University of Melbourne

Department of Chemical Engineering

CHEN20010 MATERIAL AND ENERGY BALANCES

EXERCISE SHEET B

UNITS AND DIMENSIONS

1. The minimum safe distance between two adjacent tanks is prescribed in the relevant government regulations to be 8.00 metres. What is this distance in feet?

2. What is the mass (expressed in kg) of 45.6 lb-mol of benzene?

3. The critical pressure of ethyl mercaptan, C_2H_5SH, is 5.490 MPa. What is this pressure expressed in psi?

4. A car is travelling at a speed of 103 kilometres per hour. What is this speed in ft/s?

5. In 1992 the Brassey oil field in northeast British Columbia was estimated to contain 33 MMbbl of oil. What is this volume expressed in cubic metres?

6. What is the pressure equivalent to a force of 7.56 dyne applied uniformly over an area of 56.0 square inches? Express the answer in Pa.

7. The standard heat of formation of diethyl ether is -251 kJ/mol. What is this quantity expressed in Btu/lb-mol?

8. A pressure gauge indicates that the pressure inside a reaction vessel is 312.2 psig. If the barometric pressure is 753 mm Hg what is the vessel's absolute pressure expressed in kPa?

9. A silo of skim milk concentrate is filled to a depth of 3.50 m on a day when the atmospheric pressure is 752 mm Hg. The density of the skim milk concentration is 1.179 g/mL.
   a. Calculate the gauge pressure at the bottom of the silo in psi.
   b. Calculate the absolute pressure at the bottom of the silo in kPa.

10. A steel drum weighs 17.60 kg. Into this drum is poured 3.050 Imperial gallons of a chemical having a density of 50.30 lb_m/ft^3. What is the combined mass of the drum and chemical? Express the answer in lb_m.

11. The critical specific volume of methyl ethyl ketone is 0.267 m^3/kmol? What is this specific volume in L/kg. The molecular weight of methyl ethyl ketone is 72.11.

12. The change in the specific enthalpy of gaseous propane when it is heated from 380 K to 480 K at 1.00 MPa is 232.9 kJ/kg. Express this change in enthalpy in:
    a. kcal/g
    b. Btu/lbm
    c. therm/ton

13. Natural gas is stored in a pressure vessel which does not leak. On a day when the barometric pressure is 748.3 mmHg the gauge pressure of the gas is 220.51 psi. Two days later the barometric pressure is 776.1 mm Hg. What is the new gauge pressure of the gas?

14. What force is required to accelerate a mass of 9.344 ton at a rate of 45.01 yards per minute per minute? Express the answer in N.

15. A copper bar with a circular cross-section of diameter 0.500" and a length of 7'4" weighs 5.590 lb. What is the density of the copper? Express the answer in kg/m^3.

16. A spherical tank with a diameter of 16 ft 5 in is being filled with a liquid at a constant rate of 325 L/min. How long will it take to completely fill the tank if it is initially empty? (Answer in hours.)

17. Prior to collection by road tankers milk is normally stored on the farm in refrigerated vat. On one dairy farm the milk vat has a capacity of 4000 litres. If the tanker pump empties the vat at a rate of 0.68 UK gallons per second how long will it take to empty a full vat? Express your answer in minutes.

Collection of milk by a road tanker.

18. The Universal gas constant is 8.314 J/(g-mol) K. Express this value in units of atm ft^3/(lb-mol) °R.

19. At 20°C, the specific heat of oxalic acid is 1.612 kJ/kg K. Express this specific heat as:
    a. Btu/lb °F
    b. cal/g °C

20. Use the ideal gas law, PV = nRT, to calculate the volume occupied by 17 lb-mol of argon at 639 Torr and 16.4°F. The Universal gas constant, R, is equal to 8.314 J/mol K. Express your answer in cubic metres.

21. The density of a 1% solution of potassium chlorate ($KClO_3$) solution may be related to temperature by the following equation:

$$\rho = 1.0067 - 5.7415 \times 10^{-5}\, t - 3.6723 \times 10^{-6}\, t^2$$

where, density, ρ, is expressed in kg/m^3 and t is expressed in °C. Re-write this equation with density expressed in units of lb/ft^3, and temperature expressed in units of ºF.

22. The newspaper article at right appeared in the Singapore Straits Times following the loss of the NASA Mars Climate Orbiter. The article tried to explain to the layperson how the miscalculation occurred. But is it correct? If, as the article suggests, 'a poundal is the force required to accelerate a one-pound mass one foot per second per second' then we find that one poundal does not equal 4.4 N. Using the definitions above, how many newtons are equivalent to one poundal?

Tiny mistake trips up great minds

THE error occurred as a result of miscommunication between the makers of the Mars Climate Orbiter spacecraft, Lockheed Martin, and scientists at the Jet Propulsion Laboratory (JPL) in California.

Lockheed was providing JPL with data on the amount of force imparted to the spacecraft by its thrusters, which were fired periodically. This was measured in poundals.

But the scientists at JPL assumed the figure was in newtons and incorporated it into computer models used to calculate the spacecraft's position and direction.

A newton is the force needed to accelerate a 1-kg mass one metre per second per second. A poundal is the force needed to accelerate a one-pound mass one foot per second per second.

One poundal equals about 4.4 newtons.

The tiny miscalculations of the spacecraft's course built up over time were enough to help throw the spacecraft off course so that it entered the Martian atmosphere too low and either burned up or was torn apart.

— NEW YORK TIMES

23. The van der Waals equation of state may be used to represent the non-ideal behaviour of real gases. It is given by the equation:

$$\left(P + \frac{a}{\hat{V}^2}\right)\left(\hat{V} - b\right) = RT$$

where P is the absolute pressure of the gas, $\hat{V}$ is the molar volume of the gas, R is the Universal gas constant, T is the absolute temperature of the gas, and a and b depend on the particular gas. What are the dimensions of a and b?

24. A 1500 bbl shipment of 16.1°API oil is blended with 3250 bbl of 38.2°API oil. The resultant mixture has a volume of 4750 bbl. What will be the API gravity of the mixture?

25. The specific heat capacity of ethane between -25°C and 50°C at 101.3 kPa may be approximated by the equation:

$$C_P = 1.670 + 0.003\,512\, t$$

where C_P is expressed in kJ/kg °C, and t is expressed in °C. Re-write this equation with C_P expressed in Btu/lb °F and t in °F.

26. Reynolds Number, Re, is an important *dimensionless group* often used in fluid flow calculations. For flow in pipes it may be defined as:

$$Re = \frac{\rho u d}{\mu}$$

where, ρ is the fluid density, $[\rho]$ = mass/length^3
u is the fluid velocity, $[u]$ = length/time
d is the pipe diameter, $[d]$ = length
and, μ is the fluid absolute viscosity, $[\mu]$ = mass/length time.

Calculate the Reynolds Number for the following situations :

a. Water at 20°C flowing along a 2.54 cm diameter pipe at a velocity of 0.930 m/s.
Density of water at 20°C: 998.2 kg/m^3
Absolute viscosity of water at 20°C: 1.002×10^{-3} kg/ms

b. Air at 52°C flowing at a velocity of 400 ft/min along a circular duct with a diameter of 4 inches.
Density of air at 52°C: 0.06780 lb/ft^3
Absolute viscosity of air at 52°C: 1.846×10^{-5} kg/m s

27. The flow rate of a fluid flowing through porous media is governed by Darcy's Law:

$$q = -1.125 \times 10^{-3} \frac{k A \Delta P}{\mu \Delta x}$$

where, q is the flow rate in bbl/day, k is the permeability in millidarcy, A is the area perpendicular to the direction of flow in ft^2, ΔP is the pressure drop in psi between two points Δx ft apart and μ is the viscosity of the fluid measured in centipoise. Re-write the equation with q expressed in cm^3/day, k in darcy, A in cm^2, ΔP in atm, μ in centipoise and Δx in cm.

28. When a fluid passes over a heated flat plate the heat transfer coefficient, h, may be estimated from the equation:

$$h = 0.332 \frac{k}{d} \left(\frac{\rho u d}{\mu}\right)^{1/2} \left(\frac{C_P \mu}{k}\right)^{1/3}$$

where, k is the thermal conductivity of the fluid,
d is the length of the plate,
ρ is the fluid density,
u is the velocity of the fluid over the plate,
μ is the fluid viscosity,
and, C_P is the fluid specific heat capacity.

a. If h has units of W/m^2 K, k has units of W/m K,
d has units of m, ρ has units of kg/m^3,
u has units of m/s, μ has units kg/m s, and,
C_P has units of J/kg K,
what are the units of the coefficient 0.332?

b. What velocity must water pass over the plate to achieve a value of 99.01 Btu/h ft^2 °F for h? Express your answer in m/s. The plate is 527 mm long and the properties of water at 45°C are:

k = 0.167 kcal/h ft °C
C_P = 4.181 kJ/kg K
ρ = 61.82 lb/ft^3
μ = 399 × 10^{-6} lb/ft s.

MATLAB EXERCISES – Use MATLAB to answer these problems

M29. A sample of oil has a specific gravity of 0.897. Write and run a MATLAB program to calculate the oil gravity in °API. Next write a program to produce a conversion table showing the oil gravities in °API for specific gravities from 0.850 to 1.010 in increments of 0.010.

M30. The following equation can be used to calculate the density of water as a function of temperature.

$$\frac{\rho_l}{\rho_c} = 1 + b_1\,\theta^{1/3} + b_2\,\theta^{2/3} + b_3\,\theta^{5/3} + b_4\,\theta^{16/3} + b_5\,\theta^{43/3} + b_6\,\theta^{110/3}$$

In this equation, ρ_l is the density of water expressed in kg/m^3 and θ is defined below. This equation is valid over the temperature range of 273.16 K < T < 645 K.

$$\theta = \left(1 - \frac{T}{T_c}\right)$$

Here, T is the absolute temperature expressed in K.
In these equations, T_c = 647.096 K and ρ_c = 322 kg/m^3.

b_1 = 1.992 740 64	b_2 = 1.099 653 42	b_3 = -0.510 839 303
b_4 = -1.754 934 79	b_5 = -45.517 035 2	b_6 = -6.746 944 50 × 10^5

Write and run a MATLAB program that will calculate the density of water in kg/m^3 for any temperature in °C. As a trial, what is the density of water at 50.0°C?