Problem 1 (26%)

(a) Consider a simple enzyme reaction E + S ⇌ ES → E + P, where E, S, ES, and P stand for enzyme, substrate, enzyme-substrate complex, and product, respectively. Show that the rate equation for the simple enzyme reaction can be described by the Michaelis-Menten equation:

$-r_S = \dfrac{r_{\max} C_S}{K_M + C_S}$, where the symbols remain their meanings defined in textbooks. (10%)

(b) Estimate the Michaelis constant (K_M) and the maximum initial rate (r_{max}) for the following enzyme kinetic data. The units must be included with your answers. (8%)

Substrate concentration, C_s (μmol/L)	Initial reaction rate, $-r_S$ (nM/min)
3.7	20
13	60
39	126
79	174
230	232
400	244

(c) The inhibitory mechanism for inhibitor I can be described with the following reactions.
E + S ⇌ ES → E + P
E + S ⇌ ES + I ⇌ EIS → no reaction
E + I ⇌ EI + S ⇌ EIS → no reaction
Tell how the presence of inhibitor I affects K_M and r_{max}, and explain why. (8%)

Problem 2 (24%)

A substrate is converted to a product by the catalytic action of an enzyme, E + S ⇌ ES → E + P, and the Michaelis-Menten kinetic parameters for this enzyme reaction are: K_M = 0.03 mol/L and r_{max} = 13 mol/L min.

(a) What should be the size of a steady-state CSTR to convert 95 percent of incoming substrate (C_{S0} = 10 mol/L) with a flow rate of 10 L/hr? (12%)

(b) What should be the size of the reactor if you employ a PFR instead of the CSTR in part (a)? (12%)

Problem 3 (5%)

In the absence of any friction and other irreversibilities, can a heat engine have an efficiency of 100 percent?

Problem 4 (3%)

A substance whose Joule-Thomson coefficient is negative is throttled to a lower pressure. During this process, (select the correct statement)

(a) the temperature of the substance will increase.
(b) the temperature of the substance will decrease.
(c) the entropy of the substance will remain constant.
(d) the entropy of the substance will decrease.
(e) the enthalpy of the substance will decrease.

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Problem 5 (5%)

What does it imply if the compressibility factor is larger than 1?

Problem 6 (12%)

Evaluate the following partial derivatives as functions of P, V, T, their partial derivatives and C_p

(a) $(\partial S / \partial P)_G$; (6%)

(b) $(\partial A / \partial G)_T$. (6%)

Problem 7 (25%)

A cylinder/piston contains air at ambient conditions, 101.3 kPa and 21°C with a volume of 0.283 m^3. The air is compressed to 689.5 kPa in a reversible polytropic process with exponent, $n = 1.2$, after which it is expanded back to 101.3 kPa in a reversible adiabatic process.

(a) Show the two processes in P–v and T–s diagrams. (10%)

(b) Determine the final temperature and the net work. (10%)

(c) What is the potential refrigeration capacity of the air at the final state? (5%)