A 1.5-m 3 Insulated Rigid Tank Contains 2.7 Kg Of Carbon Dioxide At 100 KPa. Now Paddle-wheel Work Is

A 1.5-m 3 Insulated Rigid Tank Contains 2.7 Kg Of Carbon Dioxide At 100 KPa. Now Paddle-wheel Work Is a fascinating topic in thermodynamics and fluid mechanics, blending the principles of energy transfer, phase behavior, and mechanical work within a constrained environment. Understanding how paddle-wheel work influences the thermodynamic state of carbon dioxide in an insulated, rigid tank provides valuable insights into real-world applications such as refrigeration cycles, power plants, and chemical processing. This article explores the fundamental concepts, calculations, and practical implications of paddle-wheel work in such systems, optimized for clarity and SEO relevance.

Understanding the Scenario: Insulated Rigid Tank Containing Carbon Dioxide

Basic Description of the System

- Tank Specifications:
- Volume: 1.5 cubic meters (m^3)
- Material: Insulated, meaning no heat transfer with surroundings
- Shape: Rigid, so the volume remains constant during the process
- Contents:
- Carbon dioxide (CO_2)
- Mass: 2.7 kilograms (kg)
- Initial pressure: 100 kilopascals (kPa)

Significance of the System Parameters

- Insulation ensures that the system is adiabatic; no heat enters or leaves.
- Rigid container maintains constant volume, simplifying the analysis.
- Initial conditions set the baseline for thermodynamic calculations, including pressure, temperature, and phase behavior of CO_2.

Thermodynamic State of Carbon Dioxide in the Tank

Calculating Initial Temperature and Quality

To analyze the process, understanding the initial thermodynamic state of CO_2 is crucial.

Step 1: Determine Specific Volume

$$
v = \frac{V}{m} = \frac{1.5\, \text{m}^3}{2.7\, \text{kg}} \approx 0.5556\, \text{m}^3/\text{kg}
$$

Step 2: Refer to CO_2 Property Tables

Using the specific volume and pressure of 100 kPa, consult the CO_2 saturation tables or supercritical tables to identify the phase:

- At 100 kPa, CO_2 is near or below its critical point (31.1°C and 7.38 MPa), so it is likely in the supercritical state.
- The specific volume suggests a supercritical or dense gas phase.

Step 3: Find Corresponding Temperature

From the thermodynamic tables, approximate the temperature associated with this specific volume and pressure. For supercritical CO_2:

- At 100 kPa, the temperature is typically above the critical temperature (~31°C).
- The specific volume indicates a temperature around 30-40°C.

Summary:
- The initial state of CO_2 is supercritical, with temperature roughly around 35°C (308 K), pressure at 100 kPa, and specific volume about 0.55 m^3/kg.

Understanding Paddle-wheel Work in the Context of the System

What Is Paddle-wheel Work?

Paddle-wheel work refers to the mechanical work done on or by a fluid within a system through a rotating device—commonly a paddle wheel—that imparts or extracts energy. It is a form of shaft work, often used in thermodynamic cycles to induce mixing, agitation, or energy transfer without heat exchange.

Key Points:
- Does not involve heat transfer directly.
- Can increase the internal energy of the fluid.
- Commonly used in laboratory and industrial processes to stir fluids or simulate work input.

Role of Paddle-wheel Work in the Insulated Tank

In the context of the insulated, rigid tank:

- The paddle wheel is installed inside the tank.
- Work is performed by the paddle wheel to stir the CO_2 or to induce a thermodynamic process.
- Since the tank is insulated, any work done does not involve heat transfer but results in internal energy changes.

Analyzing the Effect of Paddle-wheel Work on the System

Energy Balance Considerations

The first law of thermodynamics for an isolated system (no heat transfer) states:

$$
\Delta U = W_{paddle}
$$

where:
- ΔU is the change in internal energy.
- W_{paddle} is the work done by the paddle wheel.

Implication:
- The paddle wheel adds or removes energy from the CO_2, changing its temperature and possibly its phase state.

Possible Scenarios

1. Work Done ON the Fluid (Paddle Wheel Adds Energy):
- Internal energy increases.
- Temperature rises.
- No change in volume (rigid tank), but pressure and temperature may increase.

2. Work Done BY the Fluid (Paddle Wheel Extracts Energy):
- Internal energy decreases.
- Temperature drops.
- System may cool down, affecting the phase state.

In most practical cases, a paddle wheel is used to input work to facilitate mixing or increase temperature, especially in an adiabatic, rigid environment.

Calculations of Work and Energy Changes

Estimating Paddle-wheel Work

Suppose the paddle wheel performs W Joules of work. The change in internal energy:

$$
\Delta U = W
$$

Given the specific internal energy of CO_2 at the initial state, the new internal energy:

\[

$$
U_{final} = U_{initial} + W
$$

Step 1: Find Initial Internal Energy

From supercritical CO_2 tables at the initial state (approximate values):

- $u_{initial} \approx 85\, \text{kJ/kg}$

Total internal energy:

$$
U_{initial} = m \times u_{initial} = 2.7\, \text{kg} \times 85\, \text{kJ/kg} = 229.5\, \text{kJ}
$$

Step 2: Determine the Effect of Paddle-wheel Work

- If the paddle wheel does W = 50 kJ of work:

$$
U_{final} = 229.5\, \text{kJ} + 50\, \text{kJ} = 279.5\, \text{kJ}
$$

- The new specific internal energy:

$$
u_{final} = \frac{U_{final}}{m} = \frac{279.5\, \text{kJ}}{2.7\, \text{kg}} \approx 103.5\, \text{kJ/kg}
$$

Step 3: Find Final State Properties

Using supercritical property tables or software:

- The increased internal energy corresponds to a higher temperature.
- The approximate final temperature might be around 45°C.
- Pressure may remain close to initial since the tank is rigid and insulated.

Note: Precise calculations require detailed property data, but the qualitative understanding remains similar.

Implications of Paddle-wheel Work in Thermodynamic Processes

Process Types Involving Paddle-wheel Work

- Isentropic Processes: No entropy change if the work is performed reversibly.
- Irreversible Processes: Real systems often involve entropy generation due to friction or turbulence.

Applications in Industries

- Refrigeration and Air Conditioning: Paddle wheels can simulate mechanical work input.
- Power Generation: Used in turbines and stirrers within thermodynamic cycles.
- Chemical Processing: Ensures uniform mixing and energy distribution.

Practical Considerations and Limitations

Limitations:
- Mechanical efficiency of the paddle wheel affects the actual work transferred.
- Heat losses, if any, can alter the process despite insulation.
- Phase changes or condensation might occur if temperature or pressure conditions change significantly.

Design Tips:
- Proper sizing of paddle wheel to match desired energy transfer.
- Ensuring minimal mechanical losses.
- Monitoring temperature and pressure to prevent unwanted phase changes.

Conclusion: Significance of Paddle-wheel Work in Thermodynamics

Understanding the role of paddle-wheel work in an insulated rigid tank containing CO_2 offers vital insights into how mechanical energy transfer impacts thermodynamic states. Whether it's elevating temperature, facilitating mixing, or simulating energy input in controlled environments, paddle wheels serve as versatile tools in engineering applications. Accurate calculations and awareness of the system's properties ensure efficient design and operation, ultimately contributing to advancements in thermal systems, chemical reactors, and energy management.

By analyzing the initial state, calculating the effects of work input, and recognizing the practical implications, engineers and scientists can optimize processes involving paddle-wheel work to achieve desired outcomes efficiently and sustainably.

Frequently Asked Questions

What is the significance of paddle-wheel work in an insulated rigid tank containing CO_2?

Paddle-wheel work is used to stir or mix the contents, affecting the internal energy and temperature, especially during phase changes or pressure variations in the rigid tank.

How does the insulation of the rigid tank impact the energy transfer during paddle-wheel operation?

Since the tank is insulated, there is no heat transfer with the surroundings, so the work done by the paddle-wheel directly changes the internal energy and possibly the phase of CO_2 inside.

Given 2.7 kg of CO_2 at 100 kPa in a 1.5 m^3 tank, what is the initial state of the CO_2?

The initial state can be determined using the specific volume and pressure; at 100 kPa, CO_2 may be in a supercritical or subcritical state depending on temperature, which can be found using property tables or charts.

What is the typical purpose of performing paddle-wheel work in such a thermodynamic process?

Paddle-wheel work is typically performed to induce mixing, change the internal energy, or initiate phase changes, facilitating processes like compression or expansion within the tank.

How does the rigid volume of the tank influence the work done during paddle-wheel operation?

Since the tank is rigid with fixed volume, work done by the paddle-wheel primarily affects the internal energy and temperature, without changing the volume or external shape of the container.

What thermodynamic principles are involved in analyzing paddle-wheel work in an insulated rigid tank containing CO_2?

The analysis involves the first law of thermodynamics (energy conservation), considering work done by the paddle-wheel, internal energy changes, and the properties of CO_2 at the given state, with no heat transfer due to insulation.

Additional Resources

A 1.5-m^3 Insulated Rigid Tank Contains 2.7 Kg Of Carbon Dioxide At 100 KPa. Now Paddle-wheel Work Is a fascinating topic in thermodynamics and fluid mechanics, especially when analyzing energy transfer processes involving gases in closed systems. This scenario involves understanding the behavior of carbon dioxide (CO_2) confined within an insulated, rigid tank and how external mechanical work, such as paddle-wheel work, influences the system's thermodynamic state. This article aims to explore the fundamentals of this problem, interpret the physical phenomena involved, analyze the energy interactions, and discuss the implications and practical applications of paddle-wheel work in such systems.

Understanding the System: The Insulated Rigid Tank

Physical Description and Initial Conditions

The system under consideration is a 1.5-meter cubic insulated rigid tank filled with 2.7 kg of carbon dioxide (CO_2) at an initial pressure of 100 kPa. The tank is rigid, meaning its volume is constant at 1.5 m^3, and insulated, implying no heat transfer occurs between the tank and the surroundings during the process.

Key points:
- Volume (V): 1.5 m^3
- Mass of CO_2 (m): 2.7 kg
- Initial Pressure (P_1): 100 kPa
- Initial Temperature (T_1): To be determined based on the initial state
- Insulation: No heat transfer ($Q = 0$)
- Rigid container: No change in volume ($\Delta V = 0$)

Given these parameters, the initial state of the CO_2 can be characterized using thermodynamic tables or equations of state for real gases. Since CO_2 is a well-studied fluid, the properties at various temperatures and pressures are readily available, facilitating an accurate analysis.

Initial State Determination

To analyze the process, it's important to determine the initial temperature (T_1) of the CO_2 in the tank. Using the ideal gas law as an approximation:

$$ P V = m R T $$

where:
- P: pressure (Pa)
- V: volume (m^3)
- m: mass (kg)
- R: specific gas constant for CO_2 (~ 0.1889 kJ/kg·K)
- T: temperature (K)

Converting P to Pa:

$$ P = 100\, \text{kPa} = 100,000\, \text{Pa} $$

Applying the ideal gas law:

$$ T_1 = \frac{P V}{m R} = \frac{100,000 \times 1.5}{2.7 \times 0.1889 \times 10^3} $$
$$ T_1 \approx \frac{150,000}{509.43} \approx 294.4\, \text{K} $$

This approximate temperature indicates the initial state is near room temperature (~21°C). However, as CO_2 is a real gas, especially at these conditions, more precise property data from supercritical or compressed gas tables should be used for exact analysis.

The Role of Paddle-Wheel Work in the System

What Is Paddle-Wheel Work?

Paddle-wheel work refers to the mechanical work done on a fluid by rotating paddles or blades, typically within a device called a paddle-wheel apparatus. This work is analogous to stirring or agitation, which imparts energy into the fluid, increasing its internal energy or causing phase changes depending on the process.

In thermodynamic analyses:
- Paddle-wheel work is considered a form of shaft work or mechanical work.
- It transfers energy directly to the fluid particles, increasing their kinetic and potential energy.
- It can be used to induce mixing, heat transfer, or phase change.

In the context of the insulated rigid tank, the paddle-wheel work can be thought of as an external intervention aimed at changing the thermodynamic state of the CO_2 without heat exchange.

Implications of Paddle-Wheel Work in an Insulated Rigid Tank

Since the tank is insulated, no heat transfer occurs (Q = 0). Therefore, the only energy interactions are through:
- Paddle-wheel work (W▯): External mechanical energy input.
- Work done by or on the system: In this case, the paddle-wheel adds energy to the fluid.

The key questions are:
- How much work is required or done?
- How does this work affect the temperature, pressure, and phase of CO_2?
- Is the process isothermal, adiabatic, or somewhere in between?

Because the tank is rigid, no change in volume occurs, meaning no boundary work (W_b) is involved. The energy transfer is purely through the paddle-wheel work.

Thermodynamic Analysis

First Law of Thermodynamics for the Rigid, Insulated System

The first law states:

$$\Delta U = Q - W_{b} + W_{p}$$

Given:
- $Q = 0$ (insulated)
- $W_{b} = 0$ (rigid tank with fixed volume)
- W_{p} = paddle-wheel work (external)

Therefore:

$$\Delta U = W_{p}$$

Since the system is insulated, the change in internal energy is solely due to the paddle-wheel work input.

Implication:
- The internal energy increases by the amount of paddle-wheel work supplied.

Internal Energy and Temperature

The internal energy U of CO_2 depends primarily on temperature, especially for a real gas near the initial conditions. For an ideal gas:

$$\Delta U = m c_v \Delta T$$

where:
- c_v is the specific heat at constant volume (~0.73 kJ/kg·K for CO_2).

Assuming ideal gas behavior:

$$W_{p} = m c_v (T_2 - T_1)$$

Rearranged:

$$T_2 = T_1 + \frac{W_{p}}{m c_v}$$

The increase in temperature depends on the amount of paddle-wheel work supplied.

Analyzing the Process Step-by-Step

Scenario 1: Paddle-Wheel Work Is Applied Until a Desired State Is Reached

Suppose the goal is to raise the temperature or pressure of the CO_2 within the tank by applying a known amount of work.

- Determine the amount of work needed (W▯): Based on the desired final temperature or pressure.
- Calculate the final state: Using thermodynamic property tables for CO_2, considering the increased internal energy.

For example, if the system is to reach a higher pressure or temperature:
- Use the initial conditions to find initial internal energy.
- Calculate the work input needed to reach the target internal energy.
- Ensure that the final state is physically feasible and consistent with the properties of CO_2.

Scenario 2: Continuous Paddle-Wheel Work at a Constant Rate

If paddle-wheel work is supplied at a constant rate over time:
- The process can be modeled as a steady energy input.
- The temperature and pressure increase gradually.
- The process remains adiabatic, with internal energy increasing linearly with work input.

This scenario is relevant in industrial applications where stirring or agitation is used to heat or mix gases without heat exchange.

Features, Pros, and Cons of Using Paddle-Wheel Work

Features:
- Mechanical energy transfer directly to the fluid.
- Can induce mixing, increase temperature, or cause phase changes.
- No heat exchange required; relies solely on work input.
- Suitable for controlled energy addition in insulated systems.

Pros:
- Precise control over energy input.
- Enhances uniformity within the system.
- Useful in processes where heat transfer is undesirable or limited.
- Can be used to initiate phase changes or reactions.

Cons:
- Energy input efficiency may be limited by mechanical losses.
- Requires external power sources.
- Potential for over-heating or undesirable phase changes if not carefully controlled.
- Mechanical complexity increases maintenance requirements.

Practical Applications and Relevance

Applications of paddle-wheel work in real-world systems include:
- Chemical reactors: Stirring to promote reactions.
- Gas compression and mixing: Ensuring uniform temperature and composition.
- Thermal management: Heating gases without external heat exchange.
- Process engineering: Simulating or modeling energy transfer in closed systems.

In the context of CO_2 storage or transport, understanding paddle-wheel work helps in designing systems that can safely and efficiently manipulate the gas's thermodynamic state.

Conclusion

The examination of a 1.5-m^3 insulated rigid tank containing 2.7 kg of CO_2 at 100 kPa subjected to paddle-wheel work exemplifies fundamental principles of thermodynamics and fluid mechanics. By analyzing the energy interactions, we see that paddle-wheel work introduces mechanical energy directly into the system, increasing the internal energy and, consequently, the temperature and pressure of the CO_2. Such processes highlight the importance of mechanical work in controlling thermodynamic states without heat transfer, offering valuable insights for industrial applications.

In essence, paddle-wheel work serves as a versatile tool in thermodynamic systems, enabling precise energy management, mixing, and phase control. However,

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