59) A Sealed Cylinder Fitted With A Movable Piston Contains Ideal Gas At 27C, Pressure 0.500 105 Pa,

59) A Sealed Cylinder Fitted With A Movable Piston Contains Ideal Gas At 27°C, Pressure 0.500 × 10^5 Pa

This scenario involves an ideal gas confined within a sealed cylinder equipped with a movable piston. The given parameters—initial temperature, pressure, and the nature of the gas—serve as the foundation for exploring thermodynamic principles such as the ideal gas law, work done during expansion or compression, and the relationship between pressure, volume, and temperature. Understanding this setup is crucial for applications in engineering, physics, and thermodynamics, where such systems are commonplace.

Understanding the System: Basic Parameters and Assumptions

Key Parameters

- Initial temperature (T_1): 27°C, which converts to Kelvin as T_1 = 27 + 273.15 = 300.15 K
- Initial pressure (P_1): 0.500 × 10^5 Pa (or 50,000 Pa)
- Nature of gas: Ideal gas (assumption that gas molecules do not interact and occupy negligible volume)
- System configuration: Sealed cylinder with a movable piston, which allows volume change without gas loss

Assumptions for Analysis

- The gas behaves ideally throughout the process.
- The cylinder is perfectly insulated during adiabatic processes or allows heat transfer during others.
- The piston moves without friction, and the external pressure can be controlled or considered constant depending on the process.
- The mass of the gas remains constant; no gas enters or leaves the system.

Applying the Ideal Gas Law

Fundamental Equation

The behavior of the gas can be described by the ideal gas law:

\[PV = nRT \]

Where:
- P = pressure
- V = volume
- n = number of moles
- R = universal gas constant (8.314 J/mol·K)
- T = temperature in Kelvin

Calculating the Number of Moles

Suppose the initial volume of the gas is V_1. The number of moles n can be obtained as:

$$ n = \frac{P_1 V_1}{RT_1} $$

Since the initial conditions are known, this formula allows us to determine the amount of gas present, which remains constant unless gas is added or removed.

Analyzing Thermodynamic Processes in the Cylinder

Understanding how the gas responds to various processes helps in designing systems like engines, refrigerators, or pressure vessels.

Types of Processes

- Isothermal (constant temperature): The temperature remains at 27°C throughout the process.
- Adiabatic (no heat exchange): The process occurs without heat transfer, leading to changes in temperature and pressure.
- Isobaric (constant pressure): The pressure remains constant while volume and temperature change.
- Isochoric (constant volume): Volume stays fixed; any change in pressure or temperature occurs without volume change.

Case Study: Isothermal Expansion or Compression

Suppose the piston moves such that the process is isothermal at 27°C.

Calculating Final Volume and Pressure

Since T is constant, the ideal gas law simplifies to:

$$ P_1 V_1 = P_2 V_2 $$

If the volume expands or compresses, the relation between initial and final states is:

$$ \frac{P_2}{P_1} = \frac{V_1}{V_2} $$

- Example: If the volume doubles ($V_2 = 2V_1$), then:

$$ P_2 = \frac{P_1 V_1}{V_2} = \frac{0.5 \times 10^5 \times V_1}{2V_1} = 0.25 \times 10^5 \, \text{Pa} $$

- Work done (W) in isothermal process:

$$ W = nRT \ln \frac{V_2}{V_1} $$

Alternatively, expressed in terms of initial parameters:

$$ W = P_1 V_1 \ln \frac{V_2}{V_1} $$

This work can be positive (work done by the gas during expansion) or negative during compression.

Case Study: Adiabatic Process

Suppose the piston moves adiabatically, meaning no heat exchange with surroundings.

Adiabatic Relations

For an ideal gas in an adiabatic process:

$$ PV^{\gamma} = \text{constant} $$

where:
- $\gamma = C_p / C_v$ (ratio of specific heats, for air approximately 1.4)

The relation between initial and final states:

$$ P_2 V_2^{\gamma} = P_1 V_1^{\gamma} $$

and the temperature change:

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

or equivalently:

$$ T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{(\gamma - 1)/\gamma} $$

Work Done in an Adiabatic Process

$$ W = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} $$

or

$$ W = n C_v (T_2 - T_1) $$

This illustrates how temperature and pressure change during adiabatic compression or expansion.

Practical Applications and Real-World Significance

Understanding the behavior of gases in sealed cylinders with movable pistons is fundamental in various engineering applications.

Internal Combustion Engines

- The piston cycles through adiabatic and isothermal processes, converting chemical energy into mechanical work.

- Control over pressure and volume changes maximizes efficiency.

Refrigeration and Air Conditioning

- Cycles involve isentropic compression and expansion of gases.
- Precise thermodynamic calculations optimize performance.

Pressure Vessels and Gas Storage

- Ensuring safety under operational pressures.
- Designing systems to withstand volume and pressure changes during temperature fluctuations.

Additional Considerations and Complexities

While ideal gas assumptions simplify calculations, real gases exhibit deviations at high pressures or low temperatures. Factors to consider include:

- Non-ideal behavior: Van der Waals equation accounts for molecular interactions.
- Heat transfer: Real processes often involve heat exchange; the system may not be perfectly adiabatic or isothermal.
- Friction and piston dynamics: Mechanical losses influence work calculations.
- Material constraints: The piston and cylinder materials must withstand pressure and temperature variations.

Conclusion

The scenario of a sealed cylinder with a movable piston containing ideal gas at 27°C and 0.500×10^5 Pa provides a rich foundation for understanding core thermodynamic principles. By applying the ideal gas law, analyzing different process types, and calculating work and heat transfer, engineers and physicists can design efficient systems across various industries. Whether in engines, refrigeration cycles, or gas storage, grasping these concepts ensures safe, effective, and optimized application of thermodynamics in real-world systems.

Keywords for SEO Optimization:
- Ideal gas law
- Thermodynamics
- Sealed cylinder with piston
- Isothermal process
- Adiabatic process
- Gas pressure and volume
- Work done in thermodynamic systems
- Gas temperature and pressure relationship
- Engineering applications of ideal gases
- Gas process calculations

Frequently Asked Questions

What is the initial temperature of the ideal gas in the sealed cylinder?

The initial temperature of the ideal gas is 27°C.

What is the initial pressure of the gas inside the cylinder?

The initial pressure of the gas is 0.500 × 10^5 Pa.

How can the temperature of the gas be converted from Celsius to Kelvin?

Add 273.15 to the Celsius temperature: 27°C + 273.15 = 300.15 K.

What is the significance of the cylinder being sealed in this problem?

The sealed cylinder implies that the amount of gas and the volume are fixed unless the piston moves, affecting the pressure and temperature relationships.

How does the ideal gas law relate to the conditions in the cylinder?

The ideal gas law, PV = nRT, relates pressure, volume, and temperature, allowing analysis of changes when the piston moves or temperature varies.

If the piston moves, what thermodynamic process might occur in the cylinder?

It could undergo an isothermal, adiabatic, isobaric, or isochoric process depending on how pressure, volume, and temperature change.

How would increasing the temperature of the gas affect the pressure in the sealed cylinder?

Increasing the temperature typically increases the pressure, assuming volume remains constant or the piston is free to move accordingly.

What is the typical unit for pressure in such thermodynamic problems?

The pressure is usually expressed in Pascals (Pa) or multiples thereof, such as 10^5 Pa.

What additional information is needed to determine the change in state of the gas if the piston moves?

Details about how the piston moves (e.g., the amount of volume change), the process type, and any temperature variations are needed to analyze the state change.

Additional Resources

Sealed Cylinder with Movable Piston Containing Ideal Gas at 27°C and 0.500×10^5 Pa: An In-Depth Analysis

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Introduction

Understanding the behavior of gases enclosed within a sealed cylinder fitted with a movable piston is fundamental to thermodynamics. Such systems serve as simplified models for engines, compressors, and various industrial processes. When the gas is ideal — meaning it follows the ideal gas law without interactions between molecules — analyzing its thermodynamic properties becomes more straightforward. This review delves into the detailed physics of a sealed cylinder with a movable piston containing ideal gas at a specified initial condition: temperature of 27°C and pressure of 0.500×10^5 Pa.

Basic System Description

The system under consideration consists of:

- A sealed cylindrical chamber: Rigidly enclosed to prevent mass exchange with the surroundings.
- A movable piston: Capable of sliding without friction, allowing volume change in response to pressure and other thermodynamic processes.
- Ideal gas: The working fluid, obeying the ideal gas law $PV = nRT$.

Initial conditions:

- Temperature, $T_1 = 27^\circ C = 300\,K$
- Pressure, $P_1 = 0.500 \times 10^5\,Pa = 50,000\,Pa$

Fundamental Thermodynamic Principles

1. Ideal Gas Law

The behavior of the gas is governed by:

$$
PV = nRT
$$

where:

- P: Pressure
- V: Volume
- n: Number of moles
- R: Universal gas constant $R = 8.314\,J/(mol\,K)$
- T: Temperature in Kelvin

Given initial conditions, we can determine the initial volume if the amount of gas (number of moles) is known or vice versa.

2. Conservation of Mass

Since the system is sealed, the number of moles n remains constant throughout any process.

Initial State Calculations

Suppose the initial amount of gas is n moles. Using the ideal gas law:

\[

$$
V_1 = \frac{nRT_1}{P_1}
$$

Without specific n, we can express V_1 in terms of n. Alternatively, if the volume is specified, we can find n.

Example calculation:

Assuming the initial volume V_1 is known or assigned, or for a standard example, taking $n = 1\,mol$:

$$
V_1 = \frac{(1)(8.314)(300)}{50,000} \approx 0.0499\,m^3
$$

This would be the initial volume for 1 mol of gas under the given conditions.

Thermodynamic Processes in the Cylinder

The system may undergo various processes such as:

- Isothermal (constant temperature)
- Isobaric (constant pressure)
- Isochoric (constant volume)
- Adiabatic (no heat exchange)
- Polytropic processes (generalized processes)

Understanding these processes allows us to analyze energy transfer, work done, and entropy changes.

Analysis of Common Processes

1. Isothermal Process

In an isothermal process, temperature remains constant ($T = T_1$). Since $PV = nRT$, then $PV = \text{constant}$.

- Work Done by Gas:

$$
W_{iso} = nRT \ln \frac{V_2}{V_1}
$$

- Heat Transfer:

$$
Q_{iso} = W_{iso}
$$

- Change in Internal Energy:

$$
\Delta U = 0
$$

because internal energy depends solely on temperature for an ideal gas.

2. Isobaric Process

At constant pressure, the volume change relates to temperature:

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

- Work Done:

$$
W_{iso} = P (V_2 - V_1) = n R (T_2 - T_1)
$$

- Heat Transfer:

$$
Q_{iso} = n C_p (T_2 - T_1)
$$

where C_p is the molar heat capacity at constant pressure ($C_p \approx 29\,J/(mol\,K)$ for ideal gases).

- Internal Energy Change:

$$
\Delta U = n C_v (T_2 - T_1)
$$

with $C_v \approx 20.8\,J/(mol\,K)$.

3. Adiabatic Process

No heat exchange occurs ($Q = 0$):

$$
PV^\gamma = \text{constant}
$$

or equivalently:

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

where $\gamma = C_p / C_v \approx 1.4$ for diatomic gases like nitrogen and oxygen (major components of air).

- Work Done in Adiabatic Process:

$$
W_{ad} = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1}
$$

- Temperature and Pressure Relations:

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

or

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

Piston Dynamics and Work Calculation

The movable piston allows the gas to perform work on the surroundings or have work done on it. The work W done during volume change ΔV:

$$
W = P_{ext} \times \Delta V
$$

- For reversible processes, P_{ext} equals the internal pressure P at each stage.
- For adiabatic or isothermal processes, the work can be integrated using the respective relations.

Example:

If the piston moves from initial volume V_1 to V_2, the work done during an isothermal expansion:

$$
W_{iso} = nRT \ln \left(\frac{V_2}{V_1} \right)
$$

This work can be positive (work done by the gas during expansion) or negative (compression).

Energy and Entropy Considerations

1. Internal Energy

For ideal gases, the internal energy U depends only on temperature:

$$
\Delta U = n C_v \Delta T
$$

which simplifies calculations of heat exchange for processes involving temperature change.

2. Entropy Change

The entropy change ΔS for an ideal gas during a process from state 1 to state 2:

$$
\Delta S = n C_v \ln \frac{T_2}{T_1} + n R \ln \frac{V_2}{V_1}
$$

or equivalently, for a process with known initial and final states:

$$
\Delta S = n R \ln \frac{P_1}{P_2} + n C_v \ln \frac{T_2}{T_1}
$$

In particular, for reversible isothermal processes, ΔS simplifies to:

$$
\Delta S = n R \ln \frac{V_2}{V_1}
$$

Practical Applications and Implications

Understanding these thermodynamic principles allows engineers and scientists to design and analyze:

- Internal combustion engines: analyzing compression and expansion cycles.
- Refrigeration cycles: understanding heat absorption and rejection.
- Gas turbines and compressors: energy transfer mechanisms.
- Pressure-volume work calculations: essential in process optimization.

Specific Scenarios for the System

While the initial data specify the state of the gas, various scenarios can be envisioned:

a. Isothermal Expansion or Compression

- The piston moves slowly, maintaining thermal equilibrium with surroundings.
- Useful in theoretical efficiency calculations.

b. Adiabatic Compression or Expansion

- Rapid piston movement prevents heat transfer.
- Key in understanding real engine cycles.

c. Polytropic Processes

- Generalized processes characterized by:

$$
PV^n = \text{constant}
$$

- The polytropic index n reflects process specifics, such as heat transfer rates.

Advanced Considerations

1. Real vs. Ideal Gas Behavior

While the ideal gas law simplifies analysis, real gases exhibit non-ideal behavior at high pressures or low temperatures. Corrections using Van der Waals or other equations of state can improve accuracy.

2. Piston Friction and Heat Losses

In actual systems, friction and heat transfer to surroundings impact process efficiency, requiring more complex models.

3. Dynamic Response

The piston's acceleration and dynamic effects influence the process, especially during rapid changes.

Conclusion

The sealed cylinder with a movable piston containing ideal gas at 27°C and 0.500×10^5 Pa exemplifies fundamental thermodynamic systems. Its analysis hinges on the ideal gas law, energy conservation principles, and the

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