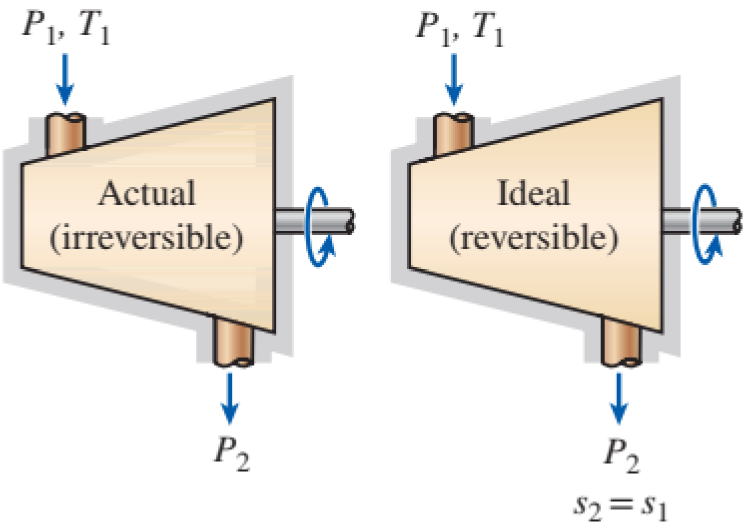
ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES

- Many steady-flow devices (E.g. Turbines, Nozzles, compressors, pumps etc) are intended to operate under adiabatic conditions.
- Therefore, the model process for these devices should be an adiabatic one.
- Furthermore, an ideal process should involve no irreversibilities since the effect of irreversibilities is always to downgrade the performance of engineering devices.
- Thus, the ideal process that can serve as a suitable model for adiabatic steady-flow devices is the *isentropic* process



The isentropic process involves no irreversibilities and serves as the ideal process for adiabatic devices.

Isentropic efficiency is a measure of the deviation of actual processes from the corresponding isentropic process for the engineering devices.

Isentropic Efficiency of Turbines

- For a turbine under steady operation, the inlet state of the working fluid and the exhaust pressure are fixed.
- Therefore, the ideal process for an adiabatic turbine is an isentropic process between the inlet state and the exhaust pressure.

Isentropic efficiency of a turbine is defined as *the ratio of the actual work output of the turbine to the work output that would be achieved if the process between the inlet state and the exit pressure were isentropic*

$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w_a}{w_s}$$

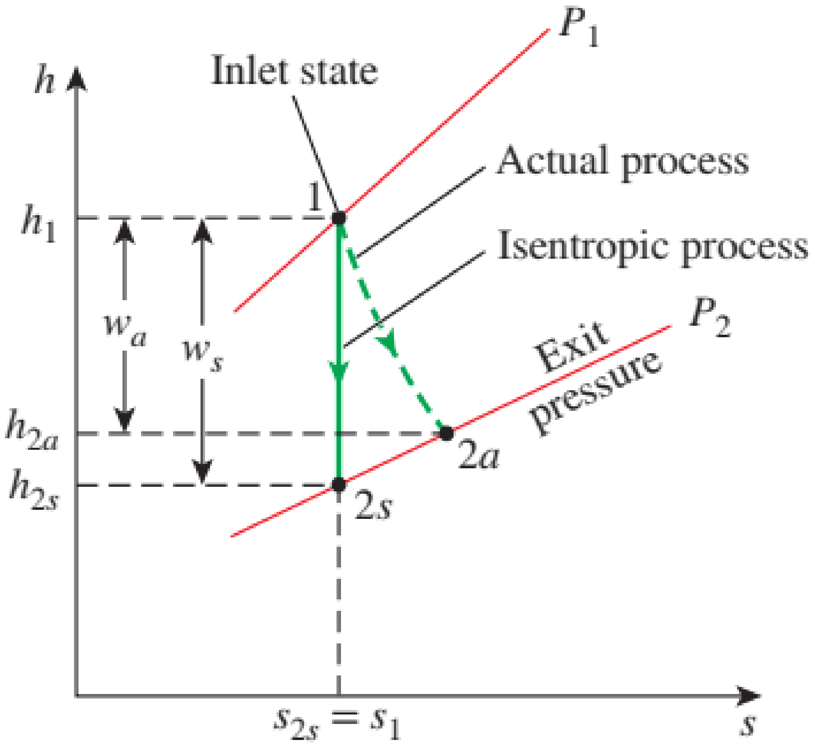


FIGURE 8–9

The *h-s* diagram for the actual and isentropic processes of an adiabatic turbine.

- The changes in kinetic and potential energies associated with a fluid stream flowing through a turbine are small relative to the change in enthalpy and can be neglected.
- Then, the work output of an adiabatic turbine simply becomes the change in enthalpy

$$\eta_T \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

Isentropic Efficiencies of Compressors and Pumps

isentropic efficiency of a compressor is defined as *the ratio of the work input required to raise the pressure of a gas to a specified value in an isentropic manner to the actual work input*

$$\eta_C = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}} = \frac{w_s}{w_a}$$

When the changes in kinetic and potential energies of the gas being compressed are negligible, the work input to an adiabatic compressor becomes equal to the change in enthalpy

$$\eta_C \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

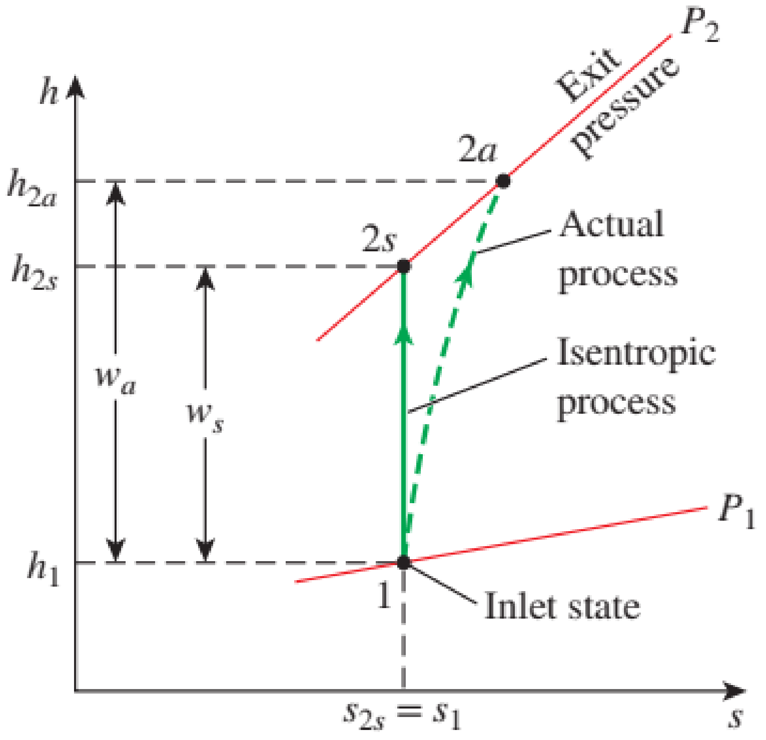


FIGURE 8–11
The h-s diagram of the actual and isentropic processes of an adiabatic compressor.

Isentropic Efficiency of Nozzles

isentropic efficiency of a nozzle is defined as *the ratio of the actual kinetic energy of the fluid at the nozzle exit to the kinetic energy value at the exit of an isentropic nozzle for the same inlet state and exit pressure*

$$\eta_N = \frac{\text{Actual KE at nozzle exit}}{\text{Isentropic KE at nozzle exit}} = \frac{V_{2a}^2}{V_{2s}^2}$$

the energy balance for this steady-flow nozzle reduces to

$$h_1 = h_{2a} + \frac{V_{2a}^2}{2}$$

the isentropic efficiency of the nozzle can be expressed in terms of enthalpies as

$$\eta_N \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

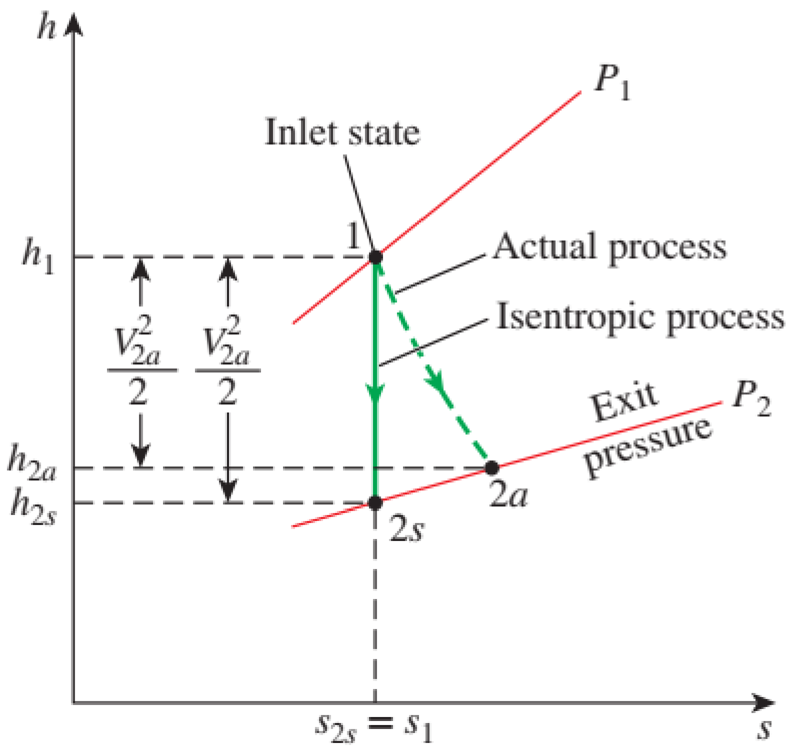


FIGURE 8–14
The *h-s* diagram of the actual and isentropic processes of an adiabatic nozzle.

ENTROPY BALANCE FOR CLOSED SYSTEMS

A closed system involves *no mass flow* across its boundaries, and its entropy change is simply the difference between the initial and final entropies of the system.

The entropy change of a closed system during a process is equal to the sum of the net entropy transferred through the system boundary by heat transfer and the entropy generated within the system boundaries.

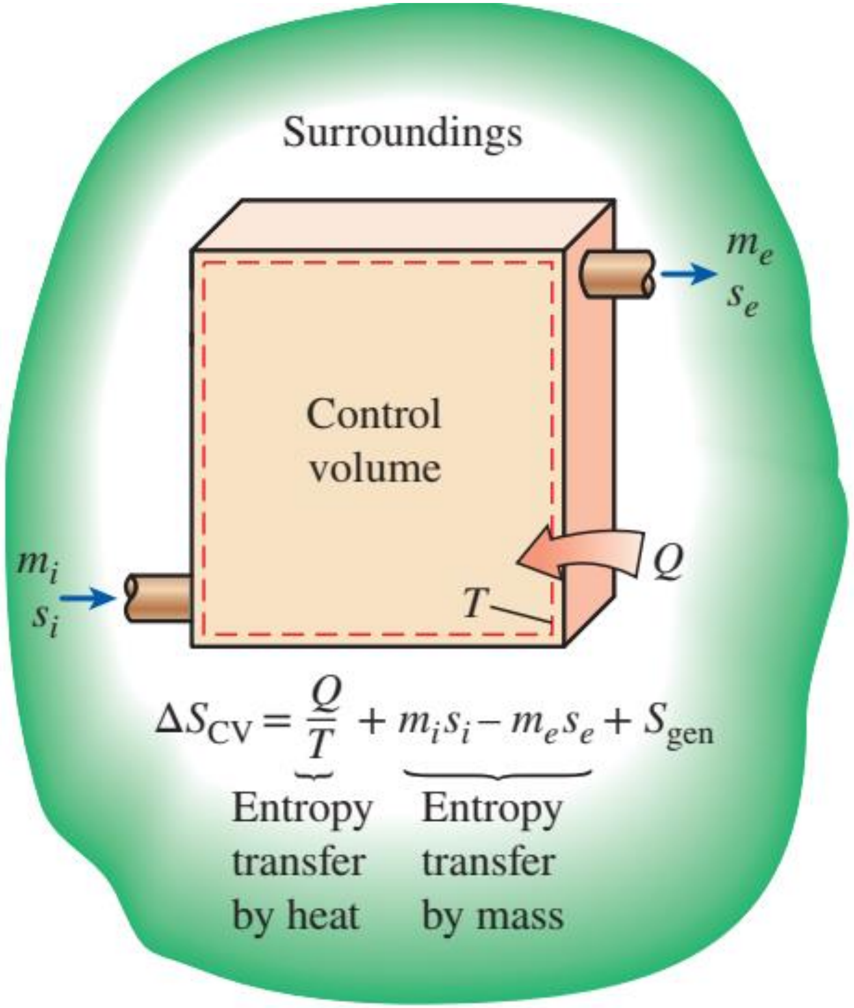
$$\sum \frac{Q_k}{T_k} + S_{\text{gen}} = \Delta S_{\text{system}} = S_2 - S_1$$

ENTROPY BALANCE FOR CONTROL VOLUMES

The entropy of a control volume changes as a result of mass flow as well as heat transfer

The rate of entropy change within the control volume during a process is equal to the sum of the rate of entropy transfer through the control volume boundary by heat transfer, the net rate of entropy transfer into the control volume by mass flow, and the rate of entropy generation within the boundaries of the control volume as a result of irreversibilities.

$$\sum\frac{\dot{Q}_k}{T_k} + \sum\dot{m}_i s_i - \sum\dot{m}_e s_e + \dot{S}_{\text{gen}} = dS_{\text{CV}}/dt$$



For *single-stream* (one inlet and one exit) steady-flow devices, the entropy balance relation simplifies to

$$\dot{S}_{\text{gen}} = \dot{m}(s_e - s_i) - \sum\frac{\dot{Q}_k}{T_k}$$