One Kilogram Of Butane (CaH1o) Is Burned With 23 Kg Of Air That Is 30C And 90 Ka. Assuming That The Combustion

One Kilogram Of Butane (CaH1o) Is Burned With 23 Kg Of Air That Is 30C And 90 Ka. Assuming That The Combustion process occurs under ideal conditions, it provides an excellent foundation to explore the intricate details of hydrocarbon combustion, energy release, and environmental implications. Butane, with its chemical formula CaH1o, is a common hydrocarbon used in various applications such as lighters, portable stoves, and fuel canisters. Understanding how it reacts with air, the amount of oxygen involved, and the resulting energy output is essential for engineers, environmental scientists, and students alike. This comprehensive article delves into the science behind butane combustion, the role of air properties, and the practical implications of these reactions.

Understanding Butane: Chemical Composition and Properties

What is Butane?

Butane is a saturated hydrocarbon belonging to the alkane family, with the molecular formula C_4H_{10}. It exists in two isomeric forms: n-butane and isobutane (methylpropane). Both isomers exhibit similar chemical properties but differ structurally, which influences their physical behaviors such as boiling points and flammability.

Physical and Chemical Properties of Butane

- Molecular weight: Approximately 58.12 g/mol
- Boiling point: Around -0.5°C (n-butane)
- Density: About 2.5 kg/m³ at standard conditions
- Flammability limits: 1.8% to 8.4% by volume in air
- Energy content: Approximately 49.1 MJ/kg

The high energy density makes butane an efficient fuel source, but its combustion must be carefully managed to ensure safety and environmental compliance.

Air Composition and Properties at 30°C and 90 kPa

Understanding the Air Conditions

In the given scenario, the air used for combustion is at a temperature of 30°C and a pressure of 90 kPa (which is slightly below standard atmospheric pressure). These conditions influence the amount of oxygen available and the combustion efficiency.

Properties of Air Under These Conditions

- Temperature: 30°C (303 Kelvin)
- Pressure: 90 kPa
- Composition: Approximately 21% oxygen, 78% nitrogen, and trace gases
- Density of air: Calculated using the ideal gas law:

$$
\rho = \frac{p}{R T}
$$

Where:
- p = pressure (90,000 Pa)
- R = specific gas constant for dry air (~287 J/kg·K)
- T = temperature in Kelvin (303 K)

Calculating:

$$
\rho = \frac{90000}{287 \times 303} \approx 1.04 \text{ kg/m}^3
$$

This density determines how much air (and thus oxygen) is available for combustion.

Stoichiometry of Butane Combustion

Balanced Chemical Equation

The complete combustion of butane (C4H10) in excess oxygen can be represented as:

$$
2 \, \mathrm{C_4H_{10}} + 13 \, \mathrm{O_2} \rightarrow 8 \, \mathrm{CO_2} + 10 \, \mathrm{H_2O}
$$

From this, the stoichiometric ratio of oxygen to butane is established:

- For 2 mol of butane, 13 mol of oxygen are required.
- Per mole of butane, oxygen requirement:

\[

$$
\frac{13}{2} = 6.5 \text{ mol O}_2
$$

Oxygen consumption per kilogram of butane:

- Molecular weight of butane: 58.12 g/mol
- Moles in 1 kg (1000 g):

$$
\frac{1000}{58.12} \approx 17.21 \text{ mol}
$$

- Oxygen needed:

$$
17.21 \times 6.5 \approx 112 \text{ mol}
$$

- Molecular weight of oxygen: 32 g/mol

$$
112 \times 32 = 3584 \text{ g} \approx 3.58 \text{ kg}
$$

Thus, approximately 3.58 kg of oxygen is required for complete combustion of 1 kg of butane.

Air Requirement and Calculations

Since air contains about 21% oxygen by volume:

- Total air needed:

$$
\frac{3.58 \text{ kg O}_2}{0.21} \approx 17.05 \text{ kg}
$$

In the scenario, 23 kg of air is supplied, which exceeds the stoichiometric requirement, ensuring complete combustion and providing excess oxygen for safety and complete reaction.

Energy Release from Butane Combustion

Calorific Value

- Higher heating value (HHV): Approximately 49.1 MJ/kg
- Lower heating value (LHV): Approximately 45.8 MJ/kg (accounting for water vapor)

Assuming complete combustion, burning 1 kg of butane releases about 49.1 MJ of energy.

Practical Implications

- The energy released can be harnessed for heating, cooking, or power generation.
- Efficiency depends on the combustion process, heat transfer, and system design.

Environmental and Safety Considerations

Emissions and Pollutants

Complete combustion of butane ideally produces carbon dioxide (CO_2) and water vapor (H_2O). However, incomplete combustion can lead to:
- Carbon monoxide (CO)
- Unburned hydrocarbons
- Nitrogen oxides (NOx) due to high-temperature reactions

Proper mixing and sufficient oxygen supply minimize pollutants.

Safety Aspects

Handling butane and its combustion involves risks:
- Explosion hazards due to flammable vapors
- Asphyxiation risk from displaced oxygen
- Proper ventilation and leak detection are essential

Additionally, the excess air supplied helps ensure complete combustion but must be managed to prevent oxygen depletion or unsafe conditions.

Practical Applications and Calculations in Industry

Designing Combustion Systems

Engineers must calculate:
- The precise amount of air needed
- Combustion chamber temperatures
- Heat transfer efficiencies

Sample Calculation: Total Energy Output

Given:
- 1 kg of butane
- HHV = 49.1 MJ/kg

Total energy released:

$$
49.1 \text{ MJ}
$$

This energy can be used for:
- Heating systems
- Power turbines
- Industrial processes

Conclusion

Burning one kilogram of butane with 23 kg of air at 30°C and 90 kPa exemplifies a controlled combustion process that efficiently converts chemical energy into heat. Understanding the detailed stoichiometry, the properties of the reactants, and the environmental implications is vital for optimizing such processes. Proper calculations ensure complete combustion, maximize energy output, and minimize pollutants, making butane a valuable and manageable fuel source in various applications. Safety precautions and environmental considerations must always be integrated into the design and operation of combustion systems involving hydrocarbons like butane.

Summary of Key Points:
- Butane (C4H10) has high energy content (~49.1 MJ/kg)
- Complete combustion requires approximately 3.58 kg of oxygen per kg of butane
- 23 kg of air supplies sufficient oxygen for complete combustion
- Air properties at 30°C and 90 kPa influence oxygen availability
- Proper combustion results in CO_2 and H_2O, with minimal pollutants if controlled
- The process releases significant heat energy, useful for industrial applications

Understanding these principles enables efficient, safe, and environmentally responsible use of butane as a fuel source across various industries.

Frequently Asked Questions

What is the chemical equation for the combustion of one kilogram of butane (C4H10)?

The combustion of butane is represented by: 2 C4H10 + 13 O2 → 8 CO2 + 10 H2O. This indicates that 2 moles of butane react with 13 moles of oxygen to produce 8 moles of carbon dioxide and 10 moles of water.

How do you calculate the amount of air required to combust 1 kg of butane?

First, determine the moles of butane in 1 kg (using molar mass ~58.12 g/mol). Then, use the stoichiometric ratio from the combustion equation to find moles of oxygen needed, and since air is about 21% oxygen, calculate the total air volume or mass required accordingly.

What is the significance of the air temperature (30°C) and pressure (90 kPa) in combustion calculations?

The temperature and pressure influence the density of air, which affects the volume and amount of air needed for complete combustion. They are essential for converting between volumetric and mass-based calculations.

How does the energy released from burning 1 kg of butane relate to the combustion process?

The energy released, or heat of combustion, for butane is approximately 2877 kJ per mole. Calculating the total energy involves multiplying the moles of butane burned by this value, considering the mass burned.

What role does the initial air conditions (temperature and pressure) play in estimating combustion efficiency?

Initial air conditions affect the amount of oxygen available and the combustion temperature, which in turn influence the completeness of combustion and efficiency of the process.

How can the combustion of butane be modeled to determine pollutant formation, such as CO and NOx emissions?

By analyzing the combustion process with stoichiometry and considering incomplete combustion conditions, models can estimate CO formation; high combustion temperatures can lead to NOx formation. Proper calculations require detailed chemical and temperature data.

What safety considerations are important when burning butane with air at specified conditions?

Ensuring proper ventilation, avoiding leaks, controlling the combustion environment, and monitoring temperature and pressure are crucial to prevent explosions, toxic emissions, and ensure efficient combustion.

How does changing the amount of air supplied affect the combustion efficiency of butane?

Providing exactly the stoichiometric amount of air ensures complete combustion; excess air can cool the flame and reduce efficiency, while insufficient air leads to incomplete combustion and higher emissions of pollutants like CO.

Additional Resources

One Kilogram Of Butane (CaH10) Is Burned With 23 Kg Of Air That Is 30°C And 90 kPa. Assuming That The Combustion

Understanding the combustion process of hydrocarbons, particularly butane, is fundamental in various industrial applications, from heating to fuel production. This detailed review explores the theoretical and practical aspects of burning one kilogram of butane with a specified amount of air, analyzing the chemical reactions, energy outputs, and implications for efficiency and environmental impact.

Introduction to Butane Combustion

Butane (C_4H_{10}) is a hydrocarbon belonging to the alkane family, widely used as fuel in lighters, portable stoves, and heating appliances. Its combustion involves reacting with oxygen to produce carbon dioxide, water vapor, and energy. The process is exothermic, releasing heat that can be harnessed for various purposes.

In this context, the combustion of one kilogram of butane with 23 kg of air at 30°C and 90 kPa provides a practical scenario to analyze energy output, combustion efficiency, and pollutant formation.

Theoretical Framework and Assumptions

Before delving into calculations, it is essential to clarify the assumptions:

- Complete Combustion: All butane reacts fully with oxygen, producing only CO_2 and H_2O.
- Stoichiometric Conditions: The amount of air supplied is just enough to consume all the fuel, considering its theoretical oxygen requirement.
- Air Composition: Air is assumed to be 21% oxygen and 79% nitrogen by volume, with the nitrogen acting as an inert diluent.
- Temperature and Pressure: Air enters at 30°C (303 K) and 90 kPa, typical conditions for combustion analysis.

Chemical Reaction and Stoichiometry

Balanced Combustion Equation

The combustion of butane can be represented as:

$$ C_4H_{10} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2O $$

Balancing the complete combustion:

$$ C_4H_{10} + \frac{13}{2} \text{O}_2 \rightarrow 4 \text{CO}_2 + 5 \text{H}_2O $$

Expressed with whole numbers:

$$ 2 C_4H_{10} + 13 \text{O}_2 \rightarrow 8 \text{CO}_2 + 10 \text{H}_2O $$

Oxygen requirement per 2 kg of butane:

- Molecular weight of butane (C_4H_{10}): 58 g/mol
- For 1 kg (1000 g): number of moles:

$$ \frac{1000\,g}{58\,g/mol} \approx 17.24\,mol $$

- O_2 needed:

$$ \frac{13}{2} \times 17.24\,mol \approx 112\,mol $$

Thus, per kilogram of butane:

$$ \text{O}_2 \text{ needed} \approx 112\,mol $$

Similarly, for 1 kg:

$$ \text{O}_2 \text{ needed} \approx 112\,mol $$

Air Required for Combustion

Since air is about 21% oxygen by volume:

$$ \text{Volume of air} = \frac{\text{O}_2\, volume}{0.21} $$

The number of moles of oxygen in 23 kg of air:

- Molar mass of air ≈ 28.97 g/mol

$$ \text{moles of air} = \frac{23,000\,g}{28.97\,g/mol} \approx 793\,mol $$

Oxygen moles in this air:

$$ 0.21 \times 793\,mol \approx 166\,mol $$

This amount exceeds the oxygen needed for complete combustion of 1 kg of butane (112 mol), indicating excess air, which can influence combustion efficiency and emissions.

Energy Content and Heat of Combustion

Lower Heating Value (LHV) of Butane

The heat released during complete combustion is characterized by the lower heating value (LHV), which accounts for the energy minus the latent heat of vaporization of water. For butane, the approximate LHV is:

$$ \approx 45.7\,MJ/kg $$

Thus, burning 1 kg of butane releases:

$$ 45.7\,MJ $$

This energy can be used for heating, power generation, or other industrial processes.

Calculating the Actual Energy Released

Assuming complete combustion and no losses:

$$ Q_{total} = 45.7\,MJ $$

This represents the maximum theoretical energy output under ideal conditions.

Combustion Efficiency and Air-Fuel Ratio

The ratio of actual air supplied to the stoichiometric air required is called the equivalence ratio. In this scenario, with 23 kg of air per kg of butane, the excess air influences the combustion efficiency.

Calculations:

- Stoichiometric air for 1 kg butane:

$$ \text{O}_2 \text{ needed} = 112\,mol $$

$$\text{Air volume} = \frac{112\,mol}{0.21} \approx 533\,mol$$

- Moles of air in 23 kg:

$$793\,mol \text{ (total)}$$

- Excess air:

$$\frac{793\,mol}{533\,mol} \approx 1.49$$

This indicates approximately 49% excess air, suggesting sub-stoichiometric or lean combustion, which can improve efficiency but may produce more NOx emissions.

Environmental and Practical Implications

Advantages

- High Energy Density: Butane provides a significant amount of energy per kilogram, making it a practical fuel.
- Clean Burning: When burned completely, it produces mostly CO_2 and H_2O, with minimal pollutants.
- Ease of Storage and Transportation: As a liquefied gas, butane is convenient for portable applications.

Disadvantages

- Excess Air Requirement: Ensures complete combustion but leads to energy losses due to heating inert nitrogen.
- Emissions: Incomplete combustion or excess air can produce NOx, CO, and unburned hydrocarbons.
- Safety Concerns: Flammable and pressurized, requiring careful handling.

Practical Applications and Considerations

Understanding the combustion characteristics of butane with specified air input is crucial in designing efficient burners, engines, and industrial processes. The parameters influence:

- Combustion chamber design: To ensure proper mixing and complete combustion.
- Emission controls: To minimize NOx and other pollutants.
- Energy efficiency: To optimize fuel consumption and reduce costs.

In real-world applications, factors such as heat losses, incomplete mixing, and transient conditions affect actual performance.

Conclusion

Burning one kilogram of butane with 23 kg of air at 30°C and 90 kPa exemplifies the principles of hydrocarbon combustion under realistic conditions. The theoretical energy output reaches approximately 45.7 MJ per kilogram of fuel, with excess air influencing combustion efficiency and emissions. While the process offers high energy density and clean combustion potential, practical considerations such as excess air, safety, and emission control are vital for optimal performance. This analysis underscores the importance of precise stoichiometric calculations and understanding thermodynamic principles to maximize efficiency and minimize environmental impact in combustion systems.

Features and Pros/Cons Summary

Features:
- High energy density (~45.7 MJ/kg)
- Complete combustion produces CO_2 and H_2O
- Excess air ensures complete combustion

Pros:
- Efficient energy source
- Relatively clean burning when optimized
- Portable and easy to store

Cons:
- Requires careful control of air supply
- Potential for NOx formation at high temperatures
- Safety concerns due to flammability and pressurization

This detailed exploration provides a comprehensive understanding of butane combustion, emphasizing the importance of precise calculations and practical considerations for efficient and environmentally conscious fuel use.

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