PHYS 346 - Midterm I

Febuary 10, 2012

34 pts total

Closed book exam. Calculators are permitted. Please attempt all questions and show your work in the blank space on this question sheet. Equations and other useful information can be found at the back of the exam. Note: questions are worth different marks.

1. (4 points) A 200MW fossil fuel plant operates using a steam cycle as discussed in class. The boiler operates at 400°C and the condenser operates at 100°C.
   (a) If the plant operates at 60% of maximum possible efficiency, how much heat is supplied to the boiler?
   (b) How much heat is dumped into the environment every second by the condenser?
2. (2 points) Pumped storage is a method for storing excess electricity by pumping water uphill to a reservoir where its potential energy can be used later to operate a hydro-electric generator plant. It is particularly useful for storing excess peak energy from renewables like wind. Assuming that the pumping process is 70% efficient, how much water in kg/s can be pumped to a height of 100m by a 500 MW electrical plant?
3. (3 points) A 10 kg chunk of aluminum with T=60°C is thrown into a large lake with a temperature of 10°C. After some time has passed, what is the entropy change of the lake? If the aluminum was initially at 5°C, how does the answer change?
4. (4 points) Two of the following are false. Please explain why. Use a counter example if possible.
   (a) The entropy of an object never decreases.
   (b) No process is possible whose result is the extraction of heat from one object and the transfer of heat to a hot object.
   (c) No process is possible whose sole result is the conversion of heat into work.

5. (5 points) Air-to-air heat pumps are used to extract heat from the outside air and dump it into the interior of a building.

   (a) Suppose the interior of a house is at 20°C and the exterior air is at -10°C. Find the minimum electrical work required to deliver 20kW of heat into the house using an air-to-air heat pump.

   (b) If the actual COP is 40% of the maximum value, how much work is required?

   (c) Name one advantage and one disadvantage of ground based heat pumps compared with air-to-air heat pumps.

6. (6 points) Liquified natural gas (LNG) is an increasingly important source of fossil fuel. By cooling natural gas (methane or CH_4) to -161°C, one can liquify it, resulting in high density for transportation in large ships.

   (a) How many kg of CO_2 are generated by burning 1 kg of CH_4?
   (Reaction: $CH_4 + 2O_2 \rightarrow CO_2 + 2(H_2O)$)

   (b) How much heat must be removed to cool 1kg of gas initially at 20°C, to liquid at -161°C? (See data at end of exam booklet)

   (c) The gas is cooled using an electrically powered refrigerator. For every 1W of heat removed from the gas it takes 2W of electricity. The electricity to run the refrigerator is generated in a thermal steam generation plant with a thermal efficiency of 40% using natural gas as a fuel. How many kg of natural gas must be burned to provide the power to condense 1kg of LNG?

7. (4 points) World natural conventional oil resources are currently estimated at 1.38×10^{12} bbl. The current consumption rate is 3.2×10^{10} bbl/year.

   (a) What is the projected lifetime of the fossil fuels assuming constant consumption rate.

   (b) Find the projected lifetime if the oil consumption grows at an annual rate such that the doubling time is 23 years.

8. (6 points) In class we considered some cases where Hubbert's model seemed to apply to particular resources, such as the oil production in Norway.

   (a) Sketch the approximate form of $Q(t)$, and dQ/dt vs t where $Q(t)$ is the total resource extracted up to time t and dQ/dt is the production rate at time t. On your graph, label important points such as Q_∞ and t_m.

   (b) Sketch the form of the quantity $\frac{1}{Q}\frac{dQ}{dt}$ vs Q for the Hubbert model. How does this differ from exponential growth?

   (c) In what ways is the Hubbert model a more realistic model than just assuming constant production rate or exponentially increasing production rate?

Equations and other useful information:

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\begin{aligned}
Exponential: \frac{dQ}{dt} &= kQ \\
Hubbert: \frac{dQ}{dt} &= kQ(1 - \frac{Q}{Q_\infty}) \\
N &= N_o \exp(k\ t) \\
k &= \ln(1 + \lambda) \\
T &= \frac{1}{k}\ \ln\left(\frac{k\ Q_T}{N_o}\ +\ 1\right) \\
Q &= m\ L_F \\
Q &= m\ L_V \\
\Delta S &= \frac{Q}{T} \\
\eta &= \frac{|W|}{|Q_H|} \leq \frac{T_H - T_C}{T_H} \\
\text{C.O.P.}_{Refrigerator} &= \frac{|Q_C|}{|W|} \leq \frac{T_C}{T_H - T_C} \\
\text{C.O.P.}_{Heat\ Pump} &= \frac{|Q_H|}{|W|} \leq \frac{T_H}{T_H - T_C}
\end{aligned}
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energy content of coal	24×10^6 J/kg
energy content of crude oil	40×10^6J/kg
energy content of natural gas	55×10^6J/kg
molecular mass of CO_2	0.044 kg/mol
molecular mass of CH_4	0.016 kg/mol
atomic mass of carbon	0.012 kg/mol
specific heat of water	4186 $J\cdot kg^{-1}\cdot K^{-1}$
specific heat of aluminum	895 $J\cdot kg^{-1}\cdot K^{-1}$
specific heat of ice	2220 $J\cdot kg^{-1}\cdot K^{-1}$
specific heat of methane vapour	2×10^3 $J\cdot kg^{-1}\cdot K^{-1}$
latent heat of fusion of water	3.33×10^5 J/kg
latent heat of vaporization for water	2.26×10^6 J/kg
latent heat of vaporization for methane	59×10^3 J/kg
density of water	1000 kg/m^3
1 Cal	4184 J
1 Btu	1055 J