Thermodynamics of Energy Conversion and Storage

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EXERCISES 1

1) Describe the forms of work and heat you know, e.g. potential energy W = m·g·h or heat capacity Q = m·c·dT. Make an example to each form with the corresponding quantity.

Heat:
latent heat: Q_m / Melting of ice $\Delta H_m(H_2O)$ = 333.55 J/g and Evaporation of water $\Delta H_m(H_2O)$ = 2257 J/g
heat capacity: Q = m·c·T / Heat capacity of water $c_p(H_2O)$ = 4.187 J/(g·K)
heat from a exothermic reaction: ΔH / $C + O_2 \rightarrow CO_2$ $\Delta H_f(CO_2)$ = -393.509 kJ/mol
Work:
kinetic energy: $W = 0.5 \cdot m \cdot v^2$ / $W = 0.5 \cdot 100kg \cdot (10m/s)^2 = 5000\ kg \cdot m^2 \cdot s^{-2}$ = 5 kJ (Person on bicycle with 36 km/h)
electrical energy: W = I·U·t / W = 240V·10A·0.05h = 120 Wh (Heating 1 liter of water from 10° to 100°C)
potential energy: W = m·g·h / W = 100 kg · 9.81 m/s^2 · 1200 m = 1200 kJ (hiking 1200m uphill)
Expansion work: W = p·V / W = $1 \cdot 10^6 \cdot 0.001m^3$ = 1000 J (Cylinder with 10 bar and 1 liter Volume change)

2) Calculate the energy consumption of an average human (J/day) and convert into power (Watts).

Energy consumption = Food + Oil + Gas + Coal + Products
IEA report for the countries and the world: 14'000 Mtoe/(world and year) = $14 \cdot 10^3 \cdot 4.186 \cdot 10^{16}$ J/($7 \cdot 10^9 \cdot 365$) = $5.86 \cdot 10^{20}$ J/($7 \cdot 10^9 \cdot 365$) = 229 MJ/day = 2.65 kW

3) Compare in view of energy and entropy the heating of 1kg of Water from 10°C to 100°C by using coal fire (800°C).

Q = 1 kg·4.187 (kJ/kg·K)·(373-283)K = 377 kJ = 377 kWs = 105 Wh
Energy from coal: m = 0.105 kWh / 9 kWh/kg =12 g
Electricity from coal power station: m = 0.105 kWh / 9 kWh/kg /25% = 48 g
All energy is in the form of heat, therefore, the entropy change is proportional to the energy used.
$$\Delta S = \int_i^f \frac{dQ}{T} = \int_{T_i}^{T_f} \frac{mcdT}{T} = mcln\frac{T_f}{T_i} = 1kg \cdot 4.187 (KJ/Kg \cdot K) \cdot ln\frac{373}{283} = 1156\ J/K$$

4) Calculate the Exergy and Anergy of coal fire (800°C), in the steam entering the turbine (400°C), in boiling hot water (100°C) and in a heated room (22°C) when the temperature of the environment is at 15°C.

Exergy = $Q \cdot \Delta T/T_h$
coal fire (800°C): Exergy = 1 - 288/1073 = 73.2%, Anergy = 100% - 73.2% = 26.8%
steam in turbine (400°C): Exergy = 1 - 288/673 = 57.2%, Anergy = 100% - 57.2% = 42.8%
hot water (100°C): Exergy = 1 - 288/373 = 22.8%, Anergy = 100% - 22.8% = 77.2%
heated room (22°C): Exergy = 1 - 288/295 = 2.3%, Anergy = 100% - 2.3% = 97.6%

5) Calculate the primary energy necessary and the increase of entropy for drinking a cup of tea. Describe the energy chain from primary to usable energy and all the conversion steps.

Primary energy: Coal 100% (Q = 0.08 kWh)
Conversion: fire 100%, 1500°C
Secondary energy: steam 90%, 500°C
Conversion: turbine and generator 30%
Tertiary energy: electricity 30%
Conversion: water heater 30%
Quarternary energy: hot water 25%, 100°C (Q = 0.02 kWh)
Q= 0.2kg·4.187(KJ/Kg·K) · (373-283)/($3.6 \cdot 10^3$) = 0.02 kWh

$\Delta S = mc\ln\frac{T_f}{T_i}$ = 0.2kg·4.187(KJ/Kg·K)·ln(373/283) = 231 J/K