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CHEMICAL ENGINEERING DEPARTMENT

3130507: Chemical Engineering Thermodynamics – I

Tutorial 01: Unit Conversion

Carry out the following unit conversion:

Prob. 1: $20\ \frac{\text{g}}{\text{m s}} = \_\_\_\_\_\_\_\_\_\_\_\_\ \frac{\text{lb}_\text{f}\ \text{h}}{\text{ft}^2}$

Prob. 2: $0.04\ \frac{g}{\min\ in^3} = \_\_\_\_\_\_\_\_\_\_\_\_\ \frac{lb_m}{h\ ft^3}$

Prob. 3: $2\ \frac{L}{s} = \_\_\_\_\_\_\ \frac{ft^3}{day}$

Prob. 4: What are the units of a & b in SI system of units for the following equation:

$$P = \frac{R\,T}{\left(\hat{V} - b\right)} - \frac{a}{T^{\frac{1}{2}}\hat{V}\left(\hat{V} + b\right)}$$

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Tutorial 02:

Prob. 1:

An elevator with a mass of 2500kg rests at a level 10 m above the base of an elevator shaft. It is raised to 100 m above the base of the shaft, where the cable holding it breaks. The elevator falls freely to the base of the shaft and strikes a strong spring. The spring is designed to bring the elevator to rest and, by means of a catch arrangement, to hold the elevator at the position of maximum spring compression. Assuming the entire process to be frictionless and taking $g = 9.8 \text{ m s}^{-2}$, calculate:

(a) The potential energy of the elevator in its initial position relative to the base of the shaft.
(b) The work done in raising the elevator.
(c) The potential energy of the elevator in its highest position relative to the base of the shaft.
(d) The velocity and kinetic energy of the elevator just before it strikes the spring.
(e) The potential energy of the compressed spring.
(f) The energy of the system consisting of the elevator and bring (1) at the start of the process, (2) when the elevator reaches its maximum height, (3) just before the elevator strikes the spring, (4) after the elevator has come to rest.

Prob. 2:

Nitrogen gas is confined in a cylinder and the pressure of the gas is maintained by a weight placed on the piston. The mass of the piston and the weight together is 50 kg. The acceleration due to gravity is 9.81 m/s^2 and the atmospheric pressure is 1.01325 bar. Assume frictionless piston.

Determine:

(a) The force exerted by the atmosphere, the piston, and the weight on the gas if the piston is 100 mm in diameter.
(b) The pressure of the gas.
(c) If the gas is allowed to expand pushing up the piston and the weight by 400 mm, what is the work done by the gas in J?
(d) What is the change in the potential energy of the piston and the weight after the expansion in part (c)?

Prob. 3:

A spherical balloon of diameter 0.5 m contains a gas at 1 bar and 300 K. The gas is heated and the balloon is allowed to expand. The pressure inside the balloon is found to vary linearly with the diameter. What would be the work done by the gas when the pressure inside reaches 5 bar?

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Tutorial 03:

Q. 1:

Calculate ΔU and ΔH for 1 kg of water when it is vaporized at the constant temperature of 373.15 K and constant pressure of 101.325 kPa. The specific volumes of liquid and vapor water at these conditions are 0.00104 and 1.673 $m^3\ kg^{-1}$. For this change, heat in the amount of 2256.9 kJ is added to the water.

Q. 2:

Air at 1 bar and 298.15 K is compressed to 5bar and 298.15 K by two different mechanically reversible processes:

(a) Cooling at constant pressure followed by heating at constant volume.

(b) Heating at constant volume followed by cooling at constant pressure.

Calculate the heat and work requirements and ΔU and ΔH of the air for each path. The following heat capacities for air may be assumed independent of temperature:

$C_V = 20.78\ J\ mol^{-1}\ K^{-1}$. and $C_P = 29.10\ J\ mol^{-1}\ K^{-1}$.

Assume also for air that the PV/T is a constant, regardless of the changes it undergoes. At 298.15 K and 1 bar the molar volume of air is 0.02479 $m^3\ mol^{-1}$.

Q. 3:

An electric current of 0.5A from a 12 V supply is passed for 5 minutes through a resistance in thermal contact with saturated water at 1 atm. As a result, 0.798 g of water is vaporised. Assuming that the water vapour behaves ideally, calculate the molar internal energy change and enthalpy change during this process.

Q. 4:

Steam at 1800 kPa and 673.15 K steadily enters a nozzle at a rate of 5 kg/s and leaves the nozzle at 1400 kPa with a velocity of 300 m/s. The inlet area of the nozzle is 0.02 m^2. Heat losses from the nozzle per unit mass of the steam are estimated to be 3.3 kJ/kg. Determine the exit temperature of the steam.

Q. 5:

Distinguish between internal energy, kinetic energy, and potential energy of a system.

Q. 6:

Why is the specific heat at constant pressure, C_P, always greater than that at constant volume, C_V?

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Tutorial 04:

Q. 1:

Calculate the change in internal energy, change in enthalpy, work done, and the heat supplied in the following processes:

(a) An ideal gas is expanded from 5 bar to 4 bar isothermally at 600 K.

(b) An ideal gas contained in a vessel of 0.1 m^3 capacity is initially at 1 bar and 298 K. It is heated at constant volume to 400 K.

(Assume that CP = 30 J/mol K.)

Q. 2:

Twenty kilograms of air is compressed from 1 bar, 300 K to 5 bar in a single stage compressor. The process is polytropic with n = 1.25. The specific heat of air at constant pressure in kJ/kmol K is:

$$C_p = 27.4528 + 6.1839\times10^{-3}\,T - 8.9932\times10^{-7}\,T^2$$

Determine:

(a) The work done by the compressor per cycle and

(b) The amount of heat transferred to the surroundings.

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Tutorial 05:

Q. 1:

Calculate the volume occupied by one mole of oxygen at 300 K and 100 bar using

(a) The ideal gas law

(b) The van der Waals equation.

Take a = 0.1378 N m^4/mol^2 and b = 3.18 x 10^{-5} m^3/mol.

Q. 2:

Find the second and third virial coefficients of the van der Waals equation when expressed in the form of equation:

$$Z = \frac{PV}{RT} = 1 + \frac{B}{V} + \frac{C}{V^2} + \ldots\ldots\ldots\ldots\ldots$$

Q. 3:

Calculate the compressibility factor and molar volume for methanol vapour at 500 K and 10 bar by using the following equations. Experimental values of virial coefficients are, B = –2.19x10^{-4} m^3/mol ; C = –1.73x10^{-8} m^6/mol^2. The critical temperature and pressure of methanol are 512.6 K and 81 bar.

(a) Truncated form of virial equation.

(b) Redlich–Kwong equation.

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Tutorial 06:

Q. 1:

Handbook values for the latent heats of vaporization in J g^{-1} are given in the table for several pure liquids at 273.15 K (0°C) and at T_n, the normal boiling point (App. B).

	ΔH^{lv} at 273.15 K (0°C)	ΔH^{lv} at T_n
Chloroform	270.9	246.9
Methanol	1189.5	1099.5
Tetrachloromethane	217.8	194.2

For one of these substances, calculate:

(a) The value of the latent heat at T_n by Eq. (4.13), given the value at 273.15 K (0°C).
(b) The value of the latent heat at T_n by Eq. (4.12).

By what percentages do these values differ from the one listed in the table?

Q. 2:

A method for determination of the second virial coefficient of a pure gas is based on the Clapeyron equation and measurements of the latent heat of vaporization ΔH^{lv}, the molar volume of saturated liquid V^l, and the vapor pressure P^{sat}. Determine B in $cm^3\ mol^{-1}$ for methyl ethyl ketone at 348.15 K (75°C) from the following data at this temperature:

$$\Delta H^{lv} = 31\,600 \text{ J mol}^{-1} \qquad V^l = 96.49 \text{ cm}^3 \text{ mol}^{-1}$$

$$\ln P^{sat}/\text{kPa} = 48.157543 - 5622.7/T - 4.705\,04 \ln T \qquad [T = \text{K}]$$

Q. 3: .

One hundred **kmol** per hour of subcooled liquid at 300 K and 3 bar is superheated to 500 K in a steady-flow heat exchanger. Estimate the exchanger duty (in kW) for one of the following:

(a) Methanol, for which $T^{sat} = 368.0$ K at 3 bar.
(b) Benzene, for which $T^{sat} = 392.3$ K at 3 bar.
(c) Toluene, for which $T^{sat} = 426.9$ K at 3 bar.

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Tutorial 07:

Q.1:
A boiler is fired with a high-grade fuel oil having a standard heat of combustion of -43515 J g^{-1} at 25 °C with CO_2(g) and H_2O(l) as products. The temperature of the fuel and air entering the combustion chamber is 25 °C. The air is assumed dry. The flue gas leaves at 300 °C, and their average analysis (on a dry basis) is 11.2% CO_2, 0.4% CO, 6.2% O_2 and 82.2% N_2. Calculate the fraction of the heat of combustion of the oil that is transferred as heat to the boiler.

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Tutorial 08:

Q.1:
A heat engine operates between a heat source at 700 K and a heat sink at 300 K. What is the maximum efficiency of the engine?

Q.2:
A new engine is claimed to be having a power output of 4.5 hp while receiving a heat input of 6.25 kW and working between the source and sink temperature limits of 1000 K and 500 K. Determine the efficiency of the proposed engine. Is the claim for the engine admissible?

Q.3:
A particular power plant operates with a heat-source reservoir at 623.15 K (350°C) and a heat-sink reservoir at 303.15 K (30°C). It has a thermal efficiency equal to 55% of the Carnot-engine thermal efficiency for the same temperatures.
(a) What is the thermal efficiency of the plant?
(b) To what temperature must the heat-source reservoir be raised to increase the thermal efficiency of the plant to 35%? Again 7 is 55% of the Carnot-engine value.

Q.4:
For an ideal gas with constant heat capacities undergoing a reversible adiabatic process, $\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{\frac{(\gamma-1)}{\gamma}}$.

Show that this same equation results from application of equation $\frac{\Delta S}{R} = \int_{T_0}^{T} \frac{C_P^{ig}}{R}\frac{dT}{T} - \ln\frac{P}{P_0}$ with ΔS=0.

Q.5:
What is the change in entropy when 1 kmol of an ideal gas at 335 K and 10 bar is expanded irreversibly to 300 K and 1 bar? C_P = 29.3 kJ/kmol K.

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Tutorial 09:

Q.1:

A vessel contains 1 kg of H_2O as liquid and vapor in equilibrium at 1000 kPa. If the vapor occupies 70% of the volume of the vessel, determine H and S for the 1 kg of H_2O.

Q.2:

A pressure vessel contains liquid water and water vapor in equilibrium at 450.15 K (177°C). The total mass of liquid and vapor is 1.36 kg. If the volume of vapor is 50 times the volume of liquid, what is the total enthalpy of the contents of the vessel?

Q.3:

Estimate the entropy change of vaporization of benzene at 323.15 K (50°C). The vapor pressure of benzene is given by the equation:

$$\ln P^{\text{sat}}/\text{kPa} = 13.8858 - \frac{2788.51}{T - 52.94}$$

Use following equation with estimated value of latent heat of vaporization.

$$\frac{dP^{\text{sat}}}{dT} = \frac{\Delta H^{lv}}{T \Delta V^{lv}}$$

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Tutorial 10:

Q.1:

Consider the steady-state, adiabatic, irreversible flow of an incompressible liquid in a horizontal pipe of constant cross-sectional area. Show that:

a) The velocity is constant.
b) The temperature increases in the direction of flow.
c) The pressure decreases in the direction of flow.

Q.2:

Saturated vapor steam at 100 kPa (Tsat = 372.78 K) is compressed adiabatically to 300 kPa.If the compressor efficiency is 0.75, what is the work required and what are the properties of the discharge steam?

Q.3:

Water at 318.15 K and 10 kPa enters an adiabatic pump and is discharged at a pressure of 8600 kPa. Assume the pump efficiency to be 0.75. Calculate the wrk of the pump, the temperature change of the water, and the entropy change of the water.

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Tutorial 11:

Q.1:

The contents of the freezer in a home refrigerator are maintained at 253.15 K (−20°C). The kitchen temperature is 293.15 K (20°C). If heat leaks amount to 125 000 kJ per day, and if electricity costs $0.08/kWh, estimate the yearly cost of running the refrigerator. Assume a coefficient of performance equal to 60% of the Carnot value.

Q.2:

A refrigeration system requires 1.5 kW of power for a refrigeration rate of 4 kW.

(a) What is the coefficient of performance?

(b) How much heat is rejected in the condenser?

(c) If heat rejection is at 313.15 K (40°C), what is the lowest temperature the system can possibly maintain?

Q.3:

A two-stage cascade refrigeration system (see Fig. 9.3) operates between $T_C = 210$ K and $T_H = 305$ K. Intermediate temperatures are $T_C' = 255$ K and $T_H' = 260$ K. Coefficients of performance ω of each stage are 65% of the corresponding values for a Carnot refrigerator. Determine ω for the real cascade, and compare it with that for a Carnot refrigerator operating between T_C and T_H.