_2 = \frac{15.16}{1365.16} \approx 0.0111
$$

Volume percentage of SO_2:

Assuming ideal gas behavior at standard conditions, molar fractions translate directly to volume percentages:

$$
\text{SO}_2 \text{ concentration} \approx 1.11\%
$$

This indicates that under idealized conditions, approximately 1.11% of the flue gas volume is SO_2.

Environmental and Practical Implications

Pollution Control and Emission Standards

The calculated SO_2 concentration highlights the importance of emission controls in combustion processes involving sulfur-containing fuels. Regulatory standards often limit SO_2 emissions to prevent acid rain and protect air quality. The typical permissible SO_2 concentration in flue gases varies by jurisdiction but often ranges below 0.5% by volume,

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