# ANSWER ALL QUESTIONS Q1. 30 Marks Two Tanks Are Initially Filled With Air Initially At A Temperature

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## Introduction

Understanding the behavior of gases in closed containers is fundamental in thermodynamics and engineering applications. When two tanks are initially filled with air at a specific temperature, various processes such as heating, cooling, compression, or expansion can occur, affecting the pressure, temperature, and volume of the gases involved. This article provides a comprehensive analysis of the thermodynamic principles governing such systems, including detailed calculations, assumptions, and implications relevant to engineering practice.

## Initial Conditions and Assumptions

Before analyzing the process, it is crucial to establish the initial conditions and assumptions that simplify the analysis:

### Initial Conditions

- Two tanks, Tank A and Tank B, are initially filled with air.
- Both tanks are at the same initial temperature, denoted as $T_1$.
- The initial pressures are $P_{A1}$ and $P_{B1}$ for Tank A and Tank B, respectively.
- The initial volumes are $V_A$ and $V_B$.
- The air behaves as an ideal gas.

### Assumptions

- The process occurs at constant atmospheric pressure unless otherwise specified.
- Heat transfer and work interactions are considered based on the process described.
- The tanks are rigid (fixed volume) unless the problem specifies otherwise.
- No leaks or mass transfer occur during the process.
- The process is quasi-static, allowing the use of equilibrium thermodynamics.

# Thermodynamic Principles Applicable

The analysis of two tanks initially filled with air involves key thermodynamic concepts:

## Ideal Gas Law

The ideal gas law relates pressure, volume, and temperature:

$$
PV = nRT
$$

where:

- $P$ = pressure,
- $V$ = volume,
- $n$ = number of moles,
- $R$ = universal gas constant,
- $T$ = absolute temperature.

This law allows calculating the state variables during the process.

## First Law of Thermodynamics

For a closed system, the first law states:

$$
\Delta U = Q - W
$$

where:

- $\Delta U$ = change in internal energy,
- $Q$ = heat added to the system,
- $W$ = work done by the system.

In the context of gases in tanks, this principle helps analyze heat transfer and work interactions during processes like heating, cooling, or expansion.

## Adiabatic and Isothermal Processes

Depending on whether heat transfer occurs, the process can be:

- Adiabatic: no heat exchange ($Q=0$),
- Isothermal: temperature remains constant ($T$ constant).

Understanding these processes is essential for modeling the behavior of the tanks under different scenarios.

# Analysis of the Process

The specific process involving the two tanks depends on the problem statement. Common scenarios include:

## Scenario 1: Equalization of Pressure and Temperature

If the tanks are connected, allowing air to flow between them until equilibrium:

- The final state will have uniform pressure and temperature.
- The total mass of air remains constant.
- The process is assumed to be adiabatic and reversible for ideal analysis.

Calculation Steps:
1. Calculate initial moles:
$$
n_A = \frac{P_{A1} V_A}{RT_1}
$$
$$
n_B = \frac{P_{B1} V_B}{RT_1}
$$
2. Total moles:
$$
n_{total} = n_A + n_B
$$
3. Final temperature ($T_f$) and pressure ($P_f$) can be found assuming ideal gas behavior and no heat loss:
$$
P_f V_{total} = n_{total} R T_f
$$
where $V_{total} = V_A + V_B$.

4. Since the tanks are rigid, the volumes are fixed, and the final pressure can be derived accordingly.

Result:
- The final state reflects the combined mass and energy balance.
- The process is isothermal if the temperature remains constant during the exchange.

## Scenario 2: Heating or Cooling of One or Both Tanks

When heat is added or removed:

- The temperature of the air in the tanks changes.
- The process can be modeled as an isochoric (constant volume) heating/cooling process.

Calculation Steps:
1. Determine the amount of heat transfer ($Q$):

$$
Q = m C_v \Delta T
$$

where:
- $m$ = mass of air,
- $C_v$ = specific heat at constant volume,
- $\Delta T$ = temperature change.

2. Update the state variables accordingly.

Implications:
- The pressure in each tank will change as per the ideal gas law.
- If tanks are connected, temperature and pressure tend toward equilibrium, following the principles of thermodynamics.

## Scenario 3: Expansion or Compression of Air

If the tanks undergo expansion or compression:

- The process could be adiabatic or polytropic.
- The work done during expansion/compression impacts the internal energy and temperature.

Calculation Steps:
1. For adiabatic processes:

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

where $\gamma = \frac{C_p}{C_v}$ (ratio of specific heats).

2. Calculate the final state based on initial conditions and process type.

# Mathematical Derivations and Calculations

To illustrate these principles, consider a specific example:

Suppose:
- Initial temperature $T_1 = 300\,K$,

- Initial pressures $P_{A1} = 200\,kPa$, $P_{B1} = 150\,kPa$,
- Volumes $V_A = 1\,m^3$, $V_B = 2\,m^3$,
- The process involves connecting the tanks, allowing air to flow until equilibrium.

Step 1: Calculate initial moles in each tank:

$$
n_A = \frac{200 \times 10^3 \times 1}{8.314 \times 300} \approx 80.02\,mol
$$

$$
n_B = \frac{150 \times 10^3 \times 2}{8.314 \times 300} \approx 120.03\,mol
$$

Step 2: Total moles:

$$
n_{total} = 80.02 + 120.03 = 200.05\,mol
$$

Step 3: Final state:
- Total volume:

$$
V_{total} = 1 + 2 = 3\,m^3
$$

- Final pressure:

$$
P_f = \frac{n_{total} R T_f}{V_{total}}
$$

- Assuming thermal equilibrium at $T_1 = T_f = 300\,K$:

$$
P_f = \frac{200.05 \times 8.314 \times 300}{3} \approx 166,122\,Pa \approx 166.1\,kPa
$$

This indicates the pressure equilibrates to approximately 166.1 kPa after connecting the tanks.

Step 4: Check for consistency with initial conditions.

This simple calculation demonstrates how initial states influence final equilibrium conditions.

# Practical Applications and Engineering Significance

The analysis of air in tanks at different initial conditions has numerous practical applications:

- Pressure Vessel Design: Ensuring tanks withstand internal pressures during filling, heating, or expansion.

- HVAC Systems: Managing air temperature and pressure to optimize comfort and energy efficiency.
- Compressed Air Systems: Calculating storage and delivery pressures.
- Chemical Process Industry: Handling gases during reactions, distillations, or separations.
- Aerospace Engineering: Designing pressurized cabins and fuel tanks.

Understanding the thermodynamics behind these processes enables engineers to design safer, more efficient systems.

## Key Factors Influencing the Process

Several factors impact the behavior of air in tanks:

- Initial Conditions: Pressure, temperature, and volume.
- Process Path: Heating, cooling, expansion, compression, or combination.
- Material Properties: Specific heats ($C_v, C_p$), gas behavior.
- Heat Transfer: Rate and amount of heat exchanged.
- Work Interactions: Mechanical work during expansion or compression.

Optimizing these factors ensures desired outcomes, such as minimizing energy consumption or maximizing safety.

## Conclusion

The analysis of two tanks initially filled with air at a given temperature involves a thorough understanding of thermodynamic principles, including the ideal gas law, energy conservation, and process-specific behaviors. Whether the process involves pressure equalization, heating, cooling, or expansion, applying the correct assumptions and calculations allows engineers to predict the system's behavior accurately. Such insights are vital in designing and operating systems involving gases, ensuring safety, efficiency, and compliance with engineering standards.

By carefully considering initial conditions, process types, and material properties, one can develop

## Frequently Asked Questions

### Q1. Two tanks are initially filled with air at the same temperature and pressure. If one tank is heated while the other remains at constant

temperature, how does the pressure change in each tank? (30 Marks)

In the tank heated with constant volume, the pressure increases proportionally to the temperature increase (Gay-Lussac's law). For the tank at constant pressure, the volume expands with temperature, and the pressure remains constant. The specific changes depend on the temperature variation and the properties of air.

## Q2. How does the ideal gas law relate to the behavior of air in the two tanks under different temperature conditions?

The ideal gas law, $PV = nRT$, explains that for a fixed amount of gas, pressure and temperature are directly proportional at constant volume. When one tank is heated, its pressure increases if volume remains fixed. Conversely, if the tank can expand, volume changes, influencing pressure accordingly.

## Q3. What are the key assumptions made when analyzing the thermodynamic behavior of air in these tanks?

Key assumptions include treating air as an ideal gas, assuming uniform temperature and pressure within each tank, neglecting heat losses, and considering the processes to be quasi-static for accurate analysis.

## Q4. How would the process differ if the tanks were filled with a real gas instead of an ideal gas?

For real gases, deviations from ideal behavior occur at high pressures and low temperatures, affecting pressure, volume, and temperature relationships. Non-idealities like intermolecular forces would need to be considered, potentially complicating the analysis.

## Q5. What practical applications or engineering scenarios involve similar analysis of air in tanks at varying temperatures?

Applications include designing compressed air systems, thermal expansion in storage tanks, aeronautical engineering for cabin pressurization, and HVAC systems where air temperature and pressure management are critical.

## Q6. How can the principles demonstrated in this problem be used to design safer and more efficient pressurized air systems?

Understanding the thermodynamic behavior allows engineers to predict pressure changes with temperature, select appropriate materials, incorporate safety valves, and optimize system operation to prevent overpressure or structural failure.

# Additional Resources

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Investigative Analysis of Thermodynamic Processes in Two Tanks Initially Filled with Air

Understanding the thermodynamics of gases in contained systems is fundamental for numerous engineering applications, from industrial storage to aerospace designs. This article delves into a comprehensive analysis of two tanks initially filled with air at specified conditions, exploring their thermodynamic behavior under various processes and the implications thereof.

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Introduction

Two tanks, designated Tank A and Tank B, are initially filled with air at specified conditions. The initial states, process details, and subsequent transformations of these tanks serve as an exemplary model for studying ideal gas behavior, energy transfer, and thermodynamic principles. Such analyses are crucial for designing safe and efficient storage systems, understanding pressure and temperature changes, and optimizing processes involving gases.

This investigation aims to:

- Analyze the initial conditions of both tanks.
- Explore the thermodynamic processes they undergo.
- Derive relevant parameters such as pressure, temperature, work, and heat transfer.
- Discuss the practical implications of these processes.

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Initial Conditions of the Tanks

Tank Specifications and Initial State

Suppose the initial conditions are as follows:

- Tank A:
- Volume, $V_A = V_1$ (known value)
- Initial pressure, $P_{A1}$
- Initial temperature, $T_{A1}$

- Air behaves as an ideal gas with specific gas constant $R$.

- Tank B:
- Volume, $V_B = V_2$ (known value)
- Initial pressure, $P_{B1}$
- Initial temperature, $T_{B1}$

The initial states are assumed to be uniform and at equilibrium.

Assumed Parameters for Analysis

For a concrete analysis, assume:

- $V_1 = 1.0\, \text{m}^3$, $V_2 = 0.5\, \text{m}^3$
- $P_{A1} = 100\, \text{kPa}$, $T_{A1} = 300\, \text{K}$
- $P_{B1} = 200\, \text{kPa}$, $T_{B1} = 300\, \text{K}$
- Specific gas constant for air, $R = 287\, \text{J/(kg·K)}$

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Thermodynamic Principles Governing the System

Ideal Gas Law

The fundamental relation:

$$
PV = mRT
$$

where:

- $P$ = pressure,
- $V$ = volume,
- $m$ = mass,
- $R$ = specific gas constant,
- $T$ = temperature.

This law allows us to determine the masses of air in each tank initially:

$$
m = \frac{PV}{RT}
$$

### Energy Conservation and Work

Depending on the process (isothermal, adiabatic, isobaric, etc.), the work done, heat transfer, and changes in internal energy can be calculated using standard thermodynamic equations.

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## Analysis of Initial States

### Calculating Initial Masses

- Tank A:

$$
m_A = \frac{P_{A1} V_1}{R T_{A1}} = \frac{100 \times 10^{3} \times 1}{287 \times 300} \approx 1.16\, \text{kg}
$$

- Tank B:

$$
m_B = \frac{200 \times 10^{3} \times 0.5}{287 \times 300} \approx 1.16\, \text{kg}
$$

Interestingly, both tanks contain approximately the same mass of air despite differing initial pressures and volumes.

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## Possible Processes and Their Thermodynamic Impacts

### 1. Connecting the Tanks: Isothermal Mixing

Suppose the tanks are connected via a valve allowing air to flow from one to the other until equilibrium is reached at constant temperature.

Key considerations:

- Since the process is isothermal, internal energy change is zero.
- The final pressure, temperature, and volume are to be determined.
- The process involves work done by the gas and heat transfer with surroundings.

Analysis:

- Total mass:

$$
m_{total} = m_A + m_B \approx 2.32\, \text{kg}
$$

- Total initial volume:

$$
V_{total} = V_1 + V_2 = 1.5\, \text{m}^3
$$

- Final pressure:

$$
P_{final} = \frac{(m_A + m_B) R T}{V_{total}}
$$

Given the initial data, the total initial internal energy remains unchanged, but since the process is isothermal, the final temperature remains at 300 K.

- Final pressure:

$$
P_{final} = \frac{m_{total} R T_{final}}{V_{total}} = \frac{2.32 \times 287 \times 300}{1.5} \approx 133\, \text{kPa}
$$

which is between initial pressures, reflecting the redistribution of air.

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2. Adiabatic Compression or Expansion

If the tanks undergo a process where one tank compresses or expands adiabatically, the relationships involve:

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

where:

- $\gamma$ = specific heat ratio ($\approx 1.4$ for air).

Calculations involve energy conversions, with work and temperature changes governed by:

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

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## Practical Implications and Applications

### Safety Considerations

Understanding the behavior of air in tanks under different processes is essential for preventing overpressure or implosion risks. For example, if the tanks are connected and allowed to equilibrate without control, pressure surges could occur.

### Industrial Storage Optimization

By analyzing thermal and pressure changes, engineers can optimize storage conditions to minimize energy costs, ensure safety, and prolong tank lifespan.

### Thermodynamic Efficiency

Evaluating the work and heat involved in processes like compression, expansion, or mixing aids in designing efficient systems such as pneumatic actuators or compressed air energy storage.

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## Advanced Topics and Further Studies

### Non-Ideal Gas Effects

While ideal gas assumptions simplify analysis, real gases exhibit deviations at high pressures or low temperatures. Incorporating real gas models (e.g., Van der Waals equation) enhances accuracy.

### Transient Processes and Dynamic Modeling

Dynamic simulations accounting for flow rates, heat transfer coefficients, and transient states provide more detailed insights, especially for rapid processes.

### Entropy and Irreversibility

Quantifying entropy changes helps assess the reversibility of processes, guiding design improvements to minimize energy dissipation.

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Conclusion

The thermodynamic analysis of two tanks initially filled with air at specified conditions illustrates fundamental principles such as ideal gas behavior, energy conservation, and process-specific equations. Whether considering isothermal mixing or adiabatic transformations, understanding these processes is vital for safe, efficient, and economical design in various engineering applications.

Further research and more detailed modeling, including real gas effects and transient dynamics, are recommended for practical implementations. This foundational understanding serves as a stepping stone toward mastering complex thermodynamic systems involving gases.

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This article aims to provide a thorough, technical overview suitable for engineering students, professionals, or researchers interested in thermodynamic processes involving gases in contained systems.

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