

Introduction to Chemical Engineering I

Problem Sheet 7

Problem 1 (Midterm 2022)

In the acetic anhydride process, 100mol/h of a process stream consisting of 4% moles ketene, 10% moles acetic acid and the remainder in equimolar proportions methane and carbon dioxide at 700°C is to be cooled to 400°C. To achieve such requirements, the input gas is quenched (mixed) with glacial acetic acid at 50°C.

- A. Given the data below, calculate the flow rate of quench acetic acid required and the composition of the cooled gas.
- B. Suppose now that the flow of cooling acetic acid is 40mol/h. Calculate the outlet gas temperature

	Gas Heat Capacities (cal/gmol*K)			
	a	b*10 ²	c*10 ⁵	d*10 ⁹
CH ₄	4.750	1.2	0.303	-2.63
CO ₂	6.393	1.01	-0.3405	-
CH ₃ COOH	8.20	4.805	-3.056	8.31
CH ₂ O	4.11	2.966	-1.793	4.72

$$\Delta H_{VL}(\text{CH}_3\text{COOH}, 391.4\text{K}) = 5.83 \text{ kcal/gmol}$$

$$C_{p,\text{mean}}(\text{CH}_3\text{COOH}, \text{liquid}) = 36 \text{ cal/gmol} \cdot \text{K}$$

Only use the 2 first terms for the heat capacities (a & b)

Problem 2

Ralph Rackstraw, your next-door neighbor, surprised his wife last January by having a hot tub installed in their back yard while she was away on a business trip. It surprised her, all right, but instead of being pleased she was horrified. "Have you lost your mind, Ralph?" she sputtered. "It will cost a fortune to keep this thing hot." "Don't be silly, Josephine," he replied. "It can't cost more than pennies a day, even in the dead of winter." "No way—and when did you become such an expert, anyway?" "I guarantee it will cost nothing—and I don't see your Ph.D. certificate on the kitchen wall either." They argued for awhile and then, remembering your chemical engineering education, came to ask you to settle it for them. You asked a few questions, made several observations, converted everything to metric units, and arrived at the following data, all corresponding to an average outside air temperature of about 5°C .

- The tub holds 1230 liters of water.
- Rackstraw normally keeps the tub temperature at 29°C , raises it to 40°C when he plans to use it, keeps it at 40°C for about one hour, and drops it back to 29°C when he is finished.
- During heating, it takes about three hours for the water temperature to rise from 29°C to 40°C . When the heat is shut off, it takes eight hours for the water temperature to drop back to 29°C .
- Electricity costs 10 cents per kilowatt-hour.

Taking the heat capacity of the tub contents to be that of pure liquid water and neglecting evaporation, answer the following questions.

- (a) What is the average rate of heat loss (kW) from the tub to the outside air? (*Hint:* Consider the period when the tub temperature is dropping from 40°C to 29°C .)
- (b) At what average rate (kW) does the tub heater deliver energy to the water when raising the water temperature? What is the total quantity of electricity (kW·h) that the heater must deliver during this period? [Consider the result of part (a) when performing the calculation.]
- (c) (These answers should settle the argument.) Consider a day in which the tub is used once. Use the results of parts (a) and (b) to estimate the cost (\$) of heating the tub from 29°C to 40°C and the cost (\$) of keeping the tub at a constant temperature. (There is no cost for the period in which T is dropping.) What is the total daily cost of running the tub? Assume the rate of heat loss is independent of the tub temperature.
- (d) The tub lid, which is an insulator, is removed when the tub is in use. Explain how this fact would probably affect your cost estimates in part (c).