Exercise 20.28

Constants

Premium gasoline produces $1.23 \times 10^8$ J of heat per gallon when it is burned at a temperature of approximately $400 \degree C$ (although the amount can vary with the fuel mixture). If the car's engine is 25.0 % efficient, three-fourths of that heat is expelled into the air, typically at $20.0 \degree C$.

Part A

If your car gets 31.0 miles per gallon of gas, by how much does the car's engine change the entropy of the world when you drive 1.00 mile?

\[ \Delta S = \text{__________________________} \text{ J/K} \]

\[ \frac{400 \degree C}{20 \degree C} \rightarrow \frac{673 K}{293 K} \]

\[ \frac{31 \text{ miles/gallon}}{310 \text{ miles/gallon}} \text{ Thus } \frac{1.23 \times 10^8 \text{ J/gallon}}{310 \text{ miles/gallon}} = 3.97 \times 10^6 \text{ J needed to drive 100 miles} \]

\[ \Delta S = 0 \text{ for each complete heat engine for the gases.} \]

\[ Q = 3.97 \times 10^6 \text{ J is from the hot source, assumed at a constant 673K. For that hot source this is out so } Q = -3.97 \times 10^6 \text{ J} \]

\[ \Delta S_{\text{hot source}} = \frac{Q}{T} = \frac{-3.97 \times 10^6}{673} = -5.89 \times 10^3 \text{ J/K} \]

Engine is 25% efficient. Thus 25% does work and remainder

\[ Q = 0.75 \times 3.97 \times 10^6 \text{ J} = 2.98 \times 10^6 \text{ J is rejected to the cold sink, at 293K. This is positive Q for the cold sink.} \]

\[ \Delta S_{\text{cold sink}} = \frac{2.98 \times 10^6 \text{ J}}{293K} = 1.02 \times 10^4 \text{ J/K} \]

For the hot source, gas cycle, and cold sink

\[ \Delta S = -5.89 \times 10^3 \text{ J/K} + 0 + 1.02 \times 10^4 \text{ J/K} = 4300 \text{ J/K} \]

Note: When Q is transferred at a constant T, \[ \Delta S = \frac{Q}{T} \]

Part B

Does it decrease or increase the entropy of the world?

\[ \checkmark \text{ Increase.} \]

\[ \text{ Decrease.} \]
Problem 20.43

An experimental power plant at the Natural Energy Laboratory of Hawaii generates electricity from the temperature gradient of the ocean. The surface and deep-water temperatures are 30 °C and 7 °C, respectively.

**Part A**

What is the maximum theoretical efficiency of this power plant?

Express your answer using two significant figures.

**ANSWER:**

\[
\eta = \frac{303.15}{280.15} = 0.759
\]

Part B

If the power plant is to produce a power of 180 kW, at what rate must heat be extracted from the warm water? Assume the maximum theoretical efficiency.

Express your answer using two significant figures.

**ANSWER:**

\[
\dot{Q}_H = \frac{180 \times 10^3}{0.759} = 2.37 \times 10^6 \text{Watts}
\]

**Part C**

At what rate must heat be absorbed by the cold water? Assume the maximum theoretical efficiency.

Express your answer using two significant figures.

**ANSWER:**

\[
\dot{Q}_c = \dot{Q}_H - \text{Power} = 2.37 \times 10^6 - 180 \times 10^3 = 2.19 \times 10^6 \text{W}
\]

- 2.19x10^6 W is rejected by the cycle, and 2.19x10^6 W is absorbed by cold water

**Part D**

The cold water that enters the plant leaves it at a temperature of 11 °C. What must be the flow rate of cold water through the system? Give your answer in kg/s and L/s.

**ANSWER:**

\[
m = \frac{\dot{Q}_c}{C \Delta T} = \frac{2.19 \times 10^6}{11 \times 4190} = 1.31 \text{ kg/s}
\]

\[
\frac{dm}{dt} = 1.31 \text{ kg/s}
\]

**Part E**

Give \( \frac{dm}{dt} \) in \( \frac{L}{s} \), \( \frac{kg}{s} \times \frac{L}{m^3} \times \frac{1000 kg}{1000 kg} \times \frac{1000 L}{m^3} = \frac{L}{s} \)

Express your answer using two significant figures.

\[
131 \text{ kg/s} = 131 \text{ L/s}
\]
Problem 20.48

Constants

A typical coal-fired power plant generates 1000 MW of usable power at an overall thermal efficiency of 40%.

Part A

What is the rate of heat input to the plant?

\[ \dot{Q}_H = \frac{W}{\eta} \]

\[ \dot{P}_H = \dot{Q}_H = \frac{P}{\eta} \]

\[ \dot{P}_H = \frac{1000 \times 10^6 \text{W}}{0.40} = 2.50 \times 10^9 \text{W} = 2500 \text{ MW} \]

Part B

The plant burns anthracite coal, which has a heat of combustion of \(2.65 \times 10^7 \text{ J/kg}\). How much coal does the plant use per day, if it operates continuously?

\[ \text{Coal/\text{s}} = \frac{2.50 \times 10^9 \text{W}}{2.65 \times 10^7 \text{J/kg}} = 94.3 \text{kg/s} \]

\[ 94.3 \text{kg/s} \times \frac{3600 \text{s}}{\text{hr}} \times \frac{24 \text{hr}}{\text{day}} = 8.15 \times 10^6 \text{kg/day} \]

Part C

At what rate is heat ejected into the cool reservoir, which is the nearby river?

\[ \dot{Q}_c = |\dot{Q}_c| = \dot{P}_H - W = 2500 \text{ MW} - 1000 \text{ MW} = 1500 \text{ MW} \]

Part D

The river’s temperature is 18.0 °C before it reaches the power plant and 18.6 °C after it has received the plant’s waste heat. Calculate the river’s flow rate, in cubic meters per second.

\[ \Delta T = 18.6 °C - 18.0 °C = 0.6 °C \]

\[ \dot{V} = \frac{\dot{Q}_c}{\dot{m} \Delta T} \]

\[ \dot{m} = \frac{1.50 \times 10^9 \text{W}}{4190 \text{J/kg K} \times 0.6 °C} = 5.97 \times 10^5 \text{kg/s} \]

\[ \dot{V} = \frac{\dot{m}}{\rho} = \frac{5.97 \times 10^5 \text{kg/s}}{1000 \text{kg/m}^3} = 5.97 \times 10^{-2} \text{m}^3/\text{s} \]

Part E

By how much does the river’s entropy increase each second?

\[ \Delta T = 0.6 °C, \text{So } \frac{\Delta S}{T} \text{ is very close to a constant. Use } \Delta S = \frac{Q}{T} \]

with \(T = 273.15 + 18.3 = 291.45 \text{ K}\)

\[ Q = |\dot{Q}_c| = 1.5 \times 10^9 \text{J} \text{ (in one second)} \]

\[ \Delta S = \frac{1.5 \times 10^9 \text{J}}{291.45 \text{K}} = 5.15 \times 10^6 \text{J/K} \text{ (in one second)} \]
Problem 20.54

To heat 1 cup of water (250 cm³) to make coffee, you place an electric heating element in the cup. As the water temperature increases from 15.0 °C to 63.0 °C, the temperature of the heating element remains at a constant 120 °C.

**Part A**

Calculate the change in entropy of the water. (Assume that the specific heat of water is constant at 4190 J/(kg · K), and ignore the heat that flows into the ceramic coffee cup itself.)

Express your answer using three significant figures.

**ANSWER:**

\[
\Delta S = \text{J/K}
\]

\[
250 \text{ cm}^3 = 0.250 \text{ L}, \text{ water } 1 \text{ L} = 1 \text{ kg}
\]

\[
\Delta S = \frac{300 \times 4190 \times \ln\left(\frac{336}{288}\right)}{288} = 161.5 \text{ J/K}
\]

**Part B**

Calculate the change in entropy of the heating element. Treat the heating element as a heat reservoir.

Express your answer using three significant figures.

**ANSWER:**

\[
\Delta S = \text{J/K}
\]

\[
\Delta S = \frac{Q}{T} = \frac{-5.03 \times 10^4 \text{ J}}{393} = -127.9 \text{ J/K}
\]

**Part C**

What is the change in entropy of the system of water and heating element?

Express your answer using three significant figure.

**ANSWER:**

\[
\Delta S = \text{J/K}
\]

\[
\Delta S_{\text{for combined water and heating element}} = \Delta S_{\text{water}} + \Delta S_{\text{heating element}}
\]

\[
\Delta S = 161.5 \text{ J/K} + (-127.9 \text{ J/K}) = 33.6 \text{ J/K}
\]

**Part D**

Is this process reversible or irreversible?

**ANSWER:**

[ reversible ]

[ irreversible ]

Irreversible because heat flows across a ΔT between 15°C and 63°C.