Homework 1

CHEN 3370

Decimal Calendar Unit	Symbol	Definition
Second	Sc	10^{-6} Yr
Minute	Mn	10^{-5} Yr
Hour	Hr	10^{-4} Yr
Day	Dy	10^{-3} Yr
Week	Wk	10^{-2} Yr
Month	Mo	10^{-1} Yr
Year	Yr	

1.27. Energy costs vary greatly with energy source: coal @ \$35.00/ton, gasoline @ a pump price of \$2.75/gal, and electricity @ \$0.100/kW·h. Conventional practice is to put these on a common basis by expressing them in $\$\cdot GJ^{-1}$. For this purpose, assume gross heating values of 29 $MJ\cdot kg^{-1}$ for coal and 37 $GJ\cdot m^{-3}$ for gasoline.

(*a*) Rank order the three energy sources with respect to energy cost in $\$\cdot GJ^{-1}$.
(*b*) Explain the large disparity in the numerical results of part (*a*). Discuss the advantages and disadvantages of the three energy sources.

1.28. Chemical-plant equipment costs rarely vary in proportion to size. In the simplest case, cost C varies with size S according to the *allometric* equation

$$C = \alpha S^{\beta}$$

The size exponent β is typically between 0 and 1. For a wide variety of equipment types it is approximately 0.6.

(*a*) For $0 < \beta < 1$, show that cost per *unit size* decreases with increasing size. ("Economy of scale.")
(*b*) Consider the case of a spherical storage tank. The size is commonly measured by internal volume V_i^t. Show why one might expect that $\beta = 2/3$. On what parameters or properties would you expect quantity α to depend?

1.29. A laboratory reports the following vapor-pressure (P^{sat}) data for a particular organic chemical:

$t/°C$	P^{sat}/kPa
−18.5	3.18
−9.5	5.48
0.2	9.45
11.8	16.9
23.1	28.2
32.7	41.9
44.4	66.6
52.1	89.5
63.3	129.
75.5	187.

Correlate the data by fitting them to the Antoine equation:

$$\ln P^{\text{sat}}/\text{kPa} = A - \frac{B}{T/\text{K} + C}$$

That is, find numerical values of parameters A, B, and C by an appropriate regression procedure. Discuss the comparison of correlated with experimental values. What is the predicted normal boiling point (i.e. temperature at which the vapor pressure is 1(atm)) of this chemical?

2.31. Steam flows at steady state through a converging, insulated nozzle, 25 cm long and with an inlet diameter of 5 cm. At the nozzle entrance (state 1), the temperature and pressure are 325°C and 700 kPa and the velocity is 30 m·s^{-1}. At the nozzle exit (state 2), the steam temperature and pressure are 240°C and 350 kPa. Property values are:

$H_1 = 3112.5$ kJ·kg^{-1} $\quad V_1 = 388.61$ cm^3·g^{-1}

$H_2 = 2945.7$ kJ·kg^{-1} $\quad V_2 = 667.75$ cm^3·g^{-1}

What is the velocity of the steam at the nozzle exit, and what is the exit diameter?

2.32. In the following take $C_V = 20.8$ and $C_P = 29.1$ J·mol^{-1}·°C^{-1} for nitrogen gas:

(*a*) Three moles of nitrogen at 30°C, contained in a rigid vessel, is heated to 250°C. How much heat is required if the vessel has a negligible heat capacity? If the vessel weighs 100 kg and has a heat capacity of 0.5 kJ·kg^{-1}·°C^{-1}, how much heat is required?

(*b*) Four moles of nitrogen at 200°C is contained in a piston/cylinder arrangement. How much heat must be extracted from this system, which is kept at constant pressure, to cool it to 40°C if the heat capacity of the piston and cylinder is neglected?

2.33. In the following take $C_V = 5$ and $C_P = 7$ (Btu)(lb mole)$^{-1}$(°F)$^{-1}$ for nitrogen gas:

(*a*) Three pound moles of nitrogen at 70(°F), contained in a rigid vessel, is heated to 350(°F). How much heat is required if the vessel has a negligible heat capacity? If it weighs 200(lb$_m$) and has a heat capacity of 0.12(Btu)(lb$_m$)$^{-1}$(°F)$^{-1}$, how much heat is required?

(*b*) Four pound moles of nitrogen at 400(°F) is contained in a piston/cylinder arrangement. How much heat must be extracted from this system, which is kept at constant pressure, to cool it to 150(°F) if the heat capacity of the piston and cylinder is neglected?

2.34. Find an equation for the work of reversible, isothermal compression of 1 mol of gas in a piston/cylinder assembly if the molar volume of the gas is given by

$$V = \frac{RT}{P} + b$$

where b and R are positive constants.

2.35. Steam at 200(psia) and 600(°F) [state 1] enters a turbine through a 3-inch-diameter pipe with a velocity of 10(ft)·s^{-1}. The exhaust from the turbine is carried through a 10-inch-diameter pipe and is at 5(psia) and 200(°F) [state 2]. What is the power output of the turbine?

$H_1 = 1322.6$(Btu)(lb$_m$)$^{-1}$ $\quad V_1 = 3.058$(ft)^3(lb$_m$)$^{-1}$

$H_2 = 1148.6$(Btu)(lb$_m$)$^{-1}$ $\quad V_2 = 78.14$(ft)^3(lb$_m$)$^{-1}$

2.36. Steam at 1400 kPa and 350°C [state 1] enters a turbine through a pipe that is 8 cm in diameter, at a mass flow rate of 0.1 kg·s^{-1}. The exhaust from the turbine is carried through a 25-cm-diameter pipe and is at 50 kPa and 100°C [state 2]. What is the power output of the turbine?