A Piston Cylinder Device Contains 1.2 Kg Of Saturated Vapor At 200 C. Heat Is Transferred To The Vapor

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Understanding the thermodynamic behavior of saturated vapor in a piston-cylinder device is fundamental in many engineering applications, including refrigeration, power generation, and heating systems. When heat is transferred to a saturated vapor at a given temperature, it results in a series of phase and property changes that influence the pressure, volume, and internal energy of the system. This article delves into the detailed analysis of such a process, exploring the initial conditions, the effects of heating, the thermodynamic principles involved, and the implications for real-world systems.

Initial Conditions and Properties of the Saturated Vapor

Mass and Temperature

The system contains 1.2 kg of saturated vapor at 200°C. Saturation implies that the vapor is at its boiling point corresponding to the pressure exerted by the system at that temperature. The initial state is characterized by the following:

- Mass (m): 1.2 kg
- Temperature (T_1): 200°C
- Phase: Saturated vapor (steam)

Pressure and Specific Properties

Using steam tables, we can determine the initial pressure and specific properties of saturated vapor at 200°C:

- Saturation Pressure (P_1): Approximately 1.55 MPa (or 15.5 bar)
- Specific Volume (v_1): From saturated vapor tables at 200°C, $v_g \approx 0.1272\ m^3/kg$
- Initial Volume (V_1): $V_1 = m \times v_1 = 1.2\ kg \times 0.1272\ m^3/kg \approx 0.15264\ m^3$
- Internal Energy (u_1): Specific internal energy u_g at 200°C ≈ 2,781 kJ/kg
- Enthalpy (h_1): $h_g \approx 2{,}932$ kJ/kg

These initial properties serve as the baseline for analyzing the subsequent thermal process.

Thermodynamic Process: Heating the Saturated Vapor

Nature of Heat Transfer and Expected Changes

When heat is transferred to the saturated vapor, several phenomena can occur depending on the amount of heat added:

- Sensible Heating: Raising the temperature of the vapor while remaining in the saturated phase.
- Superheating: Adding enough heat to convert the vapor into superheated steam, increasing temperature beyond saturation point at constant pressure.
- Phase Change (if applicable): If the system reaches the critical point or if additional heat causes condensation or further vaporization in different contexts.

In this case, since the vapor starts at saturation and heat is added, the process may lead to superheating beyond the saturation temperature at constant pressure, or a pressure increase if the container is rigid.

Assumptions for Analysis

To simplify the analysis, the following assumptions are typically made:

- The process occurs at constant pressure (if the piston is free to move and the system is open to the atmosphere or a controlled pressure environment).
- No mass enters or leaves the system during heating.
- The process is quasi-static and reversible.
- The piston is ideal, and the process involves no heat losses to the surroundings.

Analysis of the Heating Process

Scenario 1: Heating at Constant Pressure (Piston Free to Move)

If the piston is free to move, the pressure remains constant at $P_1 \approx 1.55$ MPa during heating. The process involves:

- Increasing the temperature from 200°C to a superheated state.
- The specific volume increases from v_1 to v_2, corresponding to the superheated vapor at the final temperature.

Steps to analyze:

1. Determine the final temperature (T_2):
The amount of heat added (Q) relates to the change in internal energy and work done.

2. Calculate the final specific volume (v_2):
Using superheated steam tables at the final temperature, find v_g at T_2.

3. Determine the final state properties:
- Specific internal energy u_2
- Specific enthalpy h_2

4. Calculate the heat added (Q):
$Q = m \times (u_2 - u_1)$ + work done by the system

5. Work done (W):
Since the piston is free, the work $W = P \times \Delta V = P \times (V_2 - V_1)$

Key equations:

- $Q = m \times (u_2 - u_1) + P \times (V_2 - V_1)$

Note:
If the process reaches the saturated vapor point again or continues into superheating depends on the heat input.

Scenario 2: Heating in a Rigid Container

If the piston is fixed, the volume remains constant, and the process involves:

- Heating at constant volume.
- The vapor expands in temperature and internal energy.
- The pressure and specific volume change accordingly.

In this case:

- The final temperature (T_2) can be found from internal energy relations.
- The pressure increases with temperature at constant volume, following the ideal gas law or real steam data.

Thermodynamic Calculations and Data Use

Using Steam Tables

Steam tables are essential tools for thermodynamic calculations involving water and steam. They provide:

- Saturation properties at various temperatures and pressures.
- Superheated vapor properties at specified pressures and temperatures.
- Internal energy, enthalpy, entropy, and specific volume data.

Sample data at 200°C:

Property	Value
Saturation pressure (P_sat)	1.55 MPa
Specific volume (v_g)	0.1272 m^3/kg
Internal energy (u_g)	2781 kJ/kg
Enthalpy (h_g)	2932 kJ/kg

Calculating Final State

Suppose heat is added to raise the vapor temperature to T_2:

- Find v_2 and u_2 at T_2 from superheated steam tables.
- Calculate the change in internal energy: $\Delta u = u_2 - u_1$.
- Find the work done: $W = P \times (V_2 - V_1)$.
- Determine heat transfer: $Q = m \times \Delta u + W$.

Implications and Practical Applications

Energy Efficiency and System Design

Understanding how saturated vapor responds to heat addition is vital for optimizing system efficiency:

- Proper control of heat input can maximize work output.
- Recognizing the transition from saturation to superheating helps prevent equipment damage.
- Accurate property data ensures precise control and safety.

Relevance in Power Plants and Refrigeration

In power plants, steam cycles operate by heating water to produce superheated steam, which then drives turbines. Similarly, in refrigeration cycles, the phase change and heat transfer are fundamental to system operation.

Conclusion

The process of transferring heat to 1.2 kg of saturated vapor at 200°C involves complex thermodynamic phenomena governed by the properties of water and steam. Whether the vapor is heated at constant pressure or volume, the key considerations include the changes in temperature, pressure, specific volume, internal energy, and enthalpy. Accurate data from steam tables, along with sound assumptions, enable engineers to analyze such processes effectively. These insights are critically important in designing efficient thermal systems, ensuring safety, and optimizing performance in a variety of industrial applications.

Summary points:

- Initial state: saturated vapor at 200°C, pressure ≈ 1.55 MPa.
- Heat transfer can lead to superheating or increased pressure, depending on system constraints.
- Use steam tables for property data and thermodynamic calculations.
- System behavior depends on whether the process occurs at constant pressure or volume.
- Practical applications include power generation, refrigeration, and thermal system design.

By understanding these principles, engineers can predict system behavior, optimize operation, and develop more efficient thermal processes in real-world applications.

Frequently Asked Questions

What is the initial state of the vapor inside the piston cylinder device?

The vapor is saturated and has a mass of 1.2 kg at a temperature of 200°C.

How does adding heat to the saturated vapor affect its pressure and volume?

Adding heat increases the vapor's temperature and energy, causing it to become superheated if it exceeds saturation conditions, which generally leads to an increase in pressure and volume until equilibrium is reached.

What phase change occurs when heat is transferred to saturated vapor in a piston cylinder?

If additional heat is supplied, the saturated vapor may undergo superheating, transitioning from saturated vapor to superheated vapor without a phase change, as the phase change (liquid to vapor) has already occurred at saturation.

How can the final state of the vapor be determined after heat transfer?

The final state can be determined by applying the first law of thermodynamics, considering the heat added, work done, and initial conditions, along with property tables or equations of state for the specific refrigerant or working fluid.

Why is it important to know whether the vapor is saturated or superheated in thermodynamic processes?

Because the thermodynamic properties (pressure, specific volume, enthalpy, entropy) differ significantly between saturated and superheated vapor, affecting calculations and system performance analysis.

What safety considerations are involved when transferring heat to a saturated vapor in a piston-cylinder device?

Ensuring controlled heat addition to avoid rapid pressure increases or over-pressurization is critical, as sudden changes can lead to mechanical failure or safety hazards. Proper pressure relief and monitoring are essential.

Additional Resources

Piston Cylinder Device: An In-Depth Analysis of Saturated Vapor Heating Dynamics

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Introduction

In the realm of thermodynamics and mechanical engineering, the piston-cylinder device is a fundamental component used extensively for understanding and controlling phase changes, heat transfer, and work interactions. Today, we delve into a specific scenario involving 1.2 kg of saturated vapor at 200°C within a piston-cylinder apparatus, and examine what happens as heat is transferred to this vapor. This case study offers insights not only into the underlying physics but also into practical applications such as refrigeration cycles, steam engines, and thermal power plants.

Understanding the Initial State: Saturated Vapor at 200°C

The Nature of Saturated Vapor

Saturated vapor exists in a delicate equilibrium with its liquid phase at a specific temperature and pressure. At 200°C, the vapor pressure of water (or any other substance depending on the context) reaches a certain value, corresponding to the saturation conditions.

Key points:

- Mass of vapor: 1.2 kg
- Initial temperature: 200°C
- State: Saturated vapor (meaning the vapor is at the brink of condensation; any additional heat would lead to condensation, and any removal of heat would cause condensation to occur).

Thermodynamic Properties at 200°C

To analyze what happens during heat transfer, we need to understand the properties of saturated vapor at 200°C. These include:

- Saturation pressure (P_s): For water, approximately 1554 kPa (or 15.54 bar).
- Specific volume (v_s): About 0.1274 m^3/kg.
- Specific internal energy (u_s): Approximately 2,650 kJ/kg.
- Specific enthalpy (h_s): Around 2,805 kJ/kg.

(Note: Values are approximate and depend on the thermodynamic tables used.)

Given the mass of 1.2 kg, the initial total internal energy and enthalpy can be calculated:

- Initial internal energy (U): $U = m \times u_s = 1.2\,kg \times 2650\,kJ/kg = 3180\,kJ$
- Initial enthalpy (H): $H = m \times h_s = 1.2\,kg \times 2805\,kJ/kg = 3366\,kJ$

The Process: Transferring Heat to the Vapor

What Does Heat Addition Entail?

When heat is transferred to the saturated vapor in the piston-cylinder device, it initiates a series of thermodynamic transformations. These can be categorized into:

- Superheating: Heating beyond the saturation temperature at constant pressure.
- Phase change progression: Moving from saturated vapor toward superheated vapor.
- Work interactions: Possible piston movement (if applicable) resulting from pressure-volume changes.

The key question is: How does the vapor respond to this heat transfer?

Thermodynamic Analysis of Heat Addition

1. From Saturation to Superheating

Initially, the vapor is saturated at 200°C. When heat is added:

- The vapor absorbs energy, increasing its internal energy and enthalpy.
- The temperature begins to rise above 200°C, transitioning into a superheated vapor region.
- The pressure remains approximately constant if the piston is free to move and the process occurs at constant pressure.

Note: The process can be idealized as a constant pressure heat addition if the piston moves freely, maintaining equilibrium.

2. Quantifying the Heat Required

To determine how much heat must be transferred to reach a certain state, we consult the thermodynamic tables.

Suppose the vapor is heated from saturated vapor at 200°C to a superheated state at, say, 250°C.

Properties at 250°C (superheated vapor):

- Specific enthalpy (h): ~2,983 kJ/kg
- Specific internal energy (u): ~2,650 kJ/kg (approximate, varies with pressure)
- Specific volume (v): ~0.257 m^3/kg

Calculations:

- Enthalpy increase per kg:

$$
\Delta h = h_{superheated} - h_{saturated} = 2983\,kJ/kg - 2805\,kJ/kg = 178\,kJ/kg
$$

- Total heat transferred Q:

$$
Q = m \times \Delta h = 1.2\,kg \times 178\,kJ/kg = 213.6\,kJ
$$

This is the approximate heat needed to raise the vapor from saturated at 200°C to superheated at 250°C.

The Role of the Piston Cylinder: Work and Volume Changes

Mechanical Interactions

The piston-cylinder device not only facilitates heat transfer but also allows for the analysis of work interactions:

- Work done by the system:

$$
W = P \times \Delta V
$$

where ΔV is the change in volume due to heating.

- Initial volume:

$$
V_{initial} = m \times v_s = 1.2\,kg \times 0.1274\,m^3/kg \approx 0.1529\,m^3
$$

- Final volume at 250°C (superheated):

$$
V_{final} = m \times v_{superheated} = 1.2\,kg \times 0.257\,m^3/kg \approx 0.3084\,m^3
$$

- Change in volume:

$$
\Delta V = V_{final} - V_{initial} \approx 0.1555\,m^3
$$

Assuming the piston is free to move and the pressure remains at saturation pressure, the work done by the vapor during heating is:

$$
W = P \times \Delta V \approx 1554\,kPa \times 0.1555\,m^3 \approx 241.4\,kJ
$$

Implication:

- The process involves both heat addition and work done by the vapor.
- The energy balance considers the first law of thermodynamics:

$$
Q_{in} = \Delta U + W
$$

- Rearranged, the heat added accounts for the change in internal energy plus the work done.

Practical Considerations and Applications

1. Efficiency and Control

Understanding how heat transfer affects the phase and energy content of vapor is crucial for designing efficient thermal systems. For example:

- In steam turbines, precise control of vapor superheating improves efficiency.
- In refrigeration systems, the phase change is exploited for heat absorption and rejection.

2. Material and Design Constraints

- The piston must withstand pressure variations.
- Heat transfer rates depend on the device's insulation and heat exchange surfaces.
- Safety considerations involve managing high-pressure saturated and superheated vapors.

3. Operational Scenarios

- Controlled Heating: Achieving desired superheat levels for power generation.
- Rapid Heating: Managing transient effects during startup.
- Phase Change Management: Avoiding undesired condensation or boiling anomalies.

Final Remarks

The scenario of transferring heat to 1.2 kg of saturated vapor at 200°C within a piston-cylinder device encapsulates the core principles of thermodynamics—phase changes, energy conservation, work interactions, and material considerations. It exemplifies how controlled heat addition transforms saturated vapor into a superheated state, with significant implications for power generation, refrigeration, and thermal management.

Understanding these processes enables engineers and designers to optimize systems for efficiency, safety, and performance. As technology advances, mastering the nuances of such heat transfer scenarios will continue to be vital in pushing the boundaries of thermal energy applications.

Summary Points

- The initial state involves 1.2 kg of saturated vapor at 200°C, with known thermodynamic properties.
- Heat transfer leads to superheating, increasing internal energy, enthalpy, and volume.
- Mechanical work is performed during volume expansion at constant pressure.
- Precise property data from thermodynamic tables facilitate accurate energy calculations.
- Practical applications include power plants, refrigeration, and thermal systems, where phase change management is critical.

In essence, the piston-cylinder device and its interaction with saturated vapor exemplify the intricate dance of heat, work, and phase change—fundamental concepts that underpin countless engineering applications.

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