COVENANT UNIVERSITY NIGERIA

TUTORIAL KIT
OMEGA SEMESTER

PROGRAMME: CHEMICAL ENGINEERING

COURSE: CHE 320

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CHE320: CHEMICAL ENGINEERING PROCESS ANALYSIS I

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Q1. Distinguish amongst the three types of a system.

Q2. A house is 4500 ft² and has 12 ft ceilings. For comfort, the home owner specifies 0.3 changes of air per hour. The outside air temperature is 90°F dry bulb and 73.5° wet bulb. The air indoors is 75°F dry bulb 50% relative humidity. What is the amount of cooling required to provide the fresh air?

Q3(i) State three reasons for studying energy balances of industrial processes.

(ii) Distinguish succinctly between extensive and intensive properties, giving two examples in each property.

Q4. Given the ambient temperature is 70°F measured by a dry bulb thermometer and 60°F measured by a wet bulb thermometer, what is the relative humidity?

Q5. Distinguish succinctly between path and point functions with illustration, and give two examples of each function.
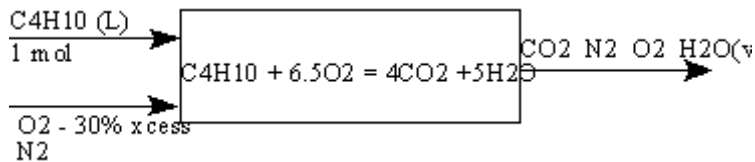
Q6. What is the heat duty for a mixer that mixes 9.2 moles of H_2O with 1 mole of 0.2 mole fraction H_2SO_4 if the inlet and outlet streams are all to be at 25°C?

Q7. Calculate the heat required in kJ to raise 200 kg of nitrogen (I) oxide, N_2O, from 35°C to 250°C in a constant-volume vessel if the heat capacity, C_v, of N_2O at constant volume in this temperature range is given by:

$$\frac{C_v}{R} = 4.328 + 1.214 \times 10^{-3} T - 0.928 \times 10^5 T^{-2}$$ [=] dimensionless, C_v [=] J/(mol K) and T [=] K

(ii) Neon gas is to be heated in an insulated plasma deposition chamber with a volume of 4.5 l by an electric resistance heater. Initially, the gas, which can be treated as an ideal gas, is at 3.5 Pa and 375 K. The 1500-ohm heater draws current at 65V for 15 minutes. What are the final gas temperature and pressure at equilibrium? The mass of the heater is 25 g and its heat capacity is 0.35 J/(g K). Assume that the heat transfer to the chamber from the gas at this low pressure and in the short time is negligible. The molal heat capacity, C_p, of the gas is 2.5R J/(mol K).

Q8. Calculate the adiabatic flame temperature of liquid butane burned with 30% excess air. Both the air and liquid butane enter at 25°C.

```
C4H10 (L)
1 mol                            CO2 N2 O2 H2O(v
          C4H10 + 6.5O2 = 4CO2 +5H2O

O2 - 30% xcess
N2
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Q9.   If an ideal gas at 350 K and 250 kPa is enclosed in a cylinder by a frictionless piston, and the gas slowly forces the piston up so that the volume of gas expands from 0.2 to 0.4 m³, calculate the work done by the gas on the piston if two different paths are used to go from the initial state to the final state [R=8.314 J/(mol K)]:

Path I: expansion occurs at constant pressure (p = 250 kPa).

Path II: expansion occurs at constant temperature (T = 350 K).

Sketch the p-V diagram for both paths.

(ii)   Air is being compressed from 100 kPa and 255 K (where it has an enthalpy of 489 kJ/kg) to 1000 kPa and 278 K (where it has an enthalpy of 509 kJ/kg). The exit velocity of the air from the compressor is 75 m/s. What is the power required (in kW) for the compressor if the load is 150 kg/h of air? The molecular weight of air is 28.9.

Q10. Methane is burned with 5% excess air in a furnace. Fig below shows the stream compositions and those variables whose values are specified. The process occurs with each stream at 1atm. Determine if the number of degrees of freedom for the process is zero.

 A table is needed to make the count of the variables and equilibrium.

The Energy balance is assumed to reduce to

Q = ΔH; replaced as a variable with p and T

Number of variables in the process :

Species in   F1   1

             F2   2

             F3   5

Total no of species is 8

Total Stream Flows   3

Stream temperature   3

Stream Pressure   3

Q   1

Extent of reaction

(2 reactions)   2

Total   20

Q11. The molal heat capacity, C_p, of n-butane at constant pressure is expressed as:

$$\frac{C_p}{R} = 1.935 + 36.915 \times 10^{-3}T - 11.402 \times 10^{-6}T^2$$ [=] dimensionless, C_p [=] J/(g mol K) and T [=] K
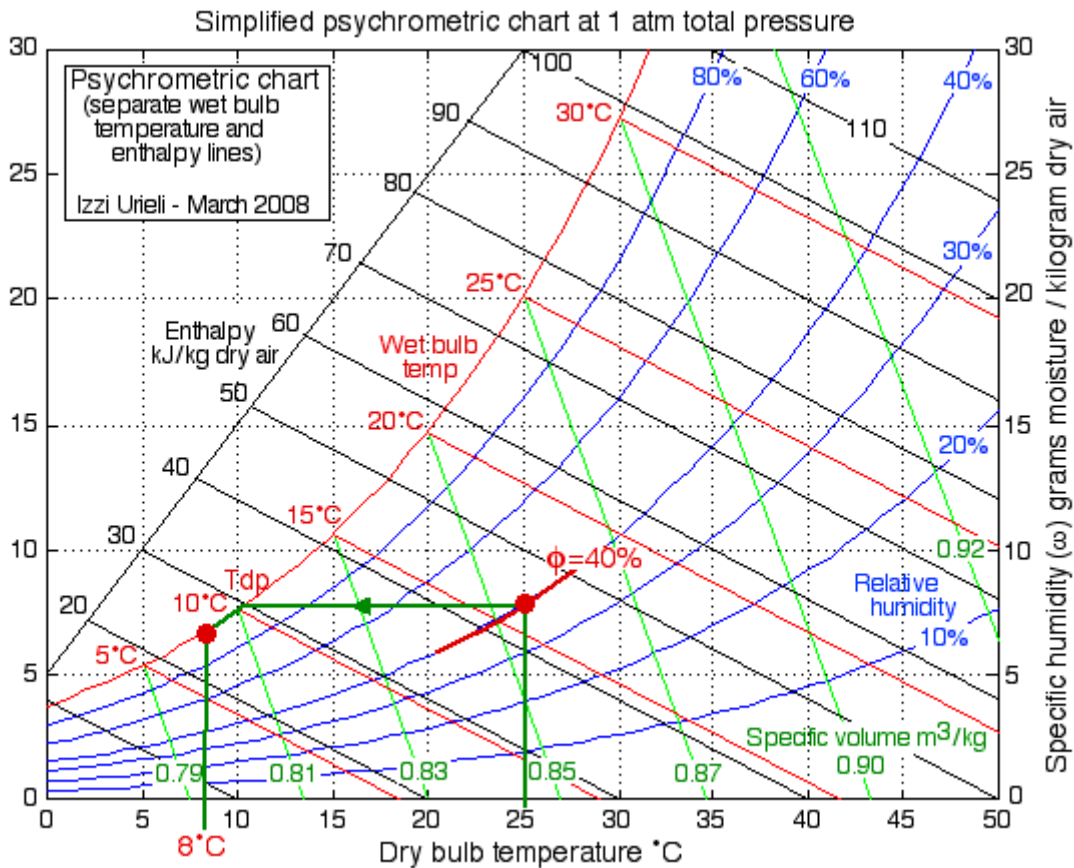
Convert this equation into a form so that the specific heat capacity can be expressed over the entire temperature range in J/(kg °C).

Q12. The conversion of solid wastes to innocuous gases can be accomplished in incinerators in an environmental acceptable fashion. However, hot exhaust gases often must be cooled or diluted with air. An economic feasibility study indicates that solid municipal waste can be burned to a gas of the following composition (on a dry basis): CO_2: 9.2%; CO: 1.5%; O_2: 7.3% and N_2: 82.0%. What is the enthalpy difference for this gas per g mol between the bottom and the top of the stack if the temperature at the bottom of the stack is 300°C and the temperature at the top is 95°C? Ignore the water vapour in the gas.   Neglect any energy effects resulting from the mixing of the gaseous components. Assume ideal gas mixture. The heat capacity equations are given in the table below.

Component	a	$b \times 10^2$	$c \times 10^5$	$b \times 10^9$
CO_2	36.11	4.233	-2.887	7.464
CO	28.95	0.4110	0.3548	-2.220
O_2	29.10	1.158	-0.6076	1.311
N_2	29.00	0.2199	0.5723	-2.871

with $C_p = a + bT + cT^2 + dT^3$ [=] J/(mol °C) and T [=]°C.

Q13. Assume that the outside air temperature is 8°C. If the air in a room is at 25°C with a relative humidity ϕ = 40%, use the psychrometric chart to determine if the windows of that room which are in contact with the outside will become foggy.

Simplified psychrometric chart at 1 atm total pressure

Q14. Calculate the enthalpy change of 1 kg of water from ice at 0°C to vapour at 120°C and 100 kPa. The latent heat of fusion of ice, $\Delta \hat{H}_f = 335 J/(g\ °C)$ at 0°C and latent heat of vaporization of steam, $\Delta \hat{H}_v = 2256 J/(g\ °C)$ at 100°C. The heat capacity equations are:

$$C_{p,liquid} = 18.296 + 47.212 \times 10^{-2} T_K - 133.88 \times 10^{-5} T_K^2 + 1314.2 \times 10^{-9} T_K^3\ [=]\ J/(g\ mol\ K)$$

$$C_{p,vapour} = 33.46 + 0.6880 \times 10^{-2} T_{°C} + 0.7604 \times 10^{-5} T_{°C}^2 - 3.593 \times 10^{-9} T_{°C}^3\ [=]\ J/(g\ mol\ °C)$$

(ii)   2.5 lb steam is cooled from 640°F and 92 psia to 480°F and 52 psia. Using the specific enthalpy values given in Table 9.1, calculate the enthalpy change in Btu.

Table 9.1. Specific enthalpy values of steam at different temperatures and pressures.

Pressure/psia	$\Delta \hat{H}_{600°F}$	$\Delta \hat{H}_{700°F}$
90	1328.7	1378.1
95	1328.4	1377.8
Pressure/psia	$\Delta \hat{H}_{400°F}$	$\Delta \hat{H}_{500°F}$
50	1258.7	1282.6
55	1258.2	1282.2

Q15.   Steam, that is used to heat a biomass, enters the steam chest, which is segregated from the biomass, at 250ºC saturated, and is completely condensed in the steam chest. The rate of the heat loss from the steam chest to the surroundings is 1.25 kJ/s. The reactants are placed in the vessel at 25ºC and at the end of the heating, the material is at 100ºC. If the charge consists of 250 kg of material with an average heat capacity, $C_p = 4.28$ J/(g K), how many kilograms of steam are needed per kg of charge?

The charge remains in the reaction vessel for 1 h. The specific heat of vaporization, $\Delta \hat{H}$, of saturated steam at 250ºC is 1701 kJ/kg.

Q16.   If air temperature of 90 F and a relative humidity of 50%. We'll figure out the mixing ratio and the dew point temperature. The problem is worked out in detail below:

First you fill in the air temperature and the RH data that you are given.

(A) since you know the air's temperature you can look up the saturation mixing ratio (30 g/kg).

(B) Then you might be able to figure out the mixing ratio in your head. Air that is filled to 50% of its capacity could hold up to 30 g/kg. Half of 30 is 15, that is the mixing ratio. Or you can substitute into the relative humidity formula and solve for the mixing ratio (the details are shown above).

Finally, to determine the dew point, we imagine cooling the air. The saturation mixing ratio decreases, the mixing ratio stays constant, and the relative humidity increases.   In this example the RH reachs 100% when the air has cooled to 70 F. That is the dew point temperature.

Q18. Question: An air conditioning system is not working well. The temperature of the evaporator coil is 53°F. The air in the room is at 76°F and 40% relative humidity. Will the air conditioner remove moisture from this air?

Q19. Water is being pumped from the bottom of a well 5 m deep at the rate of 1.0 m³/h into a vented storage tank to maintain a level of water in a tank 20 m above the ground. To prevent freezing, a small heater puts 4.20×10^7 J/h into the water during its transfer from the well to the storage tank. Heat is lost from the whole system at the constant rate of 2.70×10^7 J/h. What is the temperature of the water as it enters the storage tank, assuming that the well water is at 10ºC? A 2-horsepower (hp) pump is being used to pump the water. About 75% of the rated horsepower goes into the work of pumping and the rest is dissipated as heat to the atmosphere. The specific heat capacity of water is 4200 J/(kg ºC).

Q20. A house is 4500 ft² and has 12 ft ceilings. For comfort, the home owner specifies 0.3 changes of air per hour. The outside air temperature is 90°F dry bulb and 73.5° wet bulb. The air indoors is 75°F dry bulb 50% relative humidity. What is the amount of cooling required to provide the fresh air?

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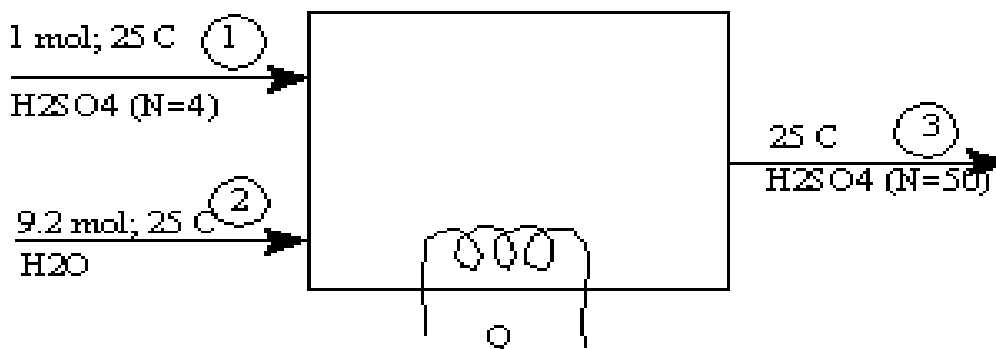**CONTRIBUTORS: DR. OLAFADEHAN. ENGR. (MRS) OJEWUMI M. E & MRS OLADIMEJI TEMITAYO**

(Q2):

 The total volume of the house is 4500 x 12 = 54,000 ft³. We need to change 54,000 x 0.3 = 16,200 ft³/hour (which equates to 270 ft³/minute or cfm). From the psychrometric chart, the enthalpy of the incoming air is 37.0 BTU/lb and the specific volume is 14.2 ft³/lb. Therefore the energy of the incoming air is 16,200 x 37 / 14.2 = 42,211 BTU/hour. Similarly, the enthalpy of the air indoors is 16,200 x 28.1 / 13.7 = 33,228 BTU/hour. The heat difference is 8,984 BTU/h, or about 0.75 tons.

Q4:

 Look at horizontal axis to find 70°F. Move a pencil up this line to meet the intersection with the diagonal line for 60°F. Identify that this point falls just over half way between the lines of relative humidly for 50% and 60%. The answer is 56% relative humidity.

Q6:

The heats of mixing given in Table Below are recorded in terms of a variable r which is the moles of water per mole of solute. We must first find this value of r (shown, however, as N in the figure below) in order to obtain the value from the table.

The energy balance for this system is

$$Q = n_3h_3 - n_1h_1 - n_2h_2$$

We need to find the enthalpy of each stream **relative to a reference enthalpy**. We can do this because we are always interested in a difference in enthalpies and so the reference will always cancel out. But, we must be sure that we choose the same reference for each stream so that the cancellation really does occur. In this case, we choose the pure components at 25°C as the reference enthalpy relative to which we will find the values of all the streams.

Stream 1:
Stream 1 is a mixture of sulfuric acid and water at 25°C. It's enthalpy relative to the pure references is simply the heat of mixing for this mixture since the pure enthalpies are identically zero by definition of the reference: $h_m = x_1h_1 + x_2h_2 + \Delta h_{mix} = 0 + 0 + \Delta h_{mix} = \Delta h_{mix}$. Therefore, we find r for this mixture in the following way, where A represents acid and W water:

$x_A = n_A/(n_W + n_A) = 0.2 = n_A/1\ mol =====>$ $n_A = 0.2\ mol$ and $n_W = 0.8\ mol$

so $r = n_W/n_A = (0.8\ mol)/(0.2\ mol) = 4.0$

From Table B.11, we therefore obtain $h_1 = -54.06\ kJ/mol\ A$

Stream 2:
This stream is pure water which is the reference state. Therefore, relative to the reference state,

$h_2 = 0$

Stream 3:
We now do a mass balance to find r for the outlet stream. The acid balance tells us that 0.2 moles of A end up in the mixture and the water balance says that 9.2 + 0.8, or 10 mol of water ends up in the final mixture. Thus,

$r = n_W/n_A = (10\ mol)/(0.2\ mol) = 50$

From Table B.11, we obtain $h_3 = -73.34\ kJ/mol\ A$

Now we complete the energy balance to obtain:

$Q = (0.2\ mol\ A)(-73.34\ kJ/mol\ A + 54.06\ kJ/mol\ A) =$ **-3.9 kJ**

Q8:

First we will perform the mass balance calculations so that we know the number of moles of each component in the inlet and outlet streams.

Mass Balances
in: $n^{\circ}_{O2} = (1\ mol)(6.5)(1.3) = 8.45\ mol$ note: 1.3 is the 30% excess O_2
        $n^{\circ}_{N2} = (79/21)n^{\circ}_{O2} = 31.79\ mol$

out: $n_{O2} = 8.45\ mol - (1\ mol)(6.5) = 1.95\ mol$
        $n_{CO2} = (1\ mol)(4) = 4\ mol$
        $n_{H2O} = (1\ mol)(5) = 5\ mol$
        $n_{N2} = n^{\circ}_{N2} = 31.79\ mol$

Energy Balances
Next we will set up the energy balance.

$Q = H_{out} - H_{in}$

We will calculate the change in enthalpy from the inlet to the outlet stream by using a path of our choice. As was explained at the top of this page, the easiest path is to react the materials at the inlet temperature and then heat everything in the outlet stream up to the final temperature. Thus, we write,
Since adiabatic,

$$0 = \xi \Delta \tilde{H}_r(25^\circ C) + \sum_i n_i \int_{25}^{T} \tilde{C}_{P_i} dT$$

where Q has been set to zero since we are finding the maximum or adiabatic flame temperature.

The heat of reaction at 25°C is easily found from the heat of combustion of propane. Note that it is not exactly the heat of combustion because the water formed by the reaction is vapor whereas it must be in the liquid phase for the heat of combustion to apply directly. By combining the combustion reaction with the "reaction" of liquid water going to vapor so that the liquid terms cancel, we find that the heat of reaction for this process is:

$\Delta H_r = \Delta H_c + 5\Delta H_{vap,H2O}(25^\circ C)$ = -2855.6 kJ/mol + 5(44.01 kJ/mol) = -2635.5 kJ/mol

The sensible enthalpy term is evaluated from the heat capacities of everything in the outlet stream. Don't forget to include the nitrogen in the air and the excess oxygen. All of these will be in the product stream and will absorb some of the heat produced by the combustion process, thereby affecting the final computed adiabatic flame temperature. Combining the heat of reaction term with the heat capacity terms shown in the energy balance gives,

$$\therefore 2635.5 kJ = (1.95 mol)\int_{25}^{T} \tilde{C}_{P_{O_2}} dT + (4\ mol)\int_{25}^{T} \tilde{C}_{P_{CO_2}} dT + (5\ mol)\int_{25}^{T} \tilde{C}_{P_{H_2O}} dT$$
$$+ (31.79 mol)\int_{25}^{T} \tilde{C}_{P_{N_2}} dT$$

The heat capacities will be a function of temperature. The final temperature, the upper limit for the integrals, will therefore be the only remaining unknown. We can therefore solve for the adiabatic flame temperature using an appropriate solver.

Q10:

A table is needed to make the count of the variables and equilibrium.

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Number of variables in the process :

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                F3   5

Total no of species is 8

Total Stream Flows   3

	Stream temperature	3
	Stream Pressure	3
	Q	1
	Extent of reaction	
	(2 reactions)	2
	Total	20

Q12.)

Component	a	$b \times 10^2$	$c \times 10^5$	$b \times 10^9$
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Q14.

The heat capacity equations are:

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Q18.

Look at the horizontal axis to find 76°F. Move a pencil up this line to meet the intersection with the exponential line for 40% relative humidity. Move the pencil to the right to read the dew point. This is 50°F. The evaporator coil is warmer than the dew point so it will not condense water from the air.

Q20.

The total volume of the house is 4500 x 12 = 54,000 ft³. We need to change 54,000 x 0.3 = 16,200 ft³/hour (which equates to 270 ft³/minute or cfm). From the psychrometric chart, the enthalpy of the incoming air is 37.0 BTU/lb and the specific volume is 14.2 ft³/lb. Therefore the energy of the incoming air is 16,200 x 37 / 14.2 = 42,211 BTU/hour. Similarly, the enthalpy of the air indoors is 16,200 x 28.1 / 13.7 = 33,228 BTU/hour. The heat difference is 8,984 BTU/h, or about 0.75 tons.