Consider 100 Kg Of Steam Initially At 20 Bar And 240 Degrees C As The System. Determine The Change In

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Introduction

Understanding the thermodynamic behavior of steam under varying conditions is fundamental in fields such as power generation, process engineering, and HVAC systems. Analyzing how steam's properties change when subjected to different processes allows engineers to optimize systems for efficiency and safety. In this article, we delve into a typical thermodynamic problem involving 100 kg of steam initially at 20 bar and 240°C, aiming to determine the change in specific properties such as enthalpy, entropy, and internal energy during a process—be it heating, cooling, expansion, or compression.

Thermodynamic Properties of Steam at Initial Conditions

Before analyzing the change, it is essential to understand the initial state of the steam and the key thermodynamic properties involved.

Initial State Parameters

- Mass of Steam (m): 100 kg
- Initial Pressure (P_1): 20 bar (which equals 2 MPa)
- Initial Temperature (T_1): 240°C

Properties of Saturated and Superheated Steam at 20 Bar

Using standard steam tables or Mollier diagrams, we can determine the properties of steam at these conditions.

Property	Value at 20 bar and 240°C	Notes
Specific Enthalpy (h_1)	Approximately 2800 kJ/kg	Superheated steam at 240°C
Specific Entropy (s_1)	Approximately 6.8 kJ/kg·K	Superheated steam
Specific Internal Energy (u_1)	Approximately 2600 kJ/kg	Derived from enthalpy and pressure-volume relations
Specific Volume (v_1)	Around 0.257 m^3/kg	From steam tables

Note: Precise values can vary slightly depending on the steam table source, but these are typical approximations.

Understanding the Process and Its Implications

Determining the change in properties requires knowledge of the process involved. Common processes include:

- Isothermal Expansion or Compression: No change in temperature.
- Isobaric Heating or Cooling: Constant pressure.
- Isochoric Process: Constant volume.
- Adiabatic Expansion or Compression: No heat exchange with surroundings.
- Throttling or Pressure Reduction: Sudden pressure drop with enthalpy remaining constant (Joule-Thomson process).

For illustration, let's consider a typical scenario: an adiabatic expansion of superheated steam from 20 bar and 240°C to a lower pressure. Alternatively, the process could involve heating or cooling at constant pressure. The specific change depends on the process path.

Calculating the Change in Thermodynamic Properties

To comprehensively determine the change, we must analyze:

1. Initial State Properties
2. Final State Properties (dependent on the process)
3. Difference in Properties

Step 1: Define the Process

Suppose the steam undergoes an adiabatic expansion from initial conditions to a final pressure of 8 bar.

- Final Pressure (P_2): 8 bar (0.8 MPa)
- Assumed Process: Adiabatic, reversible expansion (isentropic process)

Step 2: Determine Final State Properties

Using steam tables or Mollier diagrams:

Property	At 8 bar and superheated conditions near the initial temperature
Specific Enthalpy (h_2)	Approximately 2750 kJ/kg
Specific Entropy (s_2)	Approximately 6.8–6.9 kJ/kg·K

Since the process is adiabatic and assumed to be isentropic:

- $s_2 \approx s_1 = 6.8$ kJ/kg·K

Using this, we find the final temperature corresponding to s_2 at 8 bar:

- Approximate temperature (T_2) around 220°C

Step 3: Calculate Final Enthalpy and Internal Energy

- Final Enthalpy (h_2): Approximately 2750 kJ/kg
- Final Internal Energy (u_2): Approximately $h_2 - P_2 \cdot v_2$

From steam tables, at 8 bar:

- Specific Volume (v_2): ~0.37 m^3/kg

Calculate:

$u_2 \approx h_2 - P_2 \cdot v_2$

P_2 = 8 bar = 0.8 MPa

$u_2 \approx$ 2750 kJ/kg - (0.8 MPa × 0.37 m^3/kg)

Note: 1 MPa·m^3 = 1 MJ

$u_2 \approx$ 2750 kJ/kg - 0.8 MJ/kg = 2750 kJ/kg - 800 kJ/kg = 1950 kJ/kg

Step 4: Compute the Total Changes

Total change in enthalpy:

ΔH = m × (h_2 - h_1) = 100 kg × (2750 - 2800) kJ/kg = -5000 kJ

Total change in internal energy:

ΔU = m × (u_2 - u_1) = 100 kg × (1950 - 2600) kJ/kg = -65,000 kJ

Total change in entropy:

ΔS = m × (s_2 - s_1)

Assuming $s_2 \approx$ 6.9 kJ/kg·K:

ΔS = 100 kg × (6.9 - 6.8) kJ/kg·K = 10 kJ/K

Interpreting the Results

The negative change in enthalpy and internal energy indicates that the system has lost energy during the expansion process, which is typical for an adiabatic expansion where work is done by the system.

- Energy Perspective: The system does work on the surroundings, resulting in a decrease in internal energy.
- Entropy Consideration: The slight increase in entropy suggests an irreversible process or slight deviations from ideal isentropic behavior.

Additional Scenarios and Their Impacts

Depending on the process type, the change in properties can differ significantly:

- Isothermal process: Enthalpy change is zero; temperature remains constant.
- Constant pressure heating: Enthalpy increases as heat is added.
- Pressure reduction via throttling: Enthalpy remains constant; entropy increases.

Practical Applications and Significance

Understanding the change in thermodynamic properties of steam is crucial for:

- Designing turbines and expansion devices: To optimize efficiency and power output.
- Calculating work output and heat transfer: For energy balance calculations.
- Ensuring safety and operational stability: By understanding pressure and temperature changes.

- Process optimization: For minimizing energy consumption and maximizing output.

Real-World Example: Steam Turbine Expansion

In power plants, high-pressure superheated steam expands in turbines to generate electricity. Engineers analyze property changes during expansion to maximize efficiency and prevent equipment damage.

Conclusion

Analyzing the change in thermodynamic properties of 100 kg of steam initially at 20 bar and 240°C involves understanding initial conditions, defining the process, and applying steam tables to find final properties. Whether the process involves expansion, compression, heating, or cooling, determining these changes is essential for efficient system design and operation. By comprehensively examining enthalpy, entropy, internal energy, and other properties, engineers can make informed decisions to optimize thermal systems, improve efficiency, and ensure safety.

Key Takeaways:

- Accurate property data from steam tables is vital for thermodynamic calculations.
- The nature of the process (adiabatic, isothermal, etc.) significantly affects property changes.
- Energy and entropy analyses provide insights into system efficiency and irreversibilities.
- Practical applications span across turbines, heat exchangers, and refrigeration systems.

Understanding these principles enables the effective management and utilization of steam in various industrial processes, contributing to energy efficiency and operational excellence.

Frequently Asked Questions

What is the initial specific volume of the steam at 20 bar and 240°C?

Using steam tables, the specific volume at 20 bar and 240°C is approximately 0.127 m^3/kg. Therefore, for 100 kg, the initial volume is about 12.7 m^3.

If the steam undergoes a throttling process at constant enthalpy, what is the final state of the steam?

In throttling, enthalpy remains constant. The final state can be found by equating initial enthalpy to the final state, which may be a mixture of liquid and vapor at a lower pressure, indicating a partial condensation.

How to determine the change in internal energy of the system during the process?

The change in internal energy (ΔU) can be calculated using the relation $\Delta U = Q - W$, where Q is heat transfer and W is work done. For adiabatic or isolated processes, internal energy change can be found from initial and final internal energies obtained from steam tables based on the process specifics.

What is the significance of enthalpy change in analyzing this steam system?

Enthalpy change indicates the heat transfer during the process and helps determine the energy exchange, especially in processes like heating, cooling, or expansion, providing insights into the system's energy efficiency.

How does the specific volume change when steam at 20 bar and 240°C expands or condenses?

The specific volume increases during expansion (if pressure drops at constant enthalpy), indicating volume increase. If condensation occurs, the specific volume decreases as the vapor turns into liquid, approaching the saturated liquid volume.

Additional Resources

Steam System Analysis: Evaluating the Thermodynamic Changes of 100 Kg of Steam at 20 Bar and 240°C

Understanding the behavior of steam under varying conditions is fundamental in numerous industrial applications, from power generation to process industries. In this article, we delve into a detailed thermodynamic analysis of a specific scenario: a system initially containing 100 kg of steam at a pressure of 20 bar and a temperature of 240°C. Our goal is to determine the change in key properties—such as internal energy, enthalpy, entropy, and specific volume—during a process involving this steam. To do this comprehensively, we'll explore the foundational principles, relevant equations, and standard data sources, providing a thorough guide for engineers and students alike.

Understanding the Initial State of the System

Before analyzing the change, it's crucial to precisely define the initial conditions and understand the properties of the steam at this state.

Initial Conditions Recap

- Mass of steam (m): 100 kg
- Initial pressure (P_1): 20 bar (which is 2 MPa)
- Initial temperature (T_1): 240°C

Note: Since the initial temperature is 240°C at 20 bar, the steam is likely in a superheated state, as the saturated vapor temperature at 20 bar is approximately 212°C. To confirm this, we compare the temperature with saturation data.

Thermodynamic State of the Steam at 20 Bar and 240°C

Superheated or Saturated? Determining the State

- Saturation Temperature at 20 bar: ~212°C
- Initial Temperature: 240°C

Since T_1 (240°C) > T_sat at 20 bar, the steam is superheated.

Implication: The properties of superheated steam are different from saturated vapor, requiring the use of superheated steam tables for accurate data.

Properties of Superheated Steam at 20 Bar and 240°C

Using standard superheated steam tables (e.g., from IAPWS or ASHRAE data), the key properties are:

Property	Value at 20 bar & 240°C
Specific Volume (v)	≈ 0.257 m³/kg
Specific Enthalpy (h)	≈ 2792 kJ/kg
Specific Internal Energy (u)	≈ 2554 kJ/kg
Specific Entropy (s)	≈ 6.86 kJ/kg·K

Note: Values are approximate and sourced from standard thermodynamic tables.

Summary:
- Total internal energy: $U_1 = m \times u = 100 \times 2554 = 255,400\, \text{kJ}$
- Total enthalpy: $H_1 = m \times h = 100 \times 2792 = 279,200\, \text{kJ}$
- Total entropy: $S_1 = m \times s = 100 \times 6.86 = 686\, \text{kJ/K}$
- Total volume: $V_1 = m \times v = 100 \times 0.257 = 25.7\, \text{m}^3$

Defining the Process and the Change to be Determined

While the initial state is well-characterized, the problem states "Determine the Change In"—which typically refers to variables such as internal energy, enthalpy, entropy, or volume—during a specific process.

Common process types include:
- Heating or cooling at constant pressure
- Isentropic expansion or compression
- Constant volume or energy processes
- Phase change scenarios (boiling, condensation)

Since the problem is presented without explicit process details, we will consider a typical scenario: a reversible process where the steam undergoes a change in state, possibly expansion or cooling, and we aim to evaluate the change in internal energy, enthalpy, entropy, and volume.

Assumed Process: Expansion at Constant Entropy (Isentropic Expansion)

For illustration, let's assume the steam undergoes an isentropic expansion from the initial state (20 bar, superheated at 240°C) to a lower pressure, say 8 bar. This is a common process in turbines.

Why this assumption?
It allows us to examine how properties change during an idealized, reversible adiabatic expansion—a typical scenario in steam turbines.

Step 1: Find Final Pressure and State

- Final pressure (P_2): 8 bar (0.8 MPa)
- Process type: Isentropic expansion (entropy remains constant)

Step 2: Determine Final Temperature and Properties

- At 8 bar (saturated vapor): saturation temperature ≈ 170°C.
- Since the process is isentropic, the entropy after expansion remains $s_1 = 6.86\, \text{kJ/kg·K}$.

- Check if the final state is superheated or saturated:

- Superheated region: entropy at superheated steam at 8 bar and some temperature can be checked from tables.
- Saturation entropy at 8 bar: approximately 7.05 kJ/kg·K (superheated steam at 8 bar has higher entropy than saturated vapor).

Given that the initial entropy (6.86) is less than the saturated vapor entropy at 8 bar, the final state is superheated—but with entropy less than the saturated vapor, indicating sub-saturation superheated steam.

- Using superheated steam tables at 8 bar:

Property	Approximate value at 8 bar & S ≈ 6.86 kJ/kg·K
Temperature	≈ 190°C
Specific Enthalpy (h_2)	≈ 2780 kJ/kg
Specific Internal Energy (u_2)	≈ 2550 kJ/kg
Specific Volume (v_2)	≈ 0.26 m³/kg

Note: These are approximate and based on interpolated data.

Step 3: Calculate Changes in Properties

Property	Initial	Final	Change (Δ)
Internal Energy (U)	255,400 kJ	100 × 2550 = 255,000 kJ	ΔU ≈ -400 kJ
Enthalpy (H)	279,200 kJ	100 × 2780 = 278,000 kJ	ΔH ≈ -1,200 kJ
Entropy (S)	686 kJ/K	100 × 6.86 ≈ 686 kJ/K	0 (by assumption)
Volume (V)	25.7 m³	100 × 0.26 = 26 m³	ΔV ≈ +0.3 m³

Interpretation:
- The internal energy decreases slightly due to the expansion, as energy is used to do work.
- Enthalpy decreases marginally, consistent with the energy transfer.
- Entropy remains constant (idealized), characteristic of an isentropic process.
- Volume increases due to the reduced pressure and expansion.

Impact of the Change: Practical Considerations

Efficiency & Work Extraction:
The slight decrease in internal energy and enthalpy suggests that the process converts thermal energy into work, which is typical in turbines.

Volume Expansion:
The increase in volume indicates the physical expansion of steam, which must be accommodated in the system's design.

Energy Balance:
In a real system, the work output can be approximated as the difference in enthalpy before and after expansion:

$$
W_\text{out} = m \times (h_1 - h_2) = 100 \times (2792 - 2780) = 1{,}200\, \text{kJ}
$$

This represents the work extracted during the process.

Alternative Process Scenarios and Their Effects

While the above assumes an isentropic expansion, other processes can be considered:

- Constant Pressure Heating or Cooling: Changes in enthalpy and entropy are directly linked to heat transfer.
- Isochoric or Isoenthalpic Processes: These involve volume or internal energy remaining constant, respectively.
- Real-world applications often involve non-idealities, heat losses, and irreversibilities, which modify the thermodynamic changes.

Summary and Final Remarks

This in-depth analysis underscores the importance of accurately determining the properties of steam at various states. Starting from the initial superheated condition at 20 bar and 240°C, we demonstrated how to:

- Confirm the initial state as superheated steam
- Use standard steam tables to extract thermodynamic properties
- Model a typical process (isentropic expansion) to analyze property changes
- Calculate the changes in internal energy, enthalpy, entropy, and volume
- Understand how these changes influence system performance, energy transfer, and efficiency

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