Water At 1 Mpa, 250c Is Expanded In A Piston/ Cylinder To 200 Kpa, X = 1.0 In A Reversible Process Where

Water At 1 Mpa, 250c Is Expanded In A Piston/ Cylinder To 200 Kpa, X = 1.0 In A Reversible Process Where we explore the thermodynamic behavior of water undergoing a controlled expansion process. This scenario involves complex phase changes, thermodynamic properties, and energy interactions, making it a valuable case study for engineering students, professionals, and enthusiasts interested in thermodynamics and steam power cycles.

Introduction to the Process

Understanding the expansion of water from a high-pressure, high-temperature state to a lower pressure state is fundamental in thermodynamics, especially in the context of power plants and refrigeration systems. This process involves a piston-cylinder assembly where water, initially at a superheated state, expands reversibly to a lower pressure, maintaining specific thermodynamic constraints.

The initial state is characterized by:
- Pressure: 1 MPa (megapascal)
- Temperature: 250°C
- Quality (X): 1.0 (indicating saturated vapor)

The final state involves:
- Pressure: 200 kPa
- Quality (X): 1.0 (still saturated vapor at the final pressure)

The process is reversible, meaning it occurs infinitely slowly, with no entropy generation, enabling us to analyze it using ideal thermodynamic relations.

Thermodynamic Properties of Water at Initial and Final States

Accurate determination of properties like enthalpy, entropy, specific volume, and quality is crucial for analyzing the process. These properties are tabulated in steam tables, which provide detailed data at various pressures and temperatures.

Initial State: 1 MPa, 250°C, X=1.0

- Pressure: 1 MPa
- Temperature: 250°C
- Quality (X): 1.0 (saturated vapor)

Using steam tables:

Property	Value
Specific Volume (v_1)	Approx. 0.462 m^3/kg
Enthalpy (h_1)	Approx. 2728 kJ/kg
Entropy (s_1)	Approx. 7.36 kJ/kg·K

(Values are approximate; consult detailed steam tables for precise data)

Final State: 200 kPa, X=1.0

- Pressure: 200 kPa
- Quality (X): 1.0 (saturated vapor at 200 kPa)

From steam tables:

Property	Value
Specific Volume (v_2)	Approx. 0.8857 m^3/kg
Enthalpy (h_2)	Approx. 2670 kJ/kg
Entropy (s_2)	Approx. 7.30 kJ/kg·K

Understanding the Reversible Expansion Process

A reversible process is an idealized process where the system changes occur infinitely slowly, allowing the system to remain in thermodynamic equilibrium throughout.

In this scenario:

- The water is initially superheated or saturated vapor at 1 MPa and 250°C.
- It expands isentropically (constant entropy) from the initial to the final state.
- The process occurs at constant entropy because it is reversible and adiabatic (no heat transfer with surroundings).

Key Assumptions

- Reversibility: No entropy is generated.
- Adiabatic Expansion: No heat transfer to surroundings during the expansion.
- Constant Entropy (s): Since the process is reversible, $s_1 = s_2$.

Analyzing the Process Using Thermodynamic Relations

Given the initial state and the process characteristics, several thermodynamic calculations can be performed:

1. Confirming the Final State

Since the process is isentropic:

- $s_1 = s_2$

From the initial state:

- $s_1 \approx 7.36$ kJ/kg·K

Check if the saturated vapor at 200 kPa has the same entropy:

- $s_{(g@200kPa)} \approx 7.30$ kJ/kg·K

Since s_2 should be equal to s_1, and $s_{(g@200kPa)}$ is slightly less, it suggests that the final state may not be purely saturated vapor at 200 kPa if entropy is conserved.

However, because the initial and final states are both saturated vapor (X=1.0), and the process is isentropic, the actual process likely involves a slight superheated region or the process is approximated assuming ideal conditions.

Calculations in the Reversible Expansion

1. Work Done During Expansion

The work done (W) by the system during a reversible expansion:

$$
W = \int_{V_1}^{V_2} P\, dV
$$

\]

Alternatively, in terms of specific properties:

\[
W = h_1 - h_2
\]

if the process is isentropic and involves only phase change.

Using the enthalpy values:

\[
W = h_1 - h_2 = 2728\, \text{kJ/kg} - 2670\, \text{kJ/kg} = 58\, \text{kJ/kg}
\]

This indicates that approximately 58 kJ of work is done per kilogram of water during expansion.

2. Heat Transfer

Since the process is adiabatic and reversible:

\[
Q = 0
\]

The work done results in a decrease in internal energy, with no heat exchanged with surroundings.

3. Change in Internal Energy

Change in internal energy:

\[
\Delta U = h - PV
\]

But more directly, the change in internal energy per unit mass:

\[
\Delta u = u_2 - u_1
\]

Using steam tables:

Property	Approximate values
Internal energy (u_1)	Approx. 2490 kJ/kg
Internal energy (u_2)	Approx. 2440 kJ/kg

Thus,

$$
\Delta u = 2440\, \text{kJ/kg} - 2490\, \text{kJ/kg} = -50\, \text{kJ/kg}
$$

The negative sign indicates a decrease in internal energy during expansion.

Implications of the Expansion Process

This analysis demonstrates how a water vapor expands reversibly from a high-pressure, high-temperature saturated vapor to a lower-pressure state while doing work, with minimal entropy generation.

Key points include:

- Efficiency: Reversible processes are ideal; real processes involve irreversibilities, leading to entropy increases.
- Work Potential: The work output during such expansion is significant in turbines and power generation.
- Energy Conservation: Total energy remains conserved, with energy transforming from internal energy to work done on surroundings.

Applications in Thermodynamics and Power Cycles

Understanding this process is directly applicable to:

- Steam Turbines: Expansion of high-pressure steam to generate work.
- Rankine Cycle Analysis: Modeling the expansion stroke to evaluate efficiency.
- Refrigeration Cycles: Understanding idealized expansion processes in refrigeration systems.

Summary of Key Takeaways

- Water initially at 1 MPa and 250°C, with X=1.0, undergoes a reversible, adiabatic expansion to 200 kPa.
- The process involves a slight decrease in enthalpy (~58 kJ/kg) and internal energy (~50

kJ/kg).
- The work done during the expansion can be approximated by the difference in enthalpy values.
- Because the process is idealized and reversible, entropy remains constant, providing a basis for thermodynamic calculations.
- Practical systems approximate these ideal processes to optimize energy efficiency and power output.

Conclusion

Analyzing the expansion of water from a high-pressure, high-temperature state to a lower-pressure saturated vapor in a reversible process provides valuable insights into thermodynamic principles. Such understanding assists engineers in designing efficient turbines, engines, and power cycles, ultimately contributing to advancements in energy systems and thermal management. The detailed properties and calculations serve as a foundation for further exploration into real-world applications where irreversibilities and efficiencies are key considerations.

For further reading and detailed property data, consult steam tables, thermodynamics textbooks, and engineering resources specialized in phase change and power cycle analysis.

Frequently Asked Questions

What is the initial state of water at 1 MPa and 250°C in this process?

The initial state of water is a superheated vapor at 1 MPa and 250°C, with an quality (x) of 1.0 indicating it is in the vapor phase.

What does the expansion from 1 MPa to 200 kPa in a reversible process imply about the process type?

It implies a quasi-static, reversible expansion, likely an isentropic or near-isentropic process, where entropy remains constant or changes minimally.

How can the final temperature of water be determined after expansion to 200 kPa with x=1.0?

Since the final state is at 200 kPa with x=1.0, the water is still in the vapor phase, and the

temperature can be found using superheated vapor tables at 200 kPa, matching the specific entropy or quality.

Is the water still in the vapor phase after expansion, given that x=1.0?

Yes, because the quality x=1.0 indicates the water is entirely in the vapor phase after expansion.

What is the significance of the process being reversible in this context?

A reversible process ensures maximum work extraction and no entropy generation, meaning the process is ideal and allows for straightforward thermodynamic analysis using state properties.

How does the change in pressure from 1 MPa to 200 kPa affect the specific volume of water during the expansion?

The specific volume increases as pressure decreases during the expansion, and for x=1.0, it corresponds to the specific volume of saturated vapor at 200 kPa, which is higher than at 1 MPa.

Additional Resources

Water at 1 MPa, 250°C is expanded in a piston-cylinder to 200 kPa, x = 1.0 in a reversible process where

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Introduction

Water, one of the most essential and extensively studied substances in thermodynamics, exhibits a wide array of phase behaviors and properties across various temperature and pressure ranges. Understanding the expansion of water from an initial state of 1 MPa and 250°C to a final pressure of 200 kPa (roughly 2 bar) with a specific quality (x = 1.0) is fundamental in many engineering applications, including power cycles, refrigeration, and process engineering. This detailed review elucidates the thermodynamic principles governing this process, emphasizing the importance of phase behavior, the nature of the process (reversible expansion), and the implications for work, heat transfer, and entropy changes.

Initial State Characterization

Thermodynamic Properties at the Initial State

The initial condition is specified as:

- Pressure (P_1): 1 MPa (10 bar)
- Temperature (T_1): 250°C
- Quality (x_1): Not explicitly specified but typically assumed to be in the superheated region or saturated vapor if not specified. However, since the process mentions x = 1.0 at the final state, and initial state details are given as pressure and temperature, it is essential to determine the phase at initial state.

Using thermodynamic tables or software:

- At P = 1 MPa and T = 250°C:

- The saturation temperature (T_sat) at 1 MPa is approximately 179.9°C.
- Since T_1 = 250°C > T_sat, the water is in a superheated vapor state at the initial condition.

Therefore:

- The initial state is superheated steam at:

- P_1 = 1 MPa
- T_1 = 250°C
- Specific volume, enthalpy, and entropy can be obtained from superheated steam tables.

Properties from superheated steam tables at 1 MPa and 250°C:

Property	Value (approximate)
Specific Volume (v_1)	~0.25704 m^3/kg
Enthalpy (h_1)	~2758 kJ/kg
Entropy (s_1)	~6.59 kJ/kg·K

Final State Characterization

Conditions at the Final State

- Pressure (P_2): 200 kPa (0.2 MPa)

- Quality (x_2): 1.0 (saturated vapor)

Since x = 1.0 indicates saturated vapor, the final state:

- Is saturated vapor at P_2 = 200 kPa.

From saturated steam tables at P = 200 kPa:

Property	Value (approximate)
Saturation temperature (T_sat)	~120.2°C
Specific volume (v_g)	~0.12736 m^3/kg
Enthalpy of vaporization (h_fg)	~2392 kJ/kg
Enthalpy of saturated vapor (h_g)	~2676 kJ/kg

The specific enthalpy at the final state:

- $h_2 = h_g = 2676\ \text{kJ/kg}$

Process Description and Nature

The process involves:

- Expansion from 1 MPa, 250°C (superheated vapor) to 200 kPa saturated vapor.
- The expansion is reversible, implying it proceeds through a quasi-static, idealized process with no entropy generation due to irreversibilities.

This description suggests a reversible isentropic or near-isentropic expansion, but the key is to identify whether entropy remains constant or changes.

Thermodynamic Analysis of the Expansion

Phase Behavior and Quality at Final State

Given x = 1.0 at the final state, the water remains in the vapor phase, but now at a lower pressure and temperature (120.2°C). The specific volume increases from its initial value (superheated vapor) to the saturated vapor specific volume at the final pressure.

Work Done During Expansion

In a piston-cylinder device, the work interaction (W) is:

$$
W = \int_{V_1}^{V_2} P\, dV
$$

or, using specific quantities:

$$
W = \int_{v_1}^{v_2} P\, dm
$$

Since the process is reversible, the pressure varies infinitesimally, and the work can be obtained from the area under the P-v diagram.

- Initial specific volume, v_1: ~0.25704 m^3/kg
- Final specific volume, v_2: ~0.12736 m^3/kg (since saturated vapor at 200 kPa)

Note that for an idealized reversible expansion:

- The process could be approximated as isentropic if entropy remains constant.
- Alternatively, if the process is not adiabatic, the entropy change must be considered.

Entropy Change and Reversibility

Since the process is reversible, the entropy change of the system (Δs) is zero only if the process is adiabatic and reversible. But in expansion work, especially in vapor phases, the entropy can change depending on the process path.

- For an ideal isentropic expansion:

$$
s_1 = s_2
$$

- For a reversible, non-adiabatic process, $s_2 \neq s_1$.

Given the process description—"in a reversible process"—it suggests an idealized expansion with no entropy generation.

Energy and Work Calculations

Assuming a Reversible Isentropic Expansion

- Initial entropy s_1: 6.59 kJ/kg·K
- Final entropy s_2: same as s_1 if idealized

At P = 200 kPa and $s_2 = 6.59\, \text{kJ/kg·K}$, the specific volume of the vapor:

- Since s_2 is higher than the saturated vapor entropy at 200 kPa, the vapor would be superheated if s_2 exceeds s_g.

- But given $s_g \approx 7.07\, \text{kJ/kg·K}$ at 200 kPa, s_2 is less than s_g, indicating the vapor remains saturated.

Therefore, for the final state:

$$
s_2 = s_g = 7.07\, \text{kJ/kg·K}
$$

which is greater than initial s_1, implying entropy increases during the process. Since the process is reversible, entropy of the water-vapor system increases only if heat is added, or it is a phase change.

Implications of the Process Nature

Work and Heat Transfer

- Work done (W): The area under the P-v curve during expansion.
- Heat transfer (Q): For a reversible process, the first law of thermodynamics yields:

$$
\Delta U = Q - W
$$

where:

- ΔU: change in internal energy
- Q: heat added to the system
- W: work done by the system

Since water expands from a superheated vapor to saturated vapor, the internal energy decreases due to the energy spent doing work, with possible heat exchange with surroundings.

Entropy Change

- For a reversible process:

$$
\Delta s_{system} = \frac{Q_{rev}}{T}
$$

- The entropy of the surroundings remains unchanged if the process occurs reversibly and adiabatically.

Practical Engineering Considerations

Understanding such expansion processes is fundamental in designing turbines, nozzles, and other devices where vapor expansion occurs to produce work.

- Power cycles: The Rankine cycle involves vapor expansion in turbines, similar to this process.
- Efficiency implications: Reversible processes represent ideal maximum efficiencies; real processes involve irreversibilities leading to entropy generation and lower efficiencies.

Summary of Key Calculations and Results

Parameter	Initial State	Final State
Pressure	1 MPa	200 kPa
Temperature	250°C	120.2°C (saturated vapor)
Specific volume	~0.25704 m^3/kg	~0.12736 m^3/kg
Enthalpy	~2758 kJ/kg	~2676 kJ/kg
Entropy	~6.59 kJ/kg·K	~7.07 kJ/kg·K (saturated vapor)

Conclusion

This comprehensive analysis of water's expansion from a superheated vapor at 1 MPa and 250°C to saturated vapor

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