A Mass Of 39 Lbm Of Helium Undergoes A Process From An Initial State Of 50 Ft3/ Lbm And 60F To A Final

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Understanding the thermodynamic behavior of helium, especially under different temperature and pressure conditions, is essential across various scientific and engineering applications. This detailed article explores the transformation of a specified mass of helium—39 pounds mass (lbm)—as it transitions from an initial state characterized by a specific volume and temperature to a final state. We will analyze the initial and final properties, the processes involved, and the calculations required to determine the final state parameters, emphasizing the importance of thermodynamic principles and equations.

Introduction to Helium and Its Thermodynamic Properties

Helium, a noble gas, is renowned for its low atomic mass, inertness, and unique thermodynamic properties. Its behavior under different temperature and pressure conditions is well described by the ideal gas law at standard conditions, with deviations at high pressures or low temperatures.

Key properties of helium:
- Atomic mass: approximately 4.0026 atomic mass units
- Specific gas constant (R): approximately 2.078 kJ/(kg·K)
- Critical temperature: 5.2 K
- Critical pressure: 2.24 MPa

Since the initial and final states involve temperatures around 60°F (~15.56°C or 288.71 K), and volumes in ft^3/lbm, we can generally approximate helium's behavior using ideal gas assumptions for practical engineering calculations.

Initial State Conditions

The initial state of helium is characterized by:
- Mass (m): 39 lbm
- Specific volume (v): 50 ft^3/lbm
- Temperature (T): 60°F (~15.56°C or 288.71 K)

Understanding the initial specific volume:

The total initial volume (V_1):
$V_1 = m \times v = 39$ lbm × 50 ft^3/lbm = 1950 ft^3

Converting units:

To facilitate calculations, especially when applying the ideal gas law, it is often necessary to convert units into SI (International System) units:

Parameter	Value	Conversion/Notes
Mass (m)	39 lbm	1 lbm ≈ 0.453592 kg ⍰ m ≈ 17.69 kg

Specific volume (v)	50 ft^3/lbm	1 $ft^3 \approx 0.0283168\ m^3$	$v \approx 50 \times 0.0283168\ ft^3/lbm \approx 1.4158\ m^3/kg$
Temperature (T)	60°F	T (K) = (T(°F) - 32) / 1.8 + 273.15 ≈ 15.56°C + 273.15 ≈ 288.71 K	

Final State Conditions: What We Aim to Find

While the original prompt mentions a transition from an initial state to a final state, details such as the final temperature, volume, or pressure are not explicitly specified. Typically, in thermodynamic analyses, the goal is to determine the final temperature, volume, or pressure after a process such as heating, cooling, compression, or expansion.

Assumed or typical scenarios include:
- Isothermal process (constant temperature)
- Isobaric process (constant pressure)
- Isometric process (constant volume)
- Adiabatic process (no heat transfer)

For this analysis, let's assume the process is adiabatic and involves a change in volume or temperature, which is common in practical applications involving helium.

Applying the Ideal Gas Law

The ideal gas law provides a foundation for analyzing the state changes of helium:

$$PV = nRT$$

Where:
- P = absolute pressure
- V = volume
- n = number of moles
- R = specific gas constant
- T = temperature

Calculating initial pressure:

Number of moles (n):
$$n = \frac{m}{M}$$
where M is molar mass (~4.0026 g/mol).

Convert mass to grams:
$$m = 17.69\,kg \times 1000\,g/kg = 17,690\,g$$

Number of moles:
$$n = \frac{17,690\,g}{4.0026\,g/mol} \approx 4422\,mol$$

Using the ideal gas law in terms of specific volume:
$$P = \frac{RT}{v}$$

Where R (specific gas constant for helium):
$$R = \frac{8.314\,J/(mol\cdot K)}{M} = \frac{8.314}{4.0026} \approx 2.078\,J/(g\cdot K)$$
or in SI units:

$$ R_{specific} \approx 2.078\,kJ/(kg\cdot K) $$

Calculate initial pressure:
$$ P_1 = \frac{nRT}{V} $$
or directly via:
$$ P_1 = \frac{RT}{v} $$

Using SI units:
$$ P_1 = \frac{2.078\,kJ/(kg\cdot K) \times 288.71\,K}{1.4158\,m^3/kg} $$
$$ P_1 \approx \frac{2.078 \times 288.71}{1.4158} \,kPa $$
$$ P_1 \approx \frac{600.67}{1.4158} \approx 424.4\,kPa $$

Converted to psi:
$$ 1\,kPa \approx 0.145038\,psi $$
$$ P_1 \approx 424.4 \times 0.145038 \approx 61.55\,psi $$

This pressure is consistent with typical helium pressures at room temperature.

Analyzing the Process: Common Scenarios and Calculations

Depending on the process, different calculations are involved:

1. Isothermal Process

In an isothermal process, temperature remains constant, and the volume may change:

$$ P_1 V_1 = P_2 V_2 $$
$$ T_1 = T_2 $$

2. Isobaric Process (Constant Pressure)

With constant pressure, the volume change relates directly to temperature change:

$$ \frac{V_2}{V_1} = \frac{T_2}{T_1} $$

3. Adiabatic Process

For adiabatic processes involving ideal gases:

$$ PV^\gamma = \text{constant} $$
or
$$ TV^{\gamma - 1} = \text{constant} $$
where:
- γ (gamma) is the heat capacity ratio (C_p/C_v)
- For helium, $\gamma \approx 1.66$

Using the adiabatic relations, one can determine the final temperature or volume given initial conditions and process specifics.

Calculating the Final State Parameters

Let's assume the process is adiabatic compression where the volume is reduced, leading to an increase in pressure and temperature.

Suppose the final specific volume v_2 is known or desired; then, the final temperature T_2 can be calculated via:

$$ T_2 = T_1 \left(\frac{V_2}{V_1} \right)^{\gamma - 1} $$

Similarly, the final pressure:
$$ P_2 = P_1 \left(\frac{V_1}{V_2} \right)^\gamma $$

Example Calculation:

If the volume is compressed to 25 ft^3/lbm:

- Final specific volume $v_2 = 25\,ft^3/lbm = 0.7079\,m^3/kg$

Calculate the ratio:
$$ \frac{V_2}{V_1} = \frac{v_2}{v_1} = \frac{0.7079}{1.4158} \approx 0.5 $$

Calculate T_2:
$$ T_2 = 288.71\,K \times (0.5)^{0.66} $$
$$ T_2 \approx 288.71 \times 0.615 \approx 177.7\,K $$

Calculate P_2:
$$ P_2 = 61.55\,psi \times (1/0.5)^{1.66} $$
$$ P_2 = 61.55 \times 2^{1.66} $$
$$ 2^{1.66} \approx 3.17 $$
$$ P_2 \approx 61.55 \times 3.17 \approx 195.3\,psi $$

This example illustrates how volume reduction during an adiabatic process significantly increases temperature and pressure.

Summary of Key Calculations and Concepts

- Initial state parameters were derived from known data and conversions.
- Ideal gas law serves as the foundation for initial and final state calculations.
- Process type (isothermal, adiabatic, isobaric) determines the relationships among pressure, volume, and temperature.
- Final state parameters can be calculated given process specifics, such as volume change or temperature change.
-

Frequently Asked Questions

What is the initial volume of helium in cubic feet for a mass of 39 lbm at

60°F?

The initial volume is 50 ft^3 per pound-mass, so for 39 lbm, it is 50 ft^3/lbm × 39 lbm = 1950 ft^3.

What is the significance of the given 50 ft^3/lbm ratio in the analysis of helium's process?

It indicates the specific volume of helium per unit mass, which helps determine the initial and final states during the process.

How does the temperature change from 60°F affect the properties of helium during the process?

Temperature change can affect the helium's pressure and volume, especially if the process involves thermodynamic transformations; knowing the final temperature helps determine the final state parameters.

What are the typical assumptions made when analyzing a helium process with given initial specific volume and mass?

Assumptions often include ideal gas behavior, constant specific heats, and that the process may be adiabatic or polytropic unless specified otherwise.

How can the ideal gas law be applied to find the final state of helium in this process?

Using $PV = mRT$, where P is pressure, V is volume, m is mass, R is the specific gas constant, and T is temperature, you can calculate the final pressure or temperature if other variables are known.

If the process involves a temperature change from 60°F to a higher temperature, what impact does this have on the volume of helium?

According to Charles's law, increasing temperature at constant pressure increases volume; if pressure varies, the relationships adjust accordingly, but generally, volume expands with temperature.

What is the role of specific volume in determining the state changes of helium during the process?

Specific volume relates the volume per unit mass, allowing for the calculation of changes in volume during thermodynamic processes based on initial and final states.

What additional information is needed to fully analyze the final state of helium after the process?

The final temperature or pressure, the type of process (isothermal, adiabatic, etc.), and whether the process is closed or open would be necessary to complete the analysis.

Additional Resources

A mass of 39 lbm of helium undergoes a process starting from an initial state characterized by a specific volume and temperature. This scenario provides an intriguing case study in thermodynamics, fluid mechanics, and gas behavior, especially considering helium's unique properties as a noble gas with low molecular weight and high thermal conductivity. Analyzing this process involves understanding the initial conditions, the thermodynamic principles at play, and the possible outcomes of the process — whether it involves heating, cooling, compression, expansion, or a combination thereof.

Understanding the Initial Conditions

Mass and Material Properties of Helium

The initial statement specifies a mass of 39 lbm (pounds mass) of helium. Helium, with a molar mass approximately 4.00 g/mol, is a monoatomic ideal gas at standard conditions. Its low molecular weight and inert nature make it a common choice for applications requiring high thermal conductivity or low density.

- Mass (m): 39 lbm
- Material: Helium (He)
- Molecular weight (M): 4.00 g/mol
- Number of moles (n): Calculated via the relation

$$
n = \frac{m}{M} \times \frac{1000\, \text{g}}{1\, \text{kg}} \times \frac{1\, \text{kg}}{2.20462\, \text{lb}}
$$

which simplifies to:

$$
n = \frac{39\, \text{lbm}}{4\, \text{g/mol}} \times \frac{1000\, \text{g}}{1\, \text{kg}} \times \frac{1\, \text{kg}}{2.20462\, \text{lb}} \approx 44.2\, \text{moles}
$$

This quantity of helium serves as the basis for analyzing the thermodynamic process.

Initial State Conditions: Volume and Temperature

The initial specific volume per unit mass is given as 50 ft^3/lbm, and the initial temperature is 60°F.

- Specific volume (v): 50 ft^3/lbm
- Total volume (V):

$$
V_{initial} = v \times m = 50\, \text{ft}^3/\text{lbm} \times 39\, \text{lbm} = 1950\, \text{ft}^3
$$

- Initial temperature (T_1): 60°F

Converting temperature to an absolute scale (Rankine):

$$
T_1 = 60 + 459.67 = 519.67\, \text{°R}
$$

The initial state thus describes a relatively large volume of helium at near room temperature.

Thermodynamic Principles and Assumptions

Ideal Gas Behavior

Given the conditions and the nature of helium, the ideal gas law is a suitable approximation:

$$
PV = nRT
$$

Where:

- P: absolute pressure
- V: volume
- n: number of moles
- R: universal gas constant (8.314 J/mol·K; or 1545 ft·lbf/(lbm·°R))
- T: absolute temperature in Rankine

Using this law, initial pressure can be estimated:

$$
P_1 = \frac{nRT_1}{V}
$$

Alternatively, the initial pressure can be specified if known, but since it isn't, the process might involve changes in pressure, volume, and temperature, depending on the process type.

Assumption: The process involves an ideal gas behavior, with no significant interactions or deviations due to non-ideal effects.

Process Types

The nature of the process (isothermal, adiabatic, isobaric, isochoric, polytropic, etc.) greatly influences the analysis. Since the problem mentions initial and final states but only specifies part of the initial conditions, the process could involve:

- Isothermal process: temperature remains constant ($T = T_1 = T_2$)
- Adiabatic process: no heat transfer (Q=0), with P, V, T changing according to adiabatic relations
- Isobaric process: constant pressure
- Isochoric process: constant volume
- Polytropic process: general process following $PV^n = \text{constant}$

In this case, without explicit process details, we will consider the general case and analyze potential outcomes.

Analyzing the Process Dynamics

Potential Process Scenarios

Given the initial state and the mention of a "final" state, several scenarios are possible:

1. Heating or Cooling at Constant Volume: Changing temperature, leading to a change in pressure.
2. Compression or Expansion at Constant Pressure: Changing volume and temperature.
3. Adiabatic Compression or Expansion: No heat exchange, with temperature and pressure changing according to specific relations.
4. Combined Processes: For example, polytropic processes involving both heat exchange and work.

Without explicit details, let's explore these possibilities.

Scenario 1: Isothermal Process

Suppose helium undergoes an isothermal process at 60°F (519.67°R). Since temperature is constant, the ideal gas law simplifies to:

$$
PV = \text{constant}
$$

This implies that as the volume changes, the pressure adjusts proportionally, and temperature remains unchanged.

- Final volume (V_2): Could be larger or smaller depending on whether the process involves expansion or compression.

- Final state calculations:

$$
P_2 = \frac{nRT_1}{V_2}
$$

If the volume increases (expansion), the pressure decreases proportionally.

Scenario 2: Adiabatic Process

In an adiabatic process, the relations governing the state change are:

$$
PV^\gamma = \text{constant}
$$
$$
TV^{\gamma - 1} = \text{constant}
$$

Where:

- $\gamma = C_p / C_v$: specific heat ratio for helium, approximately 1.66 (monoatomic ideal gas).

Calculations:

- Initial pressure P_1: derived from initial volume and temperature.
- Final pressure P_2: related to initial pressure via the adiabatic relation.

The temperature change can be calculated as:

$$
T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma - 1}
$$

or, equivalently, pressure and temperature can be related as:

$$
\frac{P_2}{P_1} = \left(\frac{V_1}{V_2} \right)^\gamma
$$

Calculations and Analytical Approach

Step 1: Determine Initial Pressure

Using the ideal gas law:

$$
P_1 = \frac{nRT_1}{V}
$$

Constants:

- $n = 44.2$ mol
- $R = 1545\, \text{ft·lbf/(lbm·°R)}$
- $T_1 = 519.67\, \text{°R}$
- $V = 1950\, \text{ft}^3$

Calculation:

$$
P_1 = \frac{44.2 \times 1545 \times 519.67}{1950}
$$

$$
P_1 \approx \frac{44.2 \times 1545 \times 519.67}{1950}
$$

Numerically:

$$
44.2 \times 1545 \approx 68,283
$$

$$
68,283 \times 519.67 \approx 35,490,134
$$

Dividing by 1950:

$$
P_1 \approx \frac{35,490,134}{1950} \approx 18,207\, \text{psf}
$$

Converting to psi:

$$
1\, \text{psi} = 144\, \text{psf}
$$

$$
P_1 \approx \frac{18,207}{144} \approx 126.4\, \text{psi}
$$

Thus, the initial absolute pressure is approximately 126.4 psi.

Step 2: Final State Assumptions

Suppose the process involves an adiabatic expansion where the volume increases to, say, 3000 ft^3. The final temperature T_2 can be calculated:

$$
T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma - 1} = 519.67 \times \left(\frac{1950}{3000} \right)^{0.66}
$$

Calculating:

$$
\frac{1950}{3000} = 0.65
$$

$$
T_2 = 519.67 \times (0.65)^{0.66} \approx 519.67 \times 0.72 \approx 374\, \text{°R}
$$

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