How Many Grams Of Ethanol, CH3 CH2 OH, Can Be Vaporized At Its Boiling Point At 78.4 C With 500 KJ Thermal

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Understanding the process of vaporization and the energy required to convert a liquid into vapor is fundamental in fields ranging from chemical engineering to environmental science. Ethanol, also known as ethyl alcohol, is a common solvent and alcohol used in various industrial applications, beverages, and as a fuel additive. Knowing how much ethanol can be vaporized with a given amount of energy provides insights into processes like distillation, fuel production, and laboratory experiments.

In this article, we will explore in detail how to calculate the mass of ethanol that can be vaporized at its boiling point of 78.4°C with an input of 500 kilojoules (kJ) of thermal energy. We will delve into the relevant thermodynamic concepts, including latent heat of vaporization, the properties of ethanol, and the step-by-step calculation process. By the end, readers will have a comprehensive understanding of the factors involved and the methodology to perform similar calculations for other substances.

Understanding Ethanol and Its Vaporization Properties

Physical Properties of Ethanol

Ethanol (CH3 CH2 OH) is a volatile, flammable liquid with a boiling point of approximately 78.4°C at standard atmospheric pressure (1 atm). Its physical properties relevant to vaporization include:

- Boiling Point: 78.4°C
- Molar Mass: 46.07 g/mol
- Latent Heat of Vaporization (ΔHvap): Approximately 38.56 kJ/mol at its boiling point
- Density (liquid): About 0.789 g/mL at 20°C

Understanding these properties is essential for calculating the amount of heat needed to vaporize a certain mass of ethanol.

Latent Heat of Vaporization

The latent heat of vaporization is the amount of energy required to convert one mole of a liquid into vapor without changing its temperature. For ethanol, this value is approximately 38.56 kJ/mol at the boiling point.

This thermodynamic parameter is critical because it allows us to determine how much energy is needed to vaporize a specific amount of ethanol, which then enables calculating the maximum mass that can be vaporized with a given thermal input.

Calculating the Amount of Ethanol Vaporized

The core of this problem involves calculating how many grams of ethanol can be vaporized when a thermal energy of 500 kJ is supplied at the boiling point. The general approach involves the following steps:

1. Determine the number of moles of ethanol vaporized using the latent heat of vaporization.
2. Convert moles to grams to find the mass vaporized.

Let's explore this step-by-step.

Step 1: Calculate the Number of Moles Vaporized

The total heat energy supplied (Q) is related to the number of moles vaporized (n) and the molar latent heat of vaporization (ΔHvap) by the equation:

$$ Q = n \times \Delta H_{vap} $$

Rearranged to find n:

$$ n = \frac{Q}{\Delta H_{vap}} $$

Given:
- $ Q = 500\, \text{kJ} $
- $ \Delta H_{vap} = 38.56\, \text{kJ/mol} $

Calculate:

$$ n = \frac{500\, \text{kJ}}{38.56\, \text{kJ/mol}} \approx 12.96\, \text{mol} $$

This means approximately 12.96 moles of ethanol can be vaporized with 500 kJ of energy.

Step 2: Convert Moles to Grams

Using the molar mass of ethanol (46.07 g/mol):

$$ \text{Mass} = n \times \text{Molar mass} $$

$$ \text{Mass} = 12.96\, \text{mol} \times 46.07\, \text{g/mol} \approx 597.8\, \text{g} $$

Therefore, approximately 598 grams of ethanol can be vaporized at its boiling point with 500 kJ of thermal energy.

Additional Considerations and Real-World Factors

While the calculation above provides a theoretical maximum, real-world applications may involve additional factors:

1. Heat Losses

In practical scenarios, heat losses to the surroundings, container walls, and other inefficiencies mean not all the supplied energy directly contributes to vaporization. This could reduce the actual amount vaporized.

2. Non-Ideal Behavior

The calculation assumes ideal behavior, using the molar latent heat at the boiling point. Variations in pressure and temperature, as well as deviations from ideality, can influence vaporization energy.

3. Overcoming Atmospheric Pressure

The boiling point of ethanol can shift under different atmospheric pressures. The calculation assumes standard atmospheric pressure (1 atm). Changes in pressure will alter the boiling point and the latent heat.

4. Purity of Ethanol

Impurities in ethanol can affect its boiling point and the energy required to vaporize it.

Summary of Key Points

- Ethanol's molar mass: 46.07 g/mol
- Latent heat of vaporization: approximately 38.56 kJ/mol at 78.4°C
- Thermal energy supplied: 500 kJ

Calculation result:
Approximately 598 grams of ethanol can be vaporized at 78.4°C with 500 kJ of thermal energy.

Practical Applications of This Calculation

Understanding the vaporization capacity of ethanol with a given energy input is vital in several practical contexts:

- Distillation Processes: Optimizing energy consumption during ethanol purification.
- Fuel Production: Estimating fuel vaporization in combustion engines.
- Laboratory Experiments: Planning heating requirements for ethanol-based reactions.
- Environmental Engineering: Designing systems for ethanol recovery and emissions control.

Conclusion

Calculating the amount of ethanol vaporized with a specific thermal input involves understanding thermodynamic principles and physical properties of ethanol. With 500 kJ of energy supplied at ethanol's boiling point of 78.4°C, approximately 598 grams can be vaporized under ideal conditions. This calculation underscores the importance of latent heat in phase change processes and highlights the practical considerations needed when applying these principles in real-world scenarios.

By mastering these concepts, engineers, scientists, and students can better design and optimize systems involving ethanol vaporization, ensuring efficiency and safety in various industrial and laboratory applications.

Frequently Asked Questions

What is the molar mass of ethanol (CH_3CH_2OH)?

The molar mass of ethanol is approximately 46.07 g/mol.

How much energy is required to vaporize one mole of ethanol at its boiling point?

The heat of vaporization of ethanol is about 38.56 kJ/mol.

How many moles of ethanol can be vaporized with 500 kJ of energy?

Approximately 12.97 moles of ethanol can be vaporized (500 kJ / 38.56 kJ/mol).

What is the total mass of ethanol that can be vaporized with 500 kJ of energy at 78.4°C?

Approximately 598.6 grams of ethanol can be vaporized (12.97 mol × 46.07 g/mol).

Does the boiling point temperature affect the amount

of ethanol vaporized given a specific energy input?

Yes, because the energy required depends on the heat of vaporization at the boiling point, which determines how much ethanol can be vaporized with a given energy.

Can all 500 kJ of energy vaporize ethanol at its boiling point without additional heat?

Yes, if the energy supplied is exactly equal to the heat of vaporization for the amount of ethanol vaporized, it can vaporize without additional heat beyond the latent heat.

How would increasing the thermal energy input affect the amount of ethanol vaporized?

Increasing the thermal energy input would increase the amount of ethanol vaporized, assuming the temperature remains at the boiling point.

What assumptions are made in calculating the vaporized ethanol mass in this scenario?

Assumptions include that all the energy goes solely into vaporizing ethanol at its boiling point, with no heat losses, and that the heat of vaporization remains constant at the boiling temperature.

Additional Resources

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Introduction

Ethanol (CH_3CH_2OH), commonly known as ethyl alcohol, is a widely used organic solvent and beverage component. Its physical properties, particularly its boiling point and vaporization characteristics, are fundamental to numerous industrial and scientific processes. Understanding how much ethanol can be vaporized given a specific amount of thermal energy is essential for applications ranging from distillation to fuel production. This article explores, in detail, the calculation of the mass of ethanol vaporized at its boiling point (78.4°C) using an input of 500 kilojoules (kJ) of thermal energy.

Fundamental Concepts

1. Vaporization and Enthalpy of Vaporization

Vaporization is the phase transition from liquid to vapor. At the boiling point, this process involves the input of energy, known as the enthalpy of vaporization ($\Delta Hvap$), which is the energy required to convert a unit mass or mole of liquid into vapor at constant temperature and pressure.

- Enthalpy of Vaporization of Ethanol:
- At its boiling point (~78.4°C), ethanol's ΔHvap is approximately 38.56 kJ/mol.
- This value represents the energy needed to vaporize one mole of ethanol at constant pressure.

2. Moles and Mass Relationship

- The molar mass (M) of ethanol:
- Carbon (C): 12.01 g/mol
- Hydrogen (H): 1.008 g/mol
- Oxygen (O): 16.00 g/mol

$$
\text{Molar mass of ethanol} = (2 \times 12.01) + (6 \times 1.008) + 16.00 = 46.068\, \text{g/mol}
$$

- To convert moles to grams:

$$
\text{Mass (g)} = \text{Number of moles} \times \text{Molar mass}
$$

Step-by-Step Calculation

1. Determine the Number of Moles Vaporized

Given:

- Total thermal energy supplied, $Q = 500\, \text{kJ}$
- Enthalpy of vaporization, $\Delta H_{vap} = 38.56\, \text{kJ/mol}$

Number of moles vaporized:

$$
n = \frac{Q}{\Delta H_{vap}} = \frac{500\, \text{kJ}}{38.56\, \text{kJ/mol}}
$$

Calculating:

$$
n \approx 12.97\, \text{mol}
$$

2. Convert Moles to Mass

Using molar mass:

$$
\text{Mass} = n \times M = 12.97\, \text{mol} \times 46.068\, \text{g/mol}
$$

$$
\text{Mass} \approx 598.8\, \text{g}
$$

Thus, approximately 599 grams of ethanol can be vaporized with 500 kJ of thermal energy at its boiling point.

In-Depth Analysis and Considerations

1. Assumptions in the Calculation

- Constant Temperature: The calculation assumes ethanol remains at its boiling point (78.4°C) during vaporization, with no temperature change.
- Pure Substance: Ethanol is pure, with no impurities affecting vaporization energy.
- Pressure Conditions: The process occurs at atmospheric pressure, where the boiling point is well-defined.
- No Heat Losses: All supplied thermal energy is used solely for vaporization, neglecting heat losses to surroundings.

2. Real-World Factors Affecting Vaporization

- Heat Losses: In practical settings, heat losses to the environment reduce efficiency.
- Non-ideal Behavior: Ethanol's vaporization may deviate slightly from ideal behavior, especially at high vaporization rates.
- Container and Equipment Efficiency: The thermal transfer efficiency impacts the actual amount vaporized.
- Superheating or Underheating: Deviations from the boiling point can alter energy requirements.

Extended Topics

1. Latent Heat and Specific Heat Capacity

Understanding the energy involved in phase changes requires distinguishing between:

- Latent Heat of Vaporization: Energy to convert liquid to vapor at boiling point.
- Specific Heat Capacity of Liquid Ethanol: Energy needed to raise temperature of ethanol without phase change.

For completeness, the specific heat capacity (c) of ethanol is approximately 2.44 J/g°C. While not directly involved in the vaporization calculation, it is relevant if temperature changes prior to boiling.

2. Energy Required to Heat Ethanol to Its Boiling Point

If starting from a lower temperature, the total energy needed includes:

$$
Q_{total} = Q_{heating} + Q_{vaporization}
$$

Where:

$$
Q_{heating} = m \times c \times \Delta T
$$

\]

This underscores that in practical scenarios, energy input must account for both heating and vaporization.

Practical Applications and Implications

1. Industrial Distillation

- Estimating the amount of ethanol vaporized helps optimize distillation processes.
- Energy efficiency calculations depend on knowing how much ethanol can be vaporized per unit energy.

2. Fuel Production

- Ethanol is used as a biofuel; understanding vaporization aids in designing fuel processing and combustion systems.

3. Laboratory Procedures

- Accurate quantification of vaporized ethanol supports distillation experiments and chemical synthesis.

4. Safety and Handling

- Vaporization calculations contribute to safety protocols by estimating vapor concentrations and flammability risk.

Limitations and Further Considerations

- Temperature Variations: Real processes may involve temperature gradients, affecting vaporization.
- Pressure Variations: Changes in pressure alter boiling points and vaporization energy.
- Phase Equilibrium: Ensuring equilibrium conditions is vital for precise calculations.
- Recycling and Re-condensation: Systems often involve condensation steps, impacting net material balance.

Summary

In conclusion, with an input of 500 kJ of thermal energy at ethanol's boiling point (78.4°C), approximately 599 grams of ethanol can be vaporized under ideal conditions. This calculation hinges on the known enthalpy of vaporization and molar mass of ethanol, assuming perfect efficiency and no heat losses.

Understanding these fundamental thermodynamic principles is essential for engineers, chemists, and industry professionals involved in processes such as distillation, fuel production, and laboratory synthesis. Accurate energy budgeting ensures process optimization, safety, and cost-effectiveness. Future considerations include adjusting for real-world inefficiencies, phase behavior deviations, and energy inputs for heating prior to vaporization.

Final Note

This detailed analysis highlights the importance of thermodynamic data and careful calculations in real-world applications involving ethanol. Mastery of such calculations enables precise control and optimization of processes where ethanol vaporization is a critical step.

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