Thermodynamics: An Engineering Approach
8th Edition
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Topic 16

Entropy Balance

Objectives

- Introduce and apply the entropy balance to various systems.

ENTROPY BALANCE

$$\begin{pmatrix}\text{Total}\\ \text{entropy}\\ \text{entering}\end{pmatrix} - \begin{pmatrix}\text{Total}\\ \text{entropy}\\ \text{leaving}\end{pmatrix} + \begin{pmatrix}\text{Total}\\ \text{entropy}\\ \text{generated}\end{pmatrix} = \begin{pmatrix}\text{Change in the}\\ \text{total entropy}\\ \text{of the system}\end{pmatrix}$$

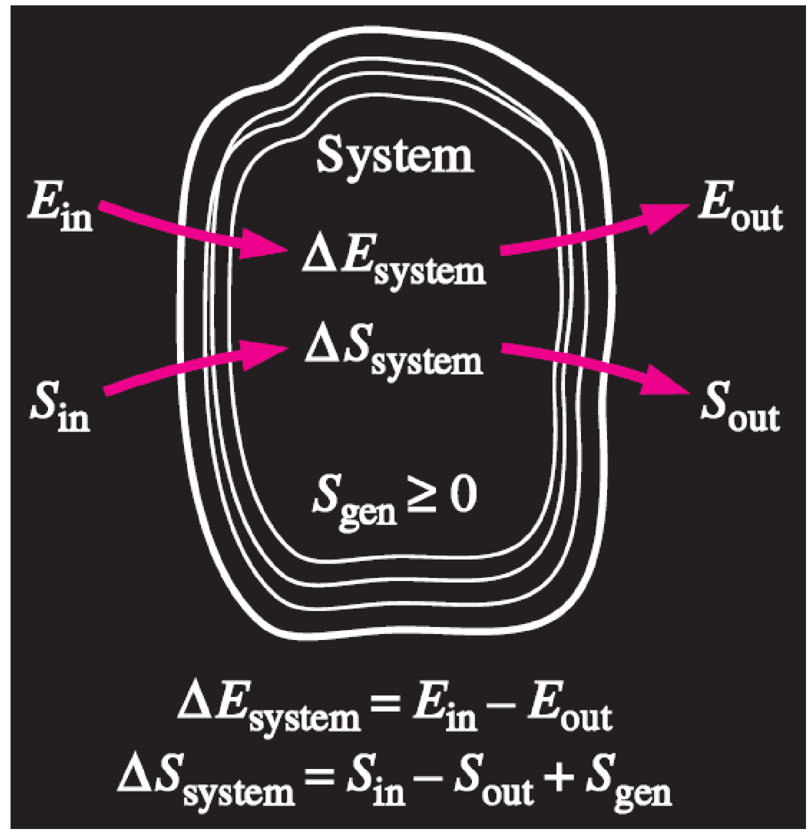
$$S_{\text{in}} - S_{\text{out}} + S_{\text{gen}} = \Delta S_{\text{system}}$$

Entropy Change of a System, ΔS_{system}

$$\Delta S_{\text{system}} = S_{\text{final}} - S_{\text{initial}} = S_2 - S_1$$

When the properties of the system are not uniform

$$S_{\text{system}} = \int s\,\delta m = \int_V s\rho\, dV$$



Energy and entropy balances for a system.

Mechanisms of Entropy Transfer, S_{in} and S_{out}

1 Heat Transfer

Entropy transfer by heat transfer:

$$S_{heat} = \frac{Q}{T} \qquad (T = \text{constant})$$

$$S_{heat} = \int_1^2 \frac{\delta Q}{T} \cong \sum \frac{Q_k}{T_k}$$

Entropy transfer by work:

$$S_{work} = 0$$

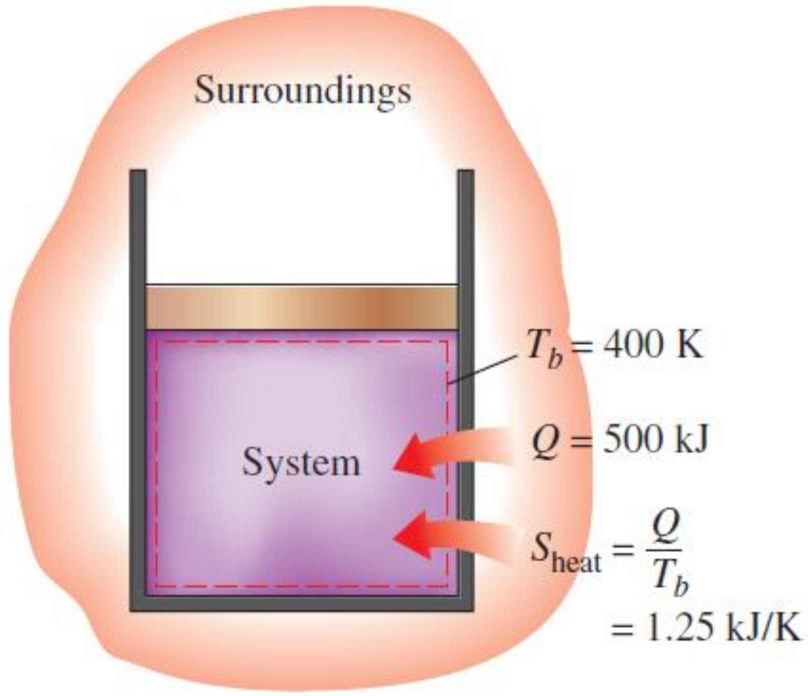
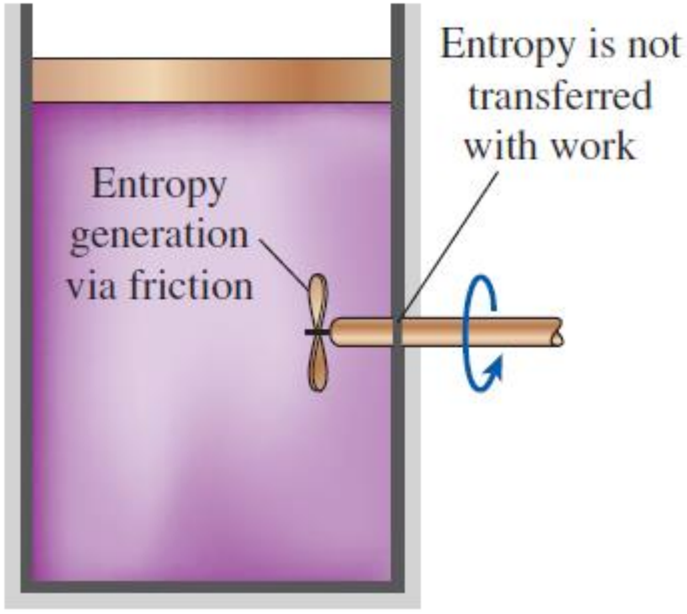


FIGURE 7–57

Heat transfer is always accompanied by entropy transfer in the amount of Q/T, where T is the boundary temperature.



No entropy accompanies work as it crosses the system boundary. But entropy may be generated within the system as work is dissipated into a less useful form of energy.

2 Mass Flow

Entropy transfer by mass:

$$S_{\text{mass}} = ms$$

When the properties of the mass change during the process

$$\dot{S}_{\text{mass}} = \int_{A_c} s\rho V_n \, dA_c$$

$$S_{\text{mass}} = \int s\,\delta m = \int_{\Delta t} \dot{S}_{\text{mass}}\,dt$$

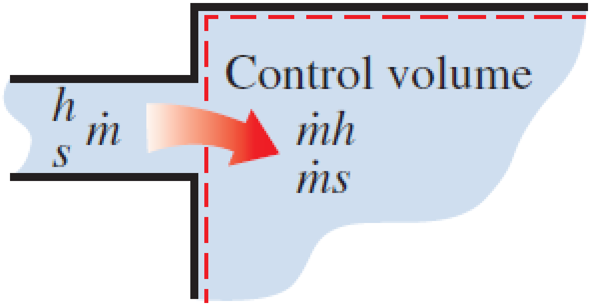


FIGURE 7–59

Mass contains entropy as well as energy, and thus mass flow into or out of system is always accompanied by energy and entropy transfer.

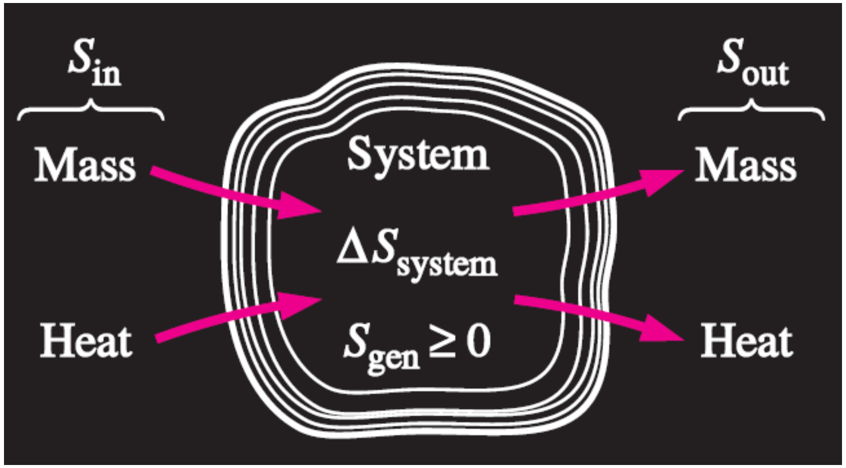
Entropy Generation, S_{gen}

$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change} \\ \text{in entropy}}} \qquad (\text{kJ/K})$$

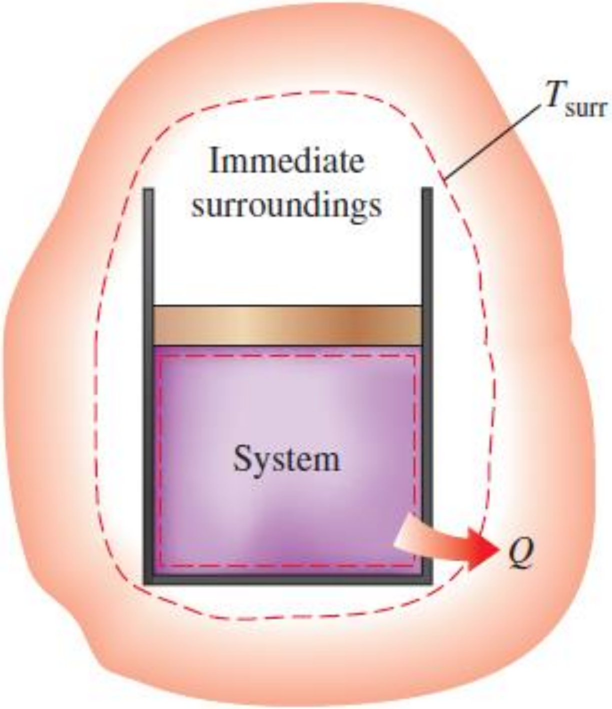
$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\substack{\text{Rate of net entropy} \\ \text{transfer by heat} \\ \text{and mass}}} + \underbrace{\dot{S}_{gen}}_{\substack{\text{Rate of entropy} \\ \text{generation}}} = \underbrace{dS_{system}/dt}_{\substack{\text{Rate of change} \\ \text{in entropy}}} \qquad (\text{kW/K})$$

$$(s_{in} - s_{out}) + s_{gen} = \Delta s_{system} \qquad (\text{kJ/kg} \cdot \text{K})$$

Entropy generation outside system boundaries can be accounted for by writing an entropy balance on an extended system that includes the system and its immediate surroundings.



Mechanisms of entropy transfer for a general system.



Closed Systems

Closed system: $$\sum \frac{Q_k}{T_k} + S_{\text{gen}} = \Delta S_{\text{system}} = S_2 - S_1 \qquad (\text{kJ/K})$$

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.

Adiabatic closed system: $$S_{\text{gen}} = \Delta S_{\text{adiabatic system}}$$

System + Surroundings: $$S_{\text{gen}} = \sum \Delta S = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}}$$

$$\Delta S_{\text{system}} = m(s_2 - s_1) \qquad \Delta S_{\text{surr}} = Q_{\text{surr}}/T_{\text{surr}}$$

Control Volumes

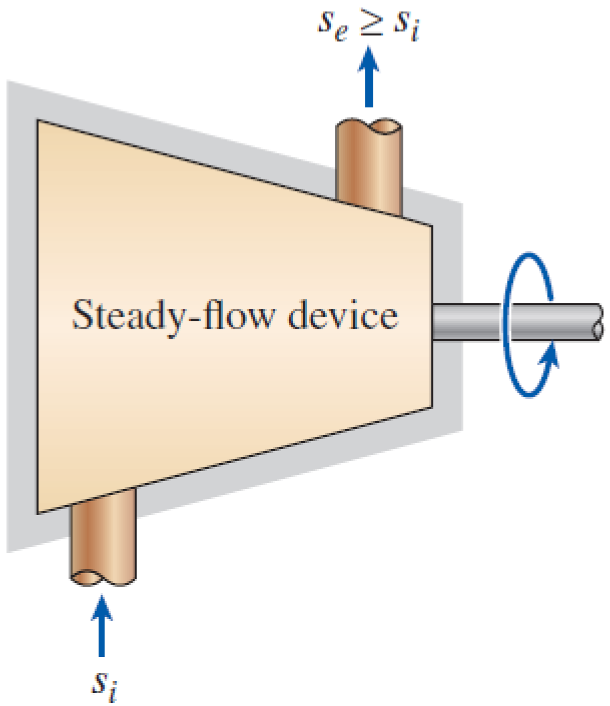
$$\sum \frac{Q_k}{T_k} + \sum m_i s_i - \sum m_e s_e + S_{gen} = (S_2 - S_1)_{CV} \qquad \text{(kJ/K)}$$

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

Steady-flow: $\dot{S}_{gen} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \sum \frac{\dot{Q}_k}{T_k}$

Steady-flow, single-stream: $\dot{S}_{gen} = \dot{m}(s_e - s_i) - \sum \frac{\dot{Q}_k}{T_k}$

Steady-flow, single-stream, adiabatic: $\dot{S}_{gen} = \dot{m}(s_e - s_i)$



The entropy of a substance always increases (or remains constant in the case of a reversible process) as it flows through a single-stream, adiabatic, steady-flow device.

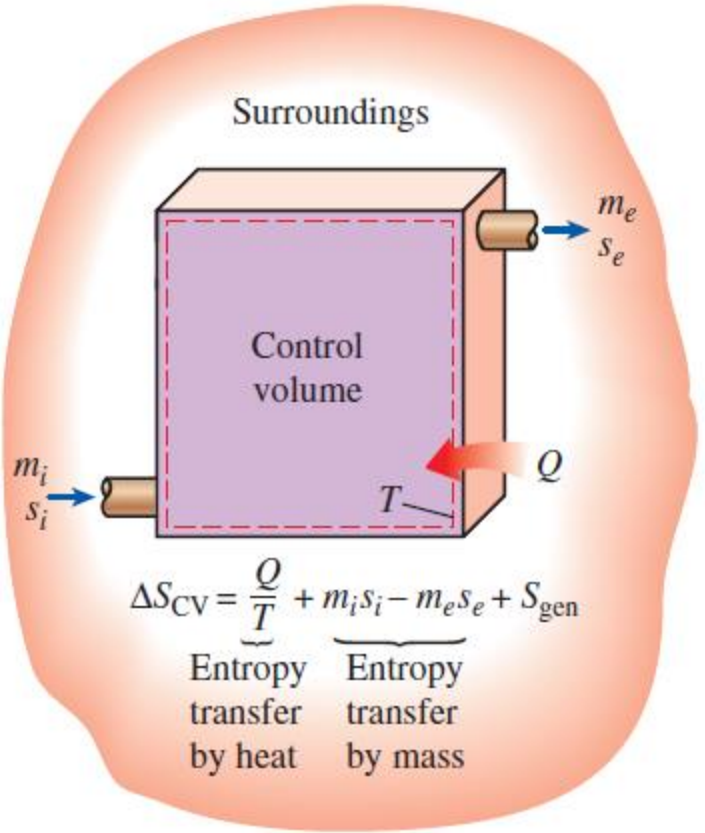
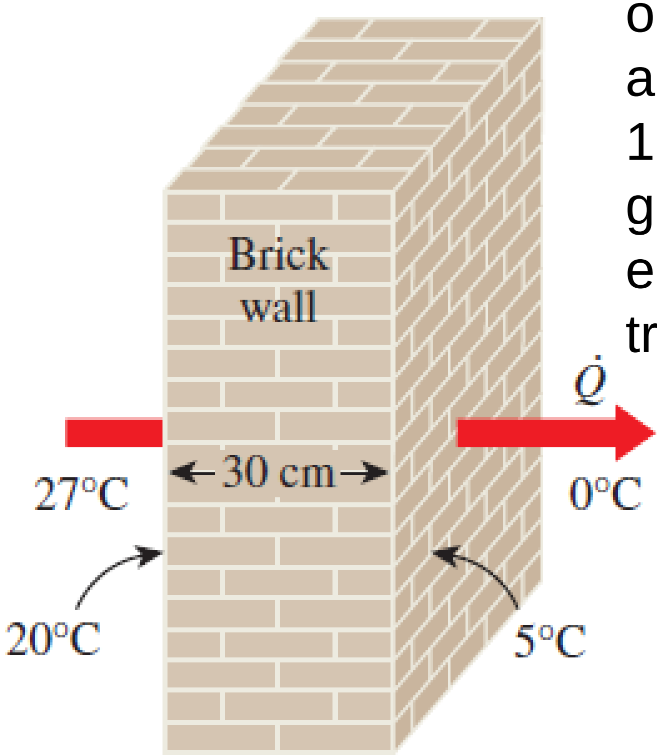


FIGURE 7–62
The entropy of a control volume changes as a result of mass flow as well as heat transfer.

Entropy Generation in a Wall



Consider steady heat transfer through a 5 m x 7 m brick wall with a thickness of 30 cm. On one side the wall, the room temperature of a house is 27ºC; the outside temperature on the other side is 0ºC. The temperature of the inner and outer surfaces are 20ºC and 5ºC, respectively, and the rate of heat transfer is measured to be 1035 W. Determine the rate of entropy generation in the wall and the rate of total entropy generation associated with the heat transfer process.

Example 1

Entropy generation associated with a heat transfer process

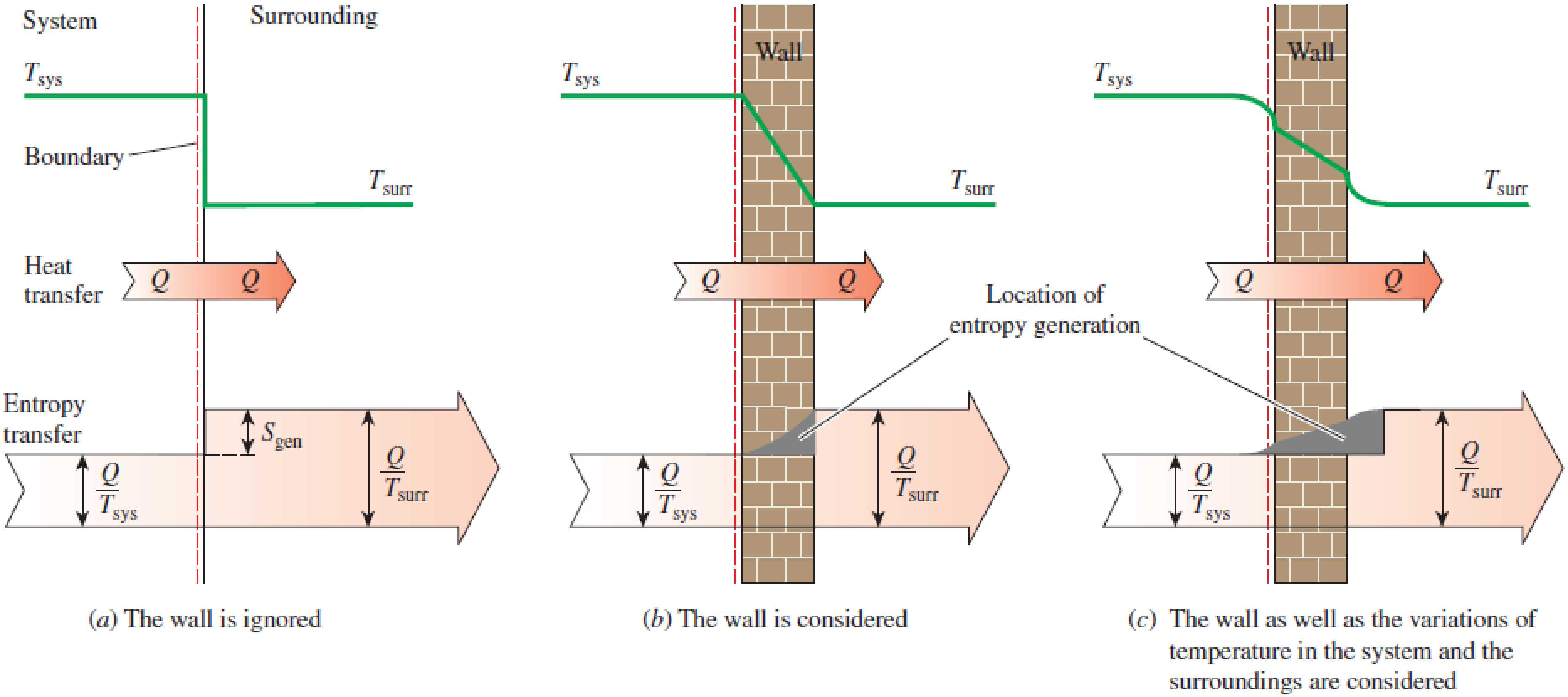
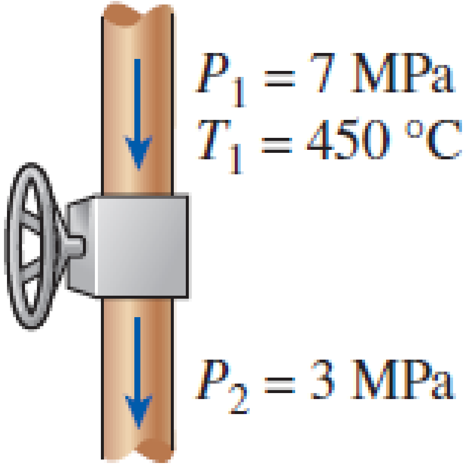


FIGURE 7–69
Graphical representation of entropy generation during a heat transfer process through a finite temperature difference.

Entropy Generation During a Throttling Process

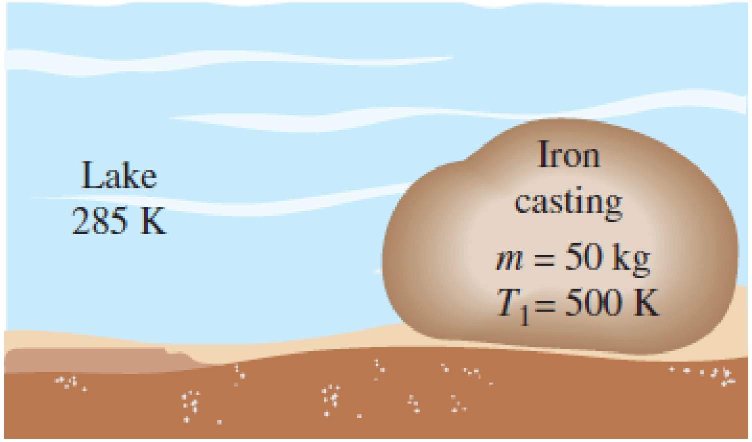
Steam at 7 MPa and 450^{o}C is throttled in a valve to a pressure of 3 MPa during a steady-flow process. Determine the entropy generated during this process and whether it satisfies the second law of thermodynamics.



Example 2

Entropy Generated when a Hot Block is Dropped in a Lake

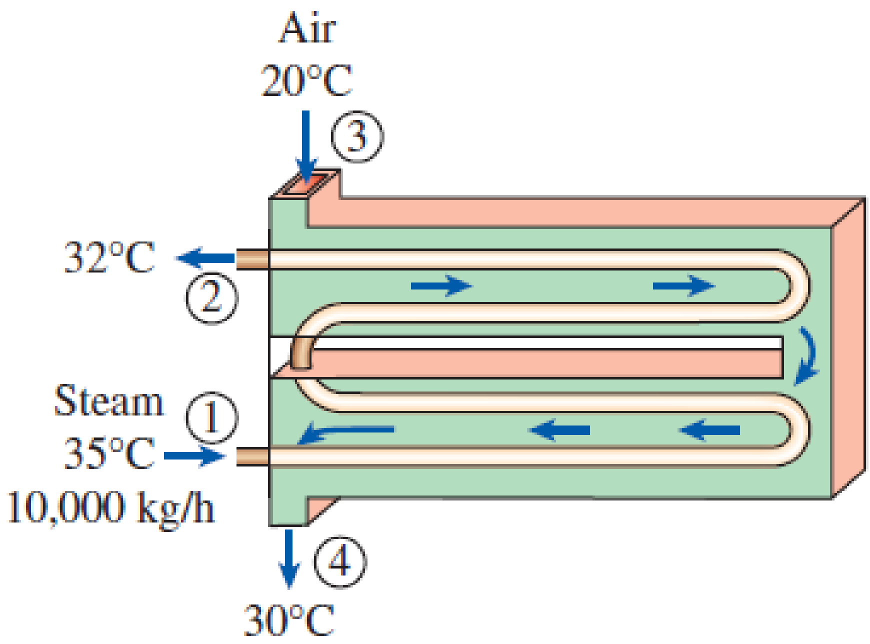
A 50-kg block of iron casting at 500 K is thrown into a large lake that is at a temperature of 285 K. The iron block eventually reaches thermal equilibrium with the lake water. Assuming an average specific heat of 0.45 kJ/kg K for the iron, determine the entropy changes of the block and of the lake and the entropy generated during the process.



Example 3

Entropy Generation in a Heat Exchanger

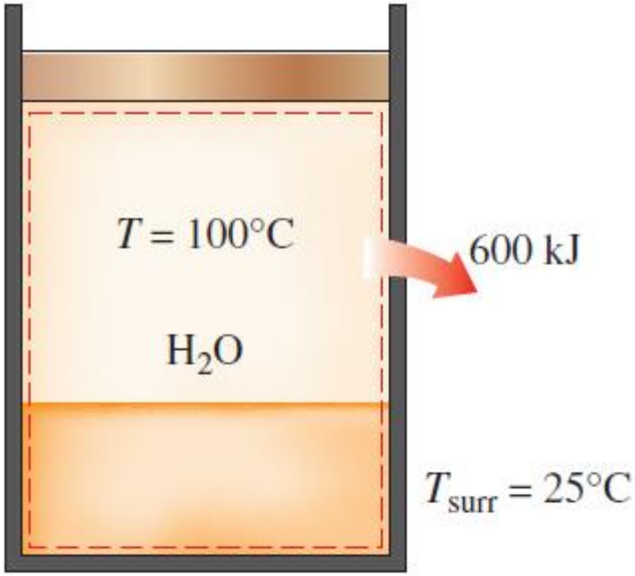
Air in a large building is kept warm by heating it with steam in a heat exchanger. Saturated water vapor enters the unit at 35ºC at a rate of 10,000 kg/hr and leaves as saturated liquid at 32ºC. Air at 1 atm enters the unit at 20ºC and leaves at 30ºC at about the same pressure. Determine the rate of entropy generated during this process.



Example 4

Entropy Generation Associated with Heat Transfer

A frictionless piston-cylinder device contains a saturated liquid-vapor mixture of water at 100^{o}C. During a constant pressure process, 600 kJ of heat is transferred to the surrounding air at 25^{o}C. As a result, part of the vapor condenses . Determine the entropy change of the water and the entropy generation during the heat transfer process.



Example 5

Summary

- Entropy balance