# Steam At 4 Mpa And 350c Is Expanded In An Adiabatic Turbine To 120 Kpa. What Is The Isentropic Efficiency

**Steam At 4 Mpa And 350°C Is Expanded In An Adiabatic Turbine To 120 Kpa. What Is The Isentropic Efficiency?**

This problem involves analyzing the performance of a steam turbine operating under idealized and real conditions. The primary goal is to determine the isentropic efficiency of the turbine based on the given inlet and outlet conditions. To do this, we need to understand the thermodynamic properties of steam at the specified states, calculate the ideal (isentropic) work output, and compare it to the actual work output. This comprehensive analysis requires applying principles of thermodynamics, particularly the first and second laws, and utilizing steam tables or Mollier diagrams for accurate property data.

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## Understanding the Problem and Relevant Concepts

### Definitions and Key Concepts

- Isentropic Process: An idealized, reversible adiabatic process where entropy remains constant. In turbines, it represents the maximum possible work output for given inlet and outlet conditions.

- Actual Process: The real expansion process where irreversibilities (like friction, turbulence) cause entropy to increase, resulting in less work output compared to the isentropic case.

- Isentropic Efficiency ($\eta_{isen}$): Measures how closely the actual turbine approaches the ideal isentropic performance. It is defined as:

$$
\eta_{isen} = \frac{\text{Actual work output}}{\text{Isentropic (ideal) work output}} = \frac{h_1 - h_2}{h_1 - h_{2s}}
$$

where:
- $h_1$: Enthalpy at inlet
- $h_2$: Enthalpy at actual outlet
- $h_{2s}$: Enthalpy at the isentropic outlet (assuming entropy remains constant)

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# Step 1: Gathering Data and Initial Conditions

## Inlet Conditions

- Pressure, $P_1 = 4\, \text{MPa}$
- Temperature, $T_1 = 350^\circ C$

From steam tables for superheated steam at 4 MPa and 350°C:

| Property | Value |
|------------|---------|
| Enthalpy, $h_1$ | Approximately 3124 kJ/kg |
| Entropy, $s_1$ | Approximately 6.75 kJ/kg·K |

(Values are approximate; precise data should be obtained from standard steam tables or Mollier diagrams.)

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## Outlet Conditions

- Pressure, $P_2 = 120\, \text{kPa}$ (or 0.12 MPa)
- The expansion is adiabatic and idealized as isentropic for the purpose of calculating $h_{2s}$.

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# Step 2: Determining the Isentropic Outlet State

## Find $s_2 = s_1$

Since the expansion is assumed isentropic:

$$
s_{2s} = s_1 \approx 6.75\, \text{kJ/kg·K}
$$

At $P_2 = 120\, \text{kPa}$, locate the state on the saturated or superheated steam tables corresponding to $s = 6.75\, \text{kJ/kg·K}$.

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## Locating $h_{2s}$

- At $P_2 = 120\, \text{kPa}$, find the enthalpy corresponding to $s = 6.75\, \text{kJ/kg·K}$.

Possible scenarios:

- If the entropy at the saturation point at 120 kPa is less than 6.75 (which is typical), the expansion is to a superheated state.

- Using the superheated steam tables at 120 kPa, find the enthalpy $h_{2s}$ corresponding to $s = 6.75\, \text{kJ/kg·K}$.

Suppose the data indicates:

| Pressure | $s_{g}$ (saturated vapor entropy) | $h_{g}$ (saturated vapor enthalpy) |
|---|---|---|
| 120 kPa | 7.0 kJ/kg·K | ~2675 kJ/kg |

Since $s_1 = 6.75$, which is slightly less than $s_g$, the expansion results in a wet vapor mixture or superheated steam. Using interpolation or superheated tables, find $h_{2s}$ at $s = 6.75$ and $P=120\, \text{kPa}$.

Assumed approximate value:

$$
h_{2s} \approx 2670\, \text{kJ/kg}
$$

(Actual values should be obtained via detailed steam tables.)

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# Step 3: Calculating Actual Outlet Enthalpy $h_2$

If the actual expansion is known or assumed to be close to the isentropic process, the main difference between actual and ideal work output hinges on the enthalpy difference involving actual entropy. However, without specific data on the actual entropy or enthalpy, we often assume that the actual entropy is slightly higher due to irreversibilities, leading to a different $h_2$.

In many problems, if no data on actual entropy is provided, the efficiency calculation relies solely on the ideal process, and the actual enthalpy at the outlet can be estimated or provided.

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## Step 4: Calculating the Isentropic Efficiency

Using the formula:

$$
\eta_{isen} = \frac{h_1 - h_2}{h_1 - h_{2s}}
$$

- $h_1 \approx 3124\, \text{kJ/kg}$
- $h_{2s} \approx 2670\, \text{kJ/kg}$
- $h_2$: Actual enthalpy at the outlet (if known or estimated)

Example:

Suppose the actual outlet enthalpy $h_2$ is 2700 kJ/kg (due to irreversibilities):

$$
\eta_{isen} = \frac{3124 - 2700}{3124 - 2670} = \frac{424}{454} \approx 0.933 \text{ or } 93.3\%
$$

This indicates a highly efficient turbine with minimal irreversibilities.

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## Step 5: Summary and Final Remarks

### Key Takeaways

- The isentropic efficiency quantifies the deviation from an ideal, reversible expansion process.
- Accurate property data from steam tables is crucial for precise calculations.
- The process involves determining the isentropic outlet enthalpy based on initial entropy and final pressure, then comparing it to the actual enthalpy.
- Real-world efficiencies typically range between 85% and 95%, depending on design and operating conditions.

### Additional Considerations

- The actual expansion can be affected by factors like blade friction, turbulence, and mechanical losses.
- For more precise calculations, detailed steam tables or software tools should be used to extract enthalpy and entropy values.
- If the problem provides actual outlet enthalpy or entropy data, the efficiency can be computed directly; otherwise, assumptions or estimations are necessary.

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# Conclusion

The isentropic efficiency of a steam turbine expanding from 4 MPa and 350°C to 120 kPa can be estimated by comparing the actual work output with the maximum possible (isentropic) work output. Using thermodynamic property data from steam tables, we determine the enthalpy at the initial state, the isentropic outlet state, and, if available, the actual outlet state. The resulting efficiency provides insight into the turbine's performance and the impact of irreversibilities. Such analyses are fundamental in thermodynamics for designing, evaluating, and optimizing turbine systems in power plants and other applications.

# Frequently Asked Questions

## What is the process involved in expanding steam from 4 MPa and 350°C to 120 kPa in an adiabatic turbine?

The process involves an adiabatic (no heat transfer) expansion of superheated steam through a turbine, where the steam does work as it expands from the initial high pressure and temperature to the lower pressure, ideally at constant entropy.

## How do you calculate the isentropic efficiency of a turbine in this process?

The isentropic efficiency is calculated as the ratio of the actual work output to the ideal (isentropic) work output, using enthalpy values from steam tables at the respective states: $\eta = (h_1 - h_{2\_actual}) / (h_1 - h_{2\_ideal})$.

## What steam properties are needed to determine the isentropic efficiency in this scenario?

You need the initial enthalpy and entropy at 4 MPa and 350°C, and the enthalpy at the turbine exit for both actual and ideal (isentropic) processes at 120 kPa, obtainable from steam tables.

## Why is the process considered adiabatic in this turbine expansion?

The process is considered adiabatic because it assumes no heat transfer occurs between the steam and surroundings during expansion, which is a common approximation for turbine operation.

## How does the temperature and pressure change during the

## expansion in an ideal adiabatic turbine?

In an ideal adiabatic (isentropic) expansion, the temperature and pressure decrease from the initial state (4 MPa, 350°C) to the final state (120 kPa), with entropy remaining constant.

## What role do steam tables play in determining the isentropic efficiency of the turbine?

Steam tables provide the thermodynamic properties (enthalpy, entropy) at various states, enabling calculation of actual and ideal enthalpy changes needed to compute the efficiency.

## What assumptions are typically made when calculating isentropic efficiency for turbines?

Assumptions include ideal adiabatic (no heat transfer), reversible expansion (no entropy generation), and steady-state operation, simplifying calculations to idealized thermodynamic processes.

## If the actual enthalpy at turbine exit is known, how can you find the isentropic efficiency?

Calculate the ideal enthalpy at the exit based on initial entropy and the final pressure (isentropic process), then use $\eta = (h_1 - h_{2\_actual}) / (h_1 - h_{2\_ideal})$ to find the efficiency.

## What is the typical range of isentropic efficiencies for steam turbines operating under these conditions?

Typical isentropic efficiencies for steam turbines range from about 85% to 95%, depending on design, size, and operating conditions.

# Additional Resources

Steam at 4 MPa and 350°C is expanded in an adiabatic turbine to 120 kPa. What is the isentropic efficiency? This question delves into the core principles of thermodynamics and the operation of turbines, which are fundamental components in power generation and various industrial processes. Understanding how to determine the isentropic efficiency of a turbine based on the given conditions provides valuable insights into turbine performance, energy conversion efficiency, and system optimization. In this article, we will comprehensively explore the concept of adiabatic expansion, the thermodynamic principles involved, step-by-step calculations, and the significance of isentropic efficiency in practical applications.

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# Understanding the Basics of Turbine Expansion

A turbine operates by converting the energy stored in a high-pressure, high-temperature fluid—commonly steam—into mechanical work. When steam expands through a turbine, its pressure and temperature decrease, and this energy conversion process is crucial for power generation systems such as steam turbines in thermal power plants.

Adiabatic Process:
In an idealized adiabatic process, there is no heat transfer to or from the working fluid during expansion. This assumption simplifies the analysis and allows us to focus solely on the conversion of internal energy into work, governed by the principles of thermodynamics.

Key Parameters in the Problem:

- Initial pressure, $P_1 = 4\,MPa$
- Initial temperature, $T_1 = 350^\circ C$
- Final pressure, $P_2 = 120\,kPa$
- Process type: adiabatic expansion
- Objective: Determine the isentropic efficiency of the turbine

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# Thermodynamic Foundations

To analyze the turbine process, we need to understand the thermodynamic properties of steam and how they change during expansion.

## Steam Properties and Data Sources

Steam properties are typically obtained from steam tables or Mollier diagrams. These provide the enthalpy ($h$), entropy ($s$), and other properties at specific pressures and temperatures. For accurate calculations, referencing standard steam tables or software like EES (Engineering Equation Solver) is recommended.

# Ideal vs. Actual Expansion

- Isentropic (ideal) expansion:
The process occurs at constant entropy ($s_1 = s_2^{\text{isentropic}}$). The enthalpy after expansion, $h_2^{\text{isentropic}}$, is determined from the initial entropy and the final pressure.

- Actual expansion:
The real process involves entropy increase due to irreversibilities, resulting in a higher exit enthalpy $h_2^{\text{actual}}$, which leads to less work output compared to the ideal case.

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# Step-by-Step Calculation of Isentropic Efficiency

The isentropic efficiency ($\eta_{isen}$) of a turbine is given by:

$$
\eta_{isen} = \frac{\text{Work output in actual process}}{\text{Work output in ideal (isentropic) process}} = \frac{h_1 - h_{2,\text{actual}}}{h_1 - h_{2,\text{isentropic}}}
$$

To find $\eta_{isen}$, follow these steps:

1. Determine initial enthalpy $h_1$.
2. Find the entropy at the initial state $s_1$.
3. Calculate the isentropic exit enthalpy $h_{2,\text{isentropic}}$ at $P_2 = 120\,kPa$ with $s_2^{\text{isentropic}} = s_1$.
4. Estimate the actual enthalpy $h_{2,\text{actual}}$.
Typically, this involves knowing the actual entropy after expansion, which can be derived if the actual entropy increase is known or assumed.

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## Calculating Initial State Properties

Using the steam tables:

- At 4 MPa and 350°C:

| Property | Value |
|------------|---------|
| Enthalpy, $h_1$ | Approximately 3120 kJ/kg |
| Entropy, $s_1$ | Approximately 6.8 kJ/kg·K |

(Note: Values are approximate; exact numbers should be obtained from detailed steam tables.)

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## Determining the Isentropic Exit State

- At 120 kPa (or 0.12 MPa), find the saturation properties:

| Property | Saturation Temperature | Enthalpy of vaporization, $h_{fg}$ | Saturated liquid enthalpy, $h_f$ | Saturated vapor enthalpy, $h_g$ |
|------------|-------------------------|------------------------------------|---------------------------------|-----------------------------|
| At 120 kPa | About 59°C | Approximately 2400 kJ/kg | $h_f \approx 340$ kJ/kg | $h_g \approx 2720$ kJ/kg |

Since the initial state is superheated at 350°C, and the pressure is 120 kPa, the entropy at the initial state, $s_1$, is higher than that of saturated vapor at 120 kPa, so the isentropic process involves superheated steam at the final pressure.

- Find $h_{2,\text{isentropic}}$:
Using the entropy $s_1 \approx 6.8$ kJ/kg·K at $P_2 = 120\,kPa$, locate the enthalpy corresponding to this entropy in the superheated steam tables. Suppose it corresponds to approximately 2800 kJ/kg.

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## Estimating the Actual Enthalpy and Efficiency

- Assume the actual entropy after expansion increases slightly due to irreversibilities:
$s_2^{\text{actual}} = s_1 + \Delta s$

- For typical turbines, $\Delta s$ is small; assuming a value such as 0.05–0.1 kJ/kg·K, then:

$$
s_2^{\text{actual}} \approx 6.8 + 0.1 = 6.9\, \text{kJ/kg·K}
$$

- Find the actual enthalpy $h_{2,\text{actual}}$ corresponding to $s_2^{\text{actual}}$ at $P_2=120\,kPa$, which might be approximately 2820 kJ/kg.

- Calculate the work outputs:

$$
W_{isentropic} = h_1 - h_{2,\text{isentropic}} \approx 3120 - 2800 = 320\, \text{kJ/kg}
$$

$$
W_{actual} = h_1 - h_{2,\text{actual}} \approx 3120 - 2820 = 300\, \text{kJ/kg}
$$

- Determine isentropic efficiency:

$$
\eta_{isen} = \frac{W_{actual}}{W_{isentropic}} = \frac{300}{320} \approx 0.9375 \text{ or } 93.75\%
$$

This high efficiency indicates a well-performing turbine with minimal irreversible losses.

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# Significance of Isentropic Efficiency in Turbine Performance

Understanding and calculating the isentropic efficiency is vital for several reasons:

- Performance Evaluation:
It quantifies how close the actual turbine performance is to ideal conditions, highlighting areas for improvement.

- Design Optimization:
Engineers can optimize materials, blade design, and operating conditions to maximize efficiency.

- Economic Impact:
Higher efficiencies translate to better energy utilization, lower fuel costs, and reduced emissions.

- Maintenance and Reliability:
Efficiency metrics help in predictive maintenance and detecting performance degradation over time.

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# Features and Pros/Cons of Turbine Efficiency Analysis

Features:

- Incorporates real-world irreversibilities
- Uses steam properties for accurate modeling
- Essential for power plant performance assessment
- Guides design improvements

Pros:

- Provides a clear measure of turbine performance
- Helps in comparing different turbines or operation conditions
- Facilitates energy audits and optimization

Cons:

- Requires detailed property data, which may be complex to obtain
- Assumes idealized adiabatic conditions, neglecting heat losses
- Actual efficiencies may vary with load, temperature, and maintenance

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## Conclusion

Determining the isentropic efficiency of a turbine expanding steam from 4 MPa and 350°C to 120 kPa involves understanding thermodynamic principles, leveraging steam tables, and performing precise calculations. The process highlights the importance of idealized versus actual performance, emphasizing how irreversibilities affect energy conversion. Accurate efficiency calculations are crucial for optimizing turbine operation, improving energy systems, and reducing operational costs. As power generation technologies evolve, mastery of such thermodynamic analyses remains fundamental for engineers and researchers aiming to design more efficient and sustainable energy systems.

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