ME-251: Thermodynamics and energetics I
Second Law IV

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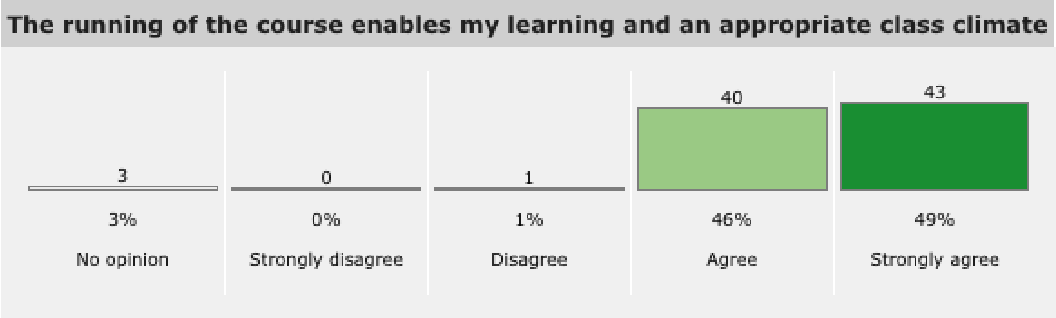
2025 Fall Semester

Photo Credit: Trougnouf

Your Indicative Feedback

Year	2025-2026
Course	Thermodynamics and energetics I
Questionnaire	Indicative feedback of teaching (since 2022-2023)
Nb Registered	345
Nb Answered	87



- Structure and pacing
- Use of CoolProp for exercise problems
- Other improvement suggestions (freezing previous slides, class noise level, writing clarity)

Last Time

- Entropy balance for closed systems

Entropy Balance for Closed Systems

change in the amount of entropy contained within the system during some time interval	=	net amount of entropy transferred in across the system boundary during the time interval	+	amount of entropy produced within the system during the time interval

$$S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma \qquad \sigma \geq 0$$

entropy change — entropy transfer — entropy production

Entropy balance is a re-interpretation of Clausius inequality

Entropy Statement of Second Law

Entropy production **is non-negative for any system**

For an isolated system (closed system with no heat transfer), entropy can only go up or stay the same

Internally reversible system: $\sigma = 0$

Closed System Entropy Rate Balance

$$\frac{dS}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{\sigma}$$

dS/dt: rate of change of system entropy

$\frac{\dot{Q}_j}{T_j}$: entropy transfer transfer rate through the part of boundary that has temperature T_j

$\dot{\sigma}$: entropy generation rate in the system

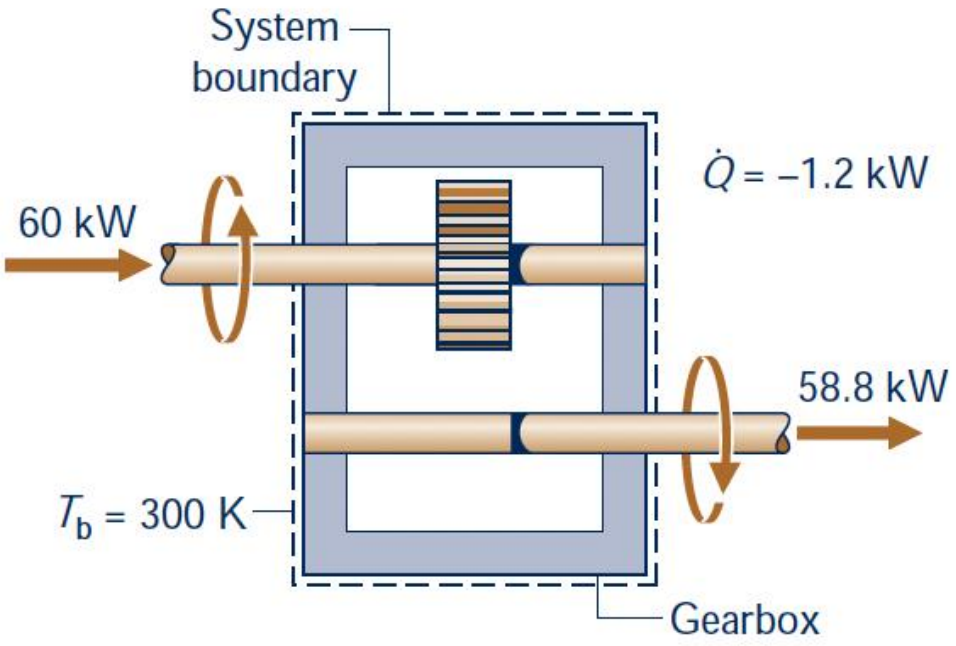
Retrieving Entropy Data

Typical tabulated entropy values: a certain reference state is chosen (for water, the entropy of saturated liquid at 0.01 °C is set to zero); **only entropy difference has physical meanings in the tabulated data**

In two-phase region, we use the quality *x* in the same way as we retrieve *u, h, v, etc.*

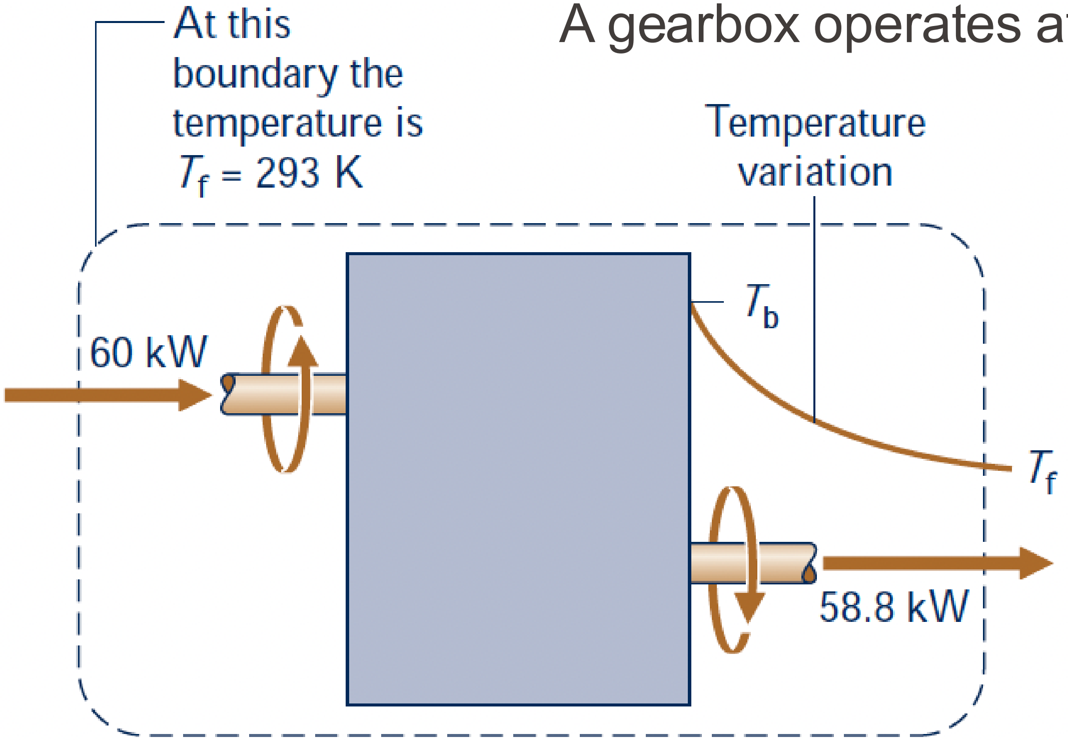
Example 6.4

A gearbox operates at steady state



Evaluate the entropy production rate $\dot{\sigma}_g$ inside the gearbox

Example 6.4



A gearbox operates at steady state

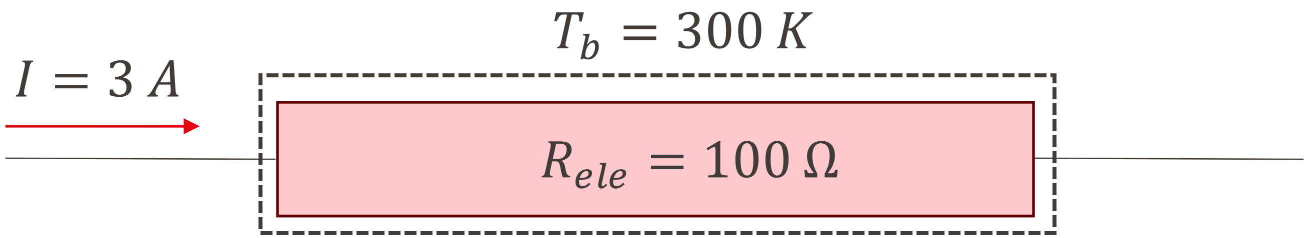
Evaluate the entropy production rate $\dot{\sigma}_s$ for an enlarged system consisting of the gearbox and enough of its surroundings such that the new boundary has temperature T_f = 293 K

Joule Heating

Scan the QR code with your device
Or go to **echo360poll.eu**

Enter Code

luepfl



Assuming steady-state, what is the entropy generation rate in the CV drawn around the resistor

A. 0 [W/K]

B. 1 [W/K]

C. 3 [W/K]

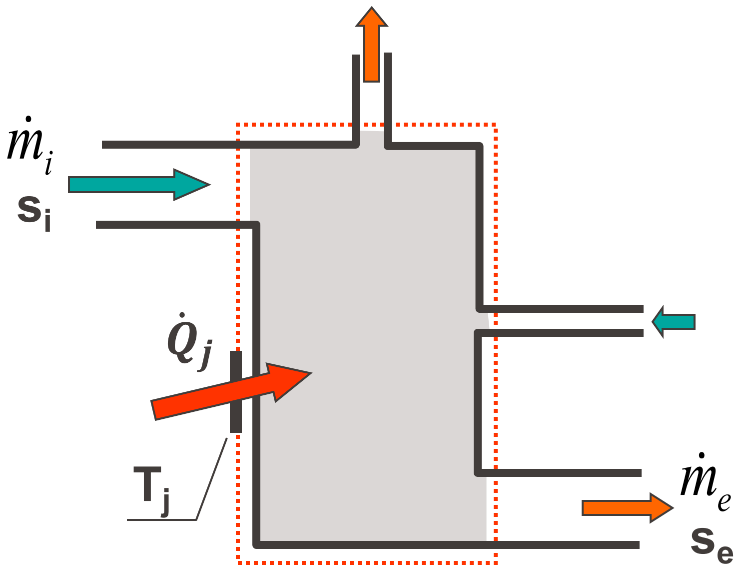
D. I don't know

ILOs Today

- Open system entropy rate balance
- Isentropic process and isentropic efficiency
- Internally reversible, steady-state flow processes

- Reading: 6.9-6.13

Open System Entropy Rate Balance



$$\sum_i \dot{m}_i = \sum_e \dot{m}_e$$

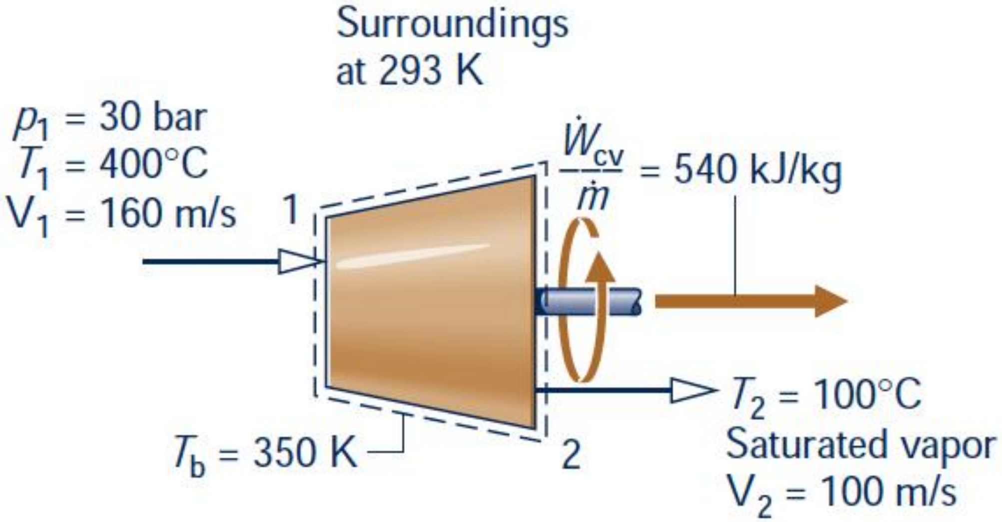
$$\frac{dE_{cv}}{dt} = \sum_j \dot{Q}_j - \dot{W}_{cv} + \sum_i \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + g z_i \right) - \sum_e \dot{m}_e \left(h_e + \frac{\vec{V}_e^2}{2} + g z_e \right)$$

Steady State

$$\frac{dS_{cv}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}_{cv}$$

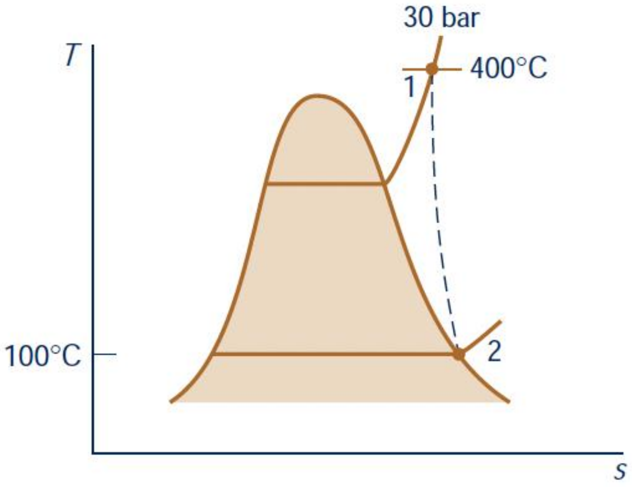
Example 6.6

1 bar = 10^5 Pa

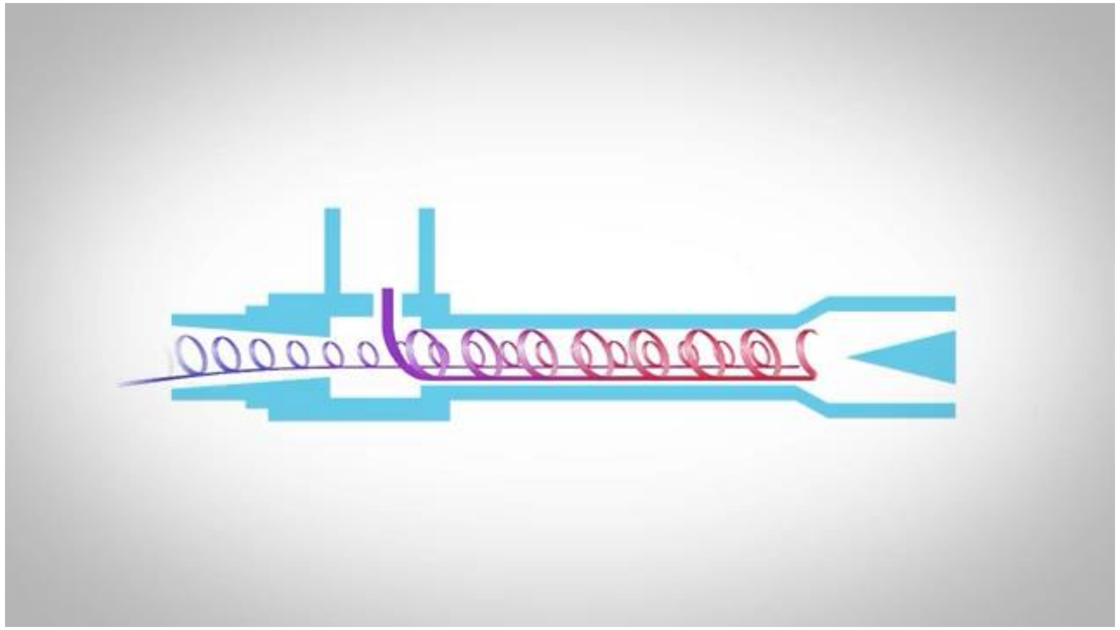


Steam expands through a turbine at steady state (change of potential energy ignored)

Determine the entropy generation per kg of steam flowing through turbine $\frac{\dot{\sigma}_{cv}}{\dot{m}}$



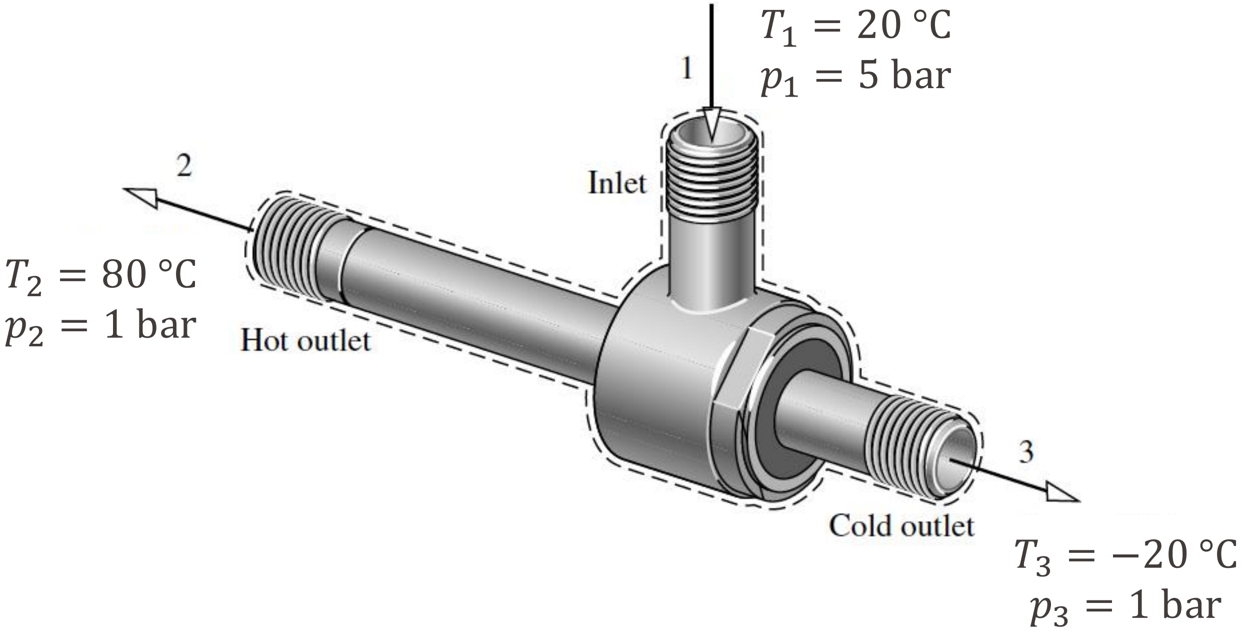
Vortex Tube



https://www.youtube.com/watch?v=ZpMe193KoHM

https://www.youtube.com/watch?v=Q_y2FvH2DHE

Example 6.7 (number adjusted)



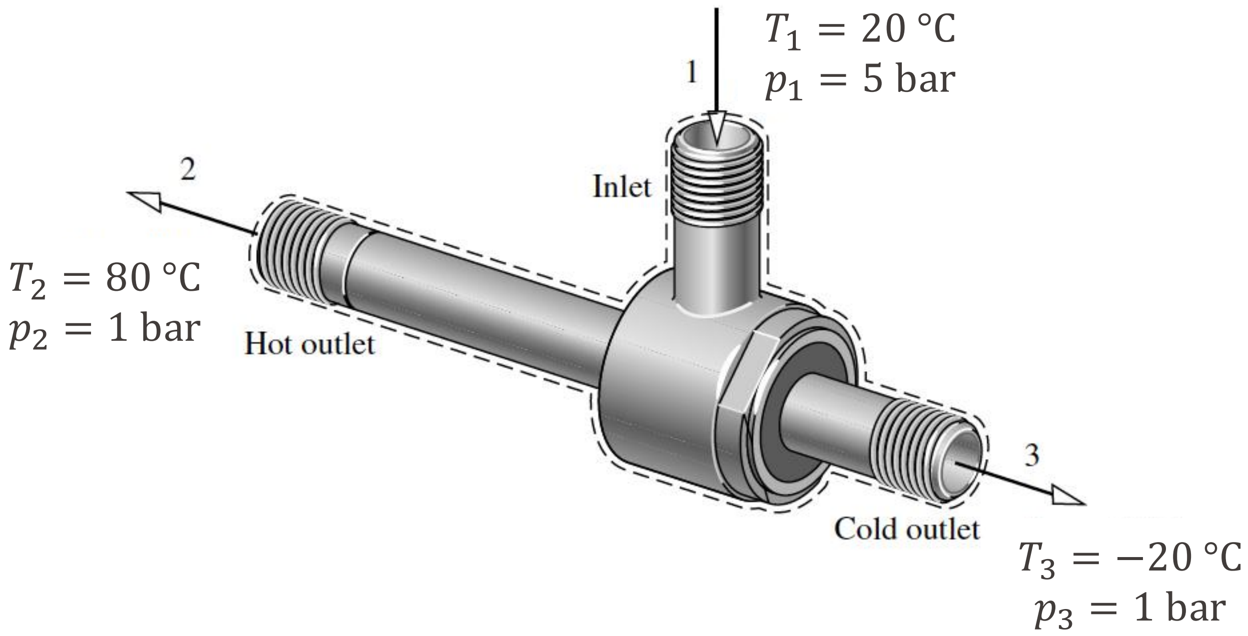
Evaluate this invention claim

A device producing hot and cold stream of air flows without additional external heat or work transfer at a steady state?

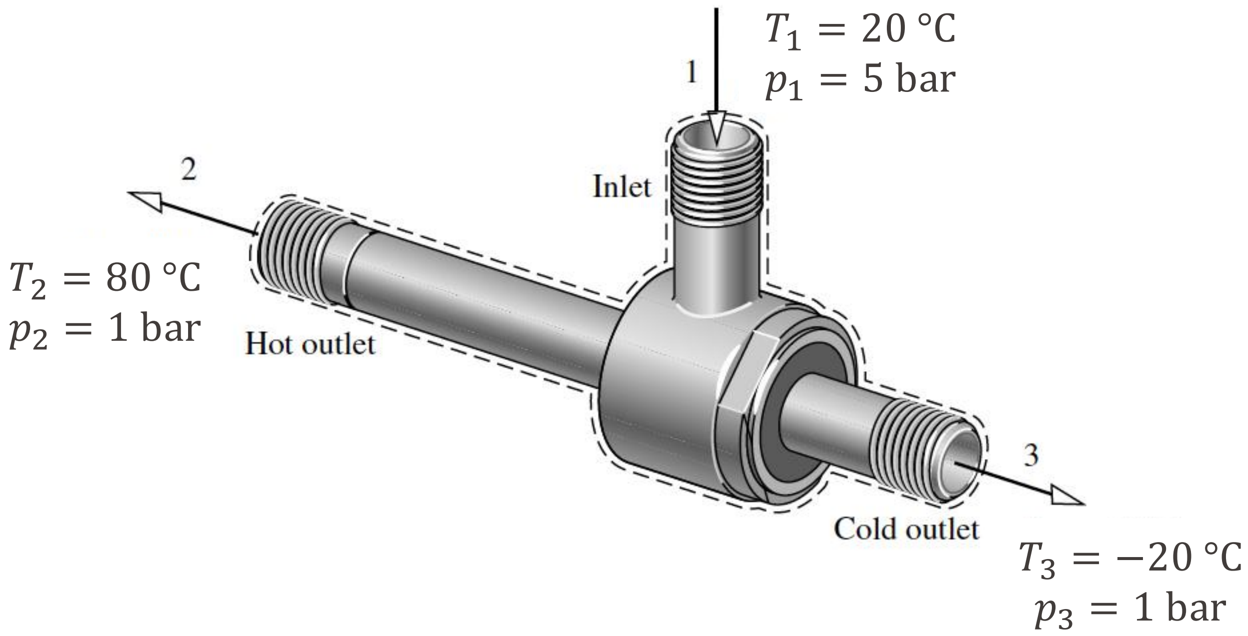
Model air as perfect gas with $c_p = 3.5R$

Does this invention violate 2nd law?

Example 6.7


1
$T_1 = 20\ °C$
$p_1 = 5\ \text{bar}$
Inlet
2
$T_2 = 80\ °C$
$p_2 = 1\ \text{bar}$
Hot outlet
3
Cold outlet
$T_3 = -20\ °C$
$p_3 = 1\ \text{bar}$

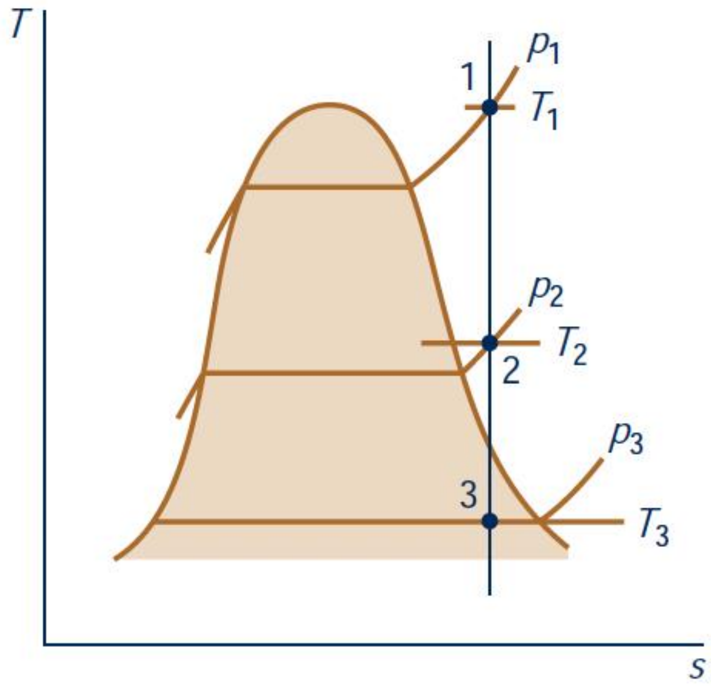
Example 6.7



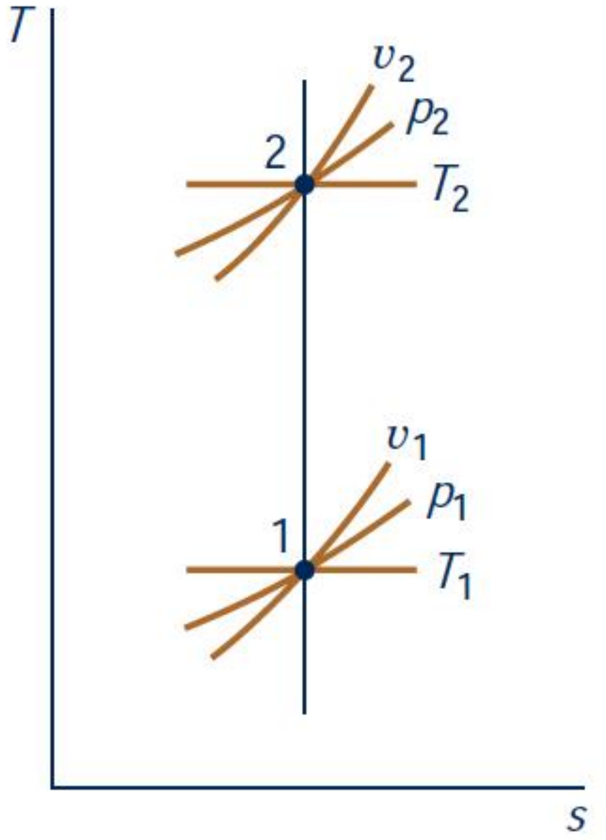
How is this possible for a steady-state device to “de-mix” air flows without additional external heat or work transfer ?

Isentropic Processes

Isentropic means constant entropy (typically constant specific entropy)

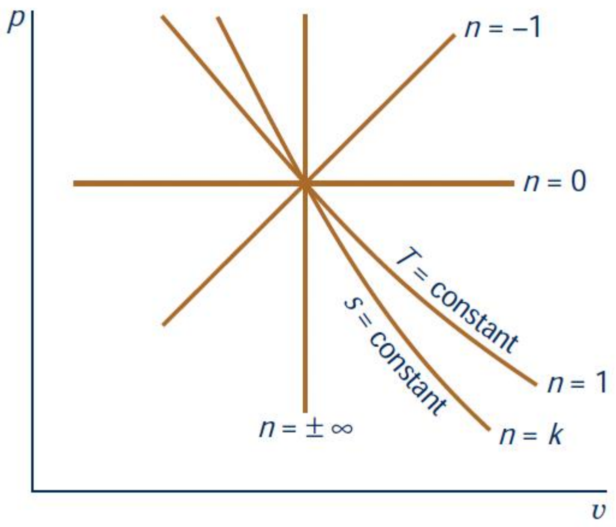


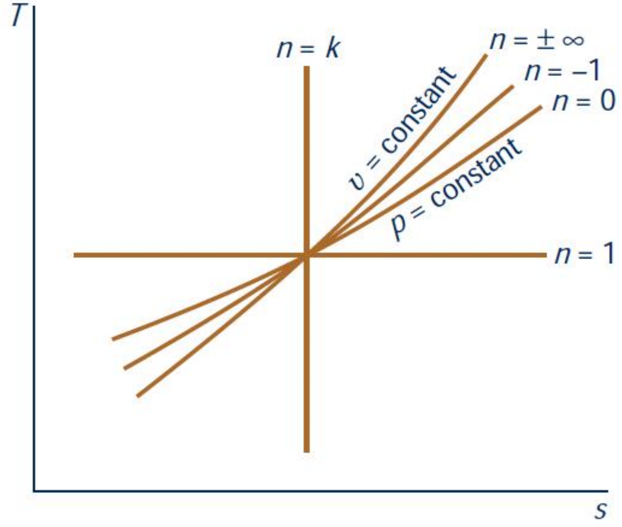
Perfect Gas Isentropic Process



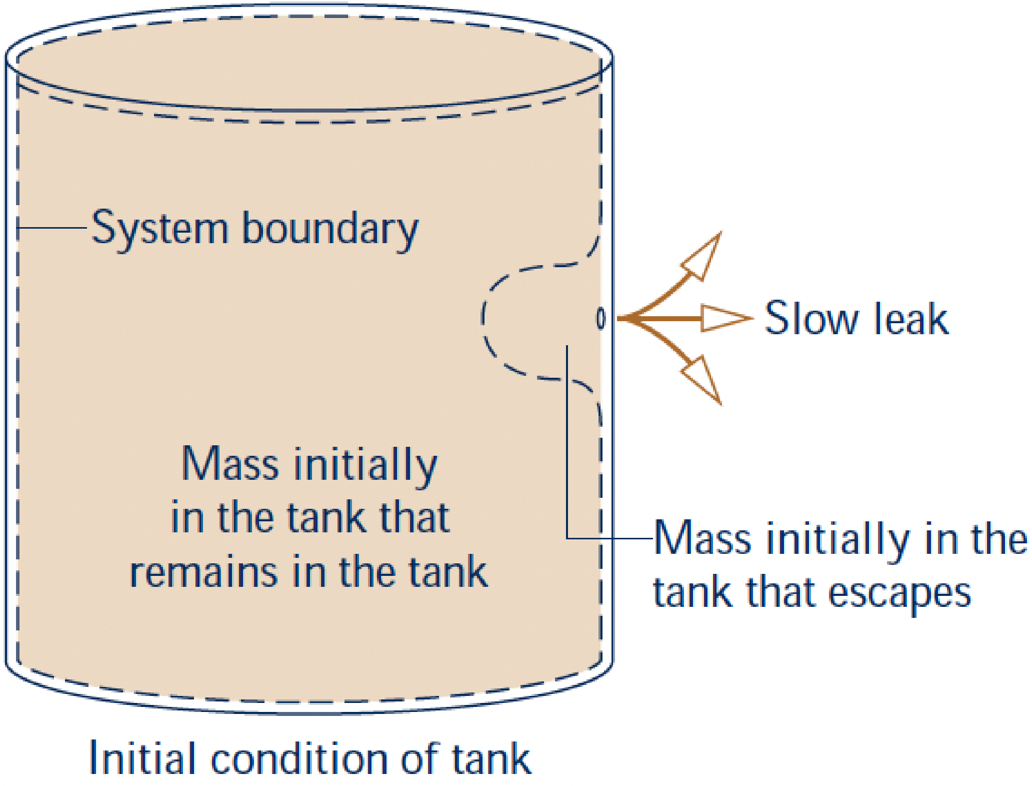
Review of Polytropic Process

- A process where $pv^n = \text{const}$
  - Isobaric process: $p = \text{const} \Rightarrow n = 0$
  - Isothermal process: $pv = RT = \text{const} \Rightarrow n = 1$
  - Isochoric processes: $v = \text{const} \Rightarrow n = +\infty \quad (p^{1/n}v = \text{const})$
  - Isentropic process: $pv^k = \text{const} \Rightarrow n = k = c_p/c_v$





Example 6.10



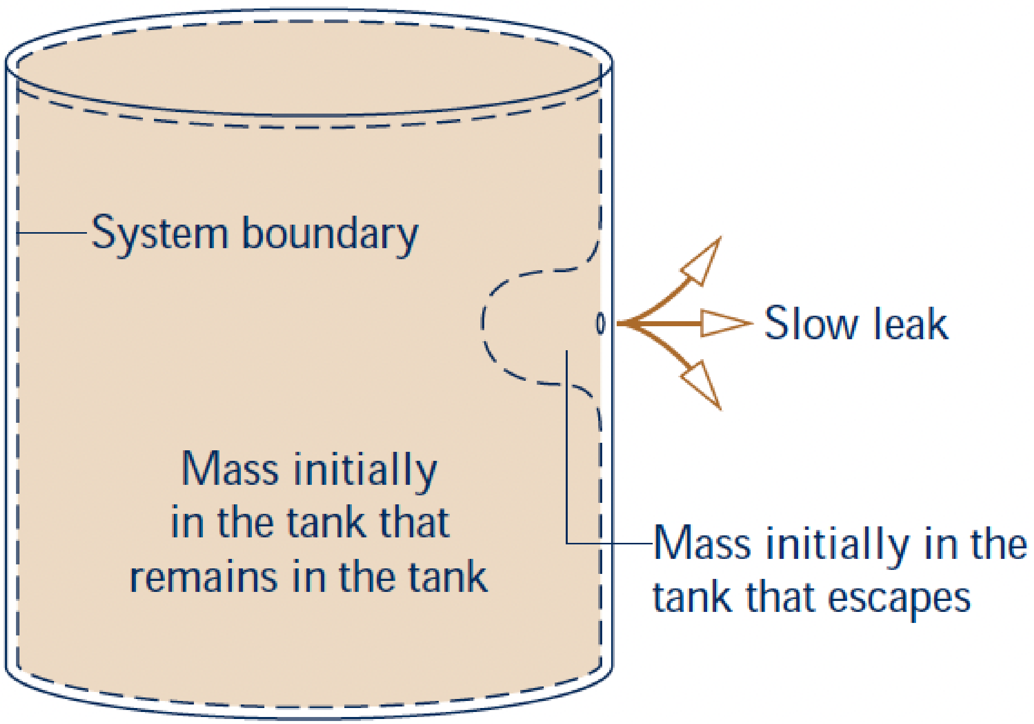
Air leaking from a rigid tank insulated from the surrounding (initially 5 kg, 5 bar, 500 K)

Air slowly escapes with no internal reversibility inside the tank, until reaching 1 bar

Assume perfect gas behavior, $c_p = 3.5R$

Determine the mass of the remaining air in the tank and its temperature

Example 6.10



Initial condition of tank

Isentropic Efficiency

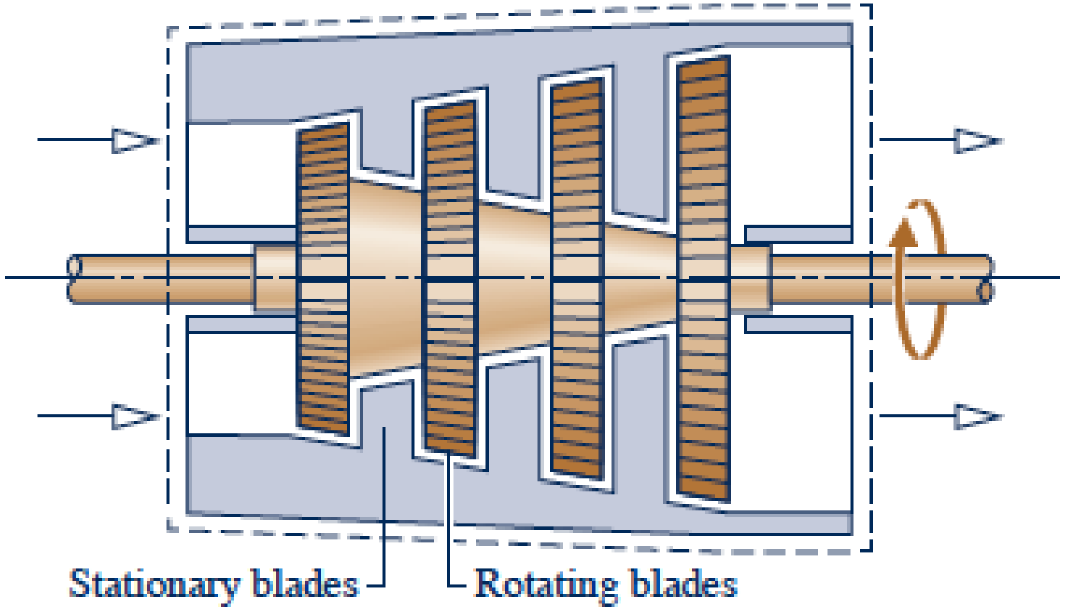
Fort turbines, nozzles, compressors, and pumps

Isentropic efficiency is to compare the actual performance of a device to the performance that would be achieved under **idealized circumstances** for the **same inlet state** and the **same exit pressure**

What’s typically assumed in the ideal case: adiabaticity and reversibility

Isentropic Turbine Efficiency

Ignore kinetic and potential energy change

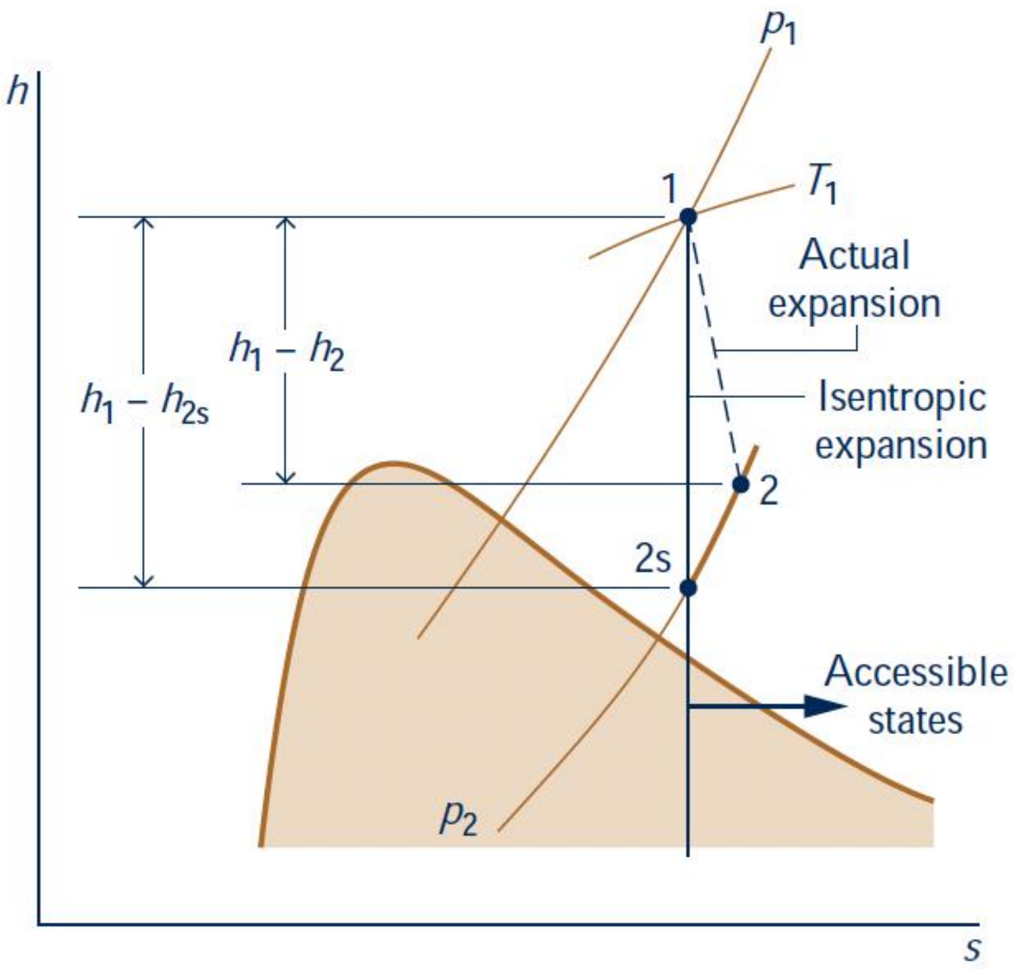


Idealized situation:

Insulated from the surrounding

No internal irreversibility

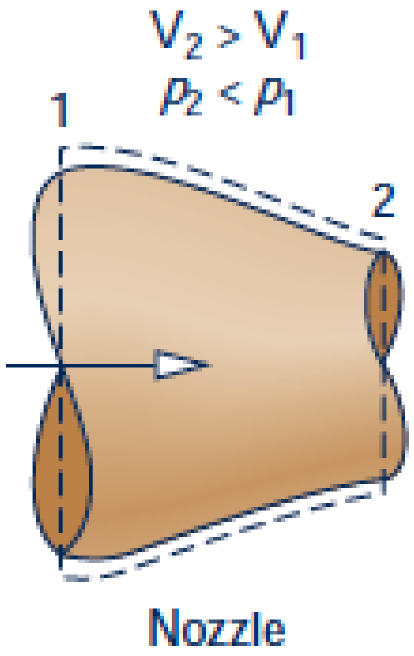
Isentropic Turbine Efficiency



Knowing the inlet state and the exit pressure, we can find the ideal exit state 2s

Isentropic Nozzle Efficiency

Ignoring potential energy change

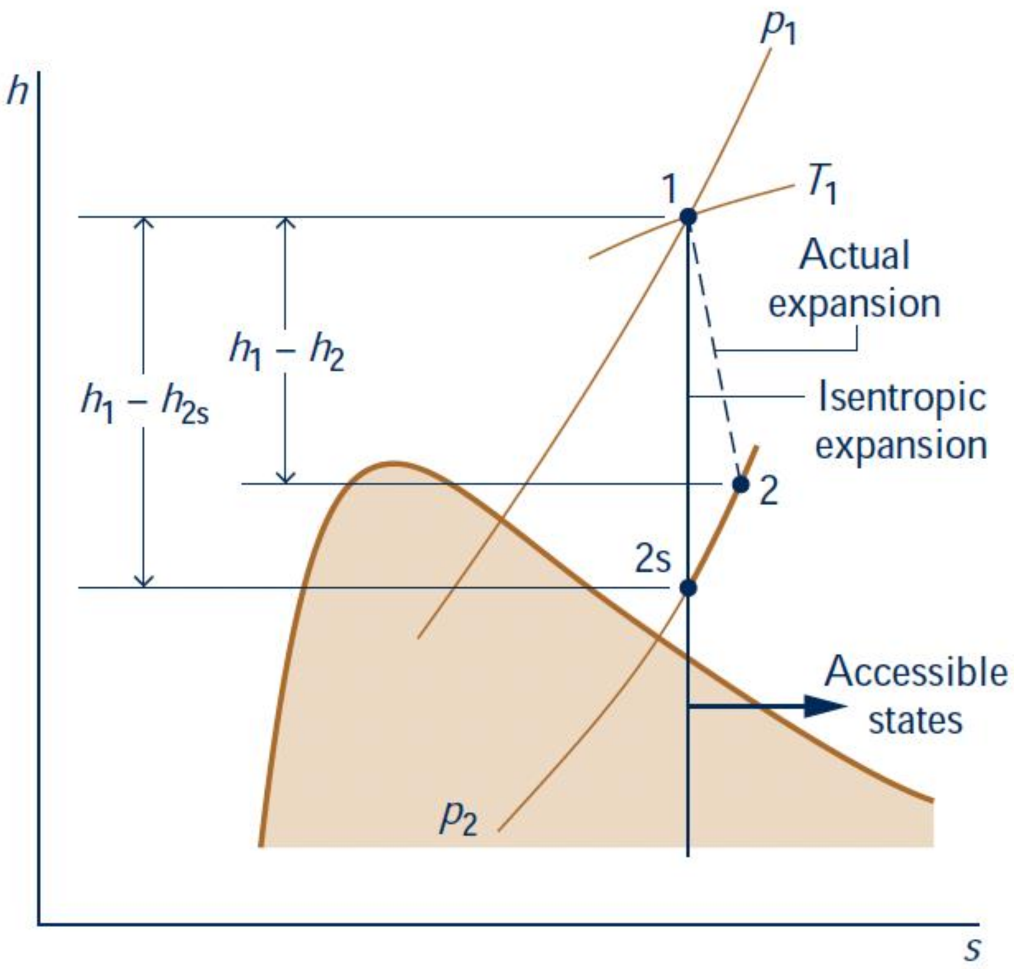


Idealized situation:

Insulated from the surrounding

No internal irreversibility

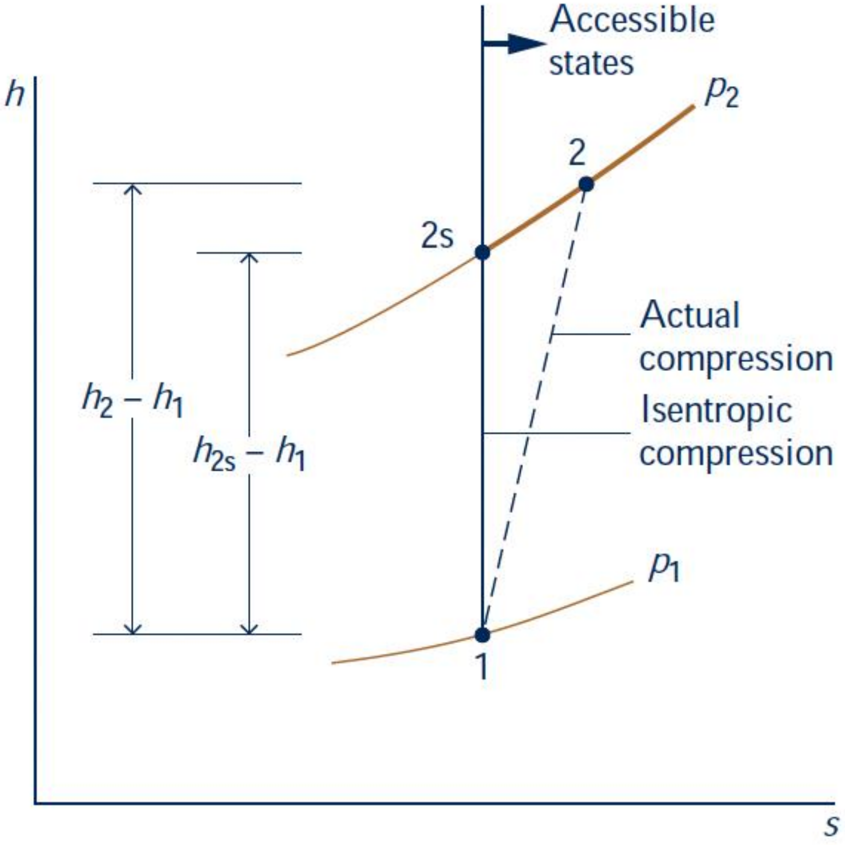
Isentropic Nozzle Efficiency



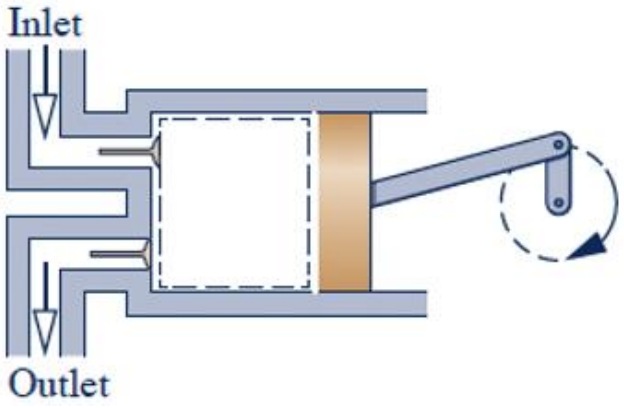
Knowing the inlet state and the exit pressure, we can find the ideal exit state 2s

For real operations,

Isentropic Compressor and Pump Efficiencies

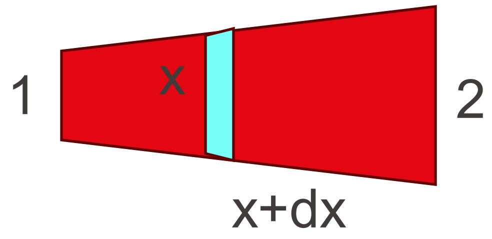


Ignore heat transfer, kinetic and potential energy change



Internally Reversible, Steady-State Flow Processes

One-inlet, one-exit control volumes at steady state



Heat transfer

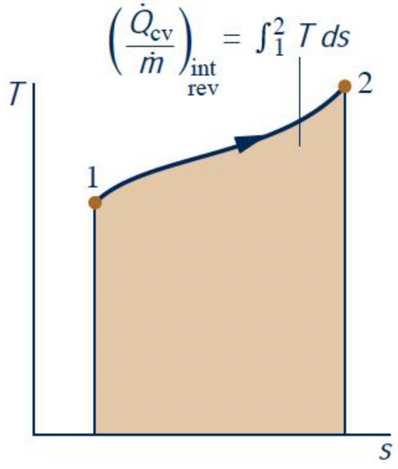
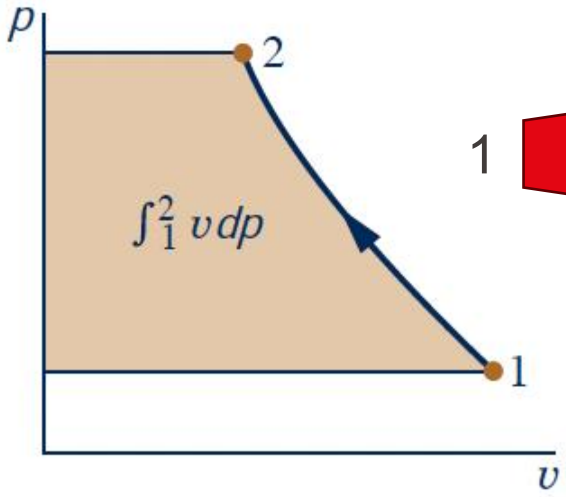


Fig. 6.13 **Area representation of heat transfer for an internally reversible flow process.**

Internally Reversible, Steady-State Flow Processes

Work transfer



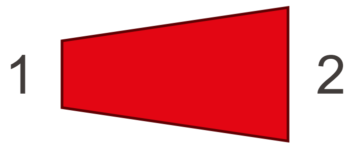


Fig. 6.14 **Area representation of $\int_1^2 v\, dp$.**

Bernoulli's Principle Rewritten

$$\int_1^2 v\,dp + \frac{\vec{V}_2^2 - \vec{V}_1^2}{2} + g(z_2 - z_1) = 0$$