PRELIM 1

VERSION: DELTA-1

NAME:

1. Prelim 1 has *two* problems and is worth a total of 50 points.
2. You may use your course notes (on the computer, iPad, etc., or paper) or other course materials, e.g., discussion problems, to formulate your solutions.
3. Do not consult with any other person regarding the prelim (except the TAs or JV), or use *any form of electronic communication* to discuss the prelim questions. Violation of this policy will result in a ZERO for the prelim.
4. Do not consult the interwebs to search for the prelim questions/solutions. Violation of this policy will result in a ZERO for the prelim.
5. Show your work and state all assumptions or simplifications.
6. Good luck!

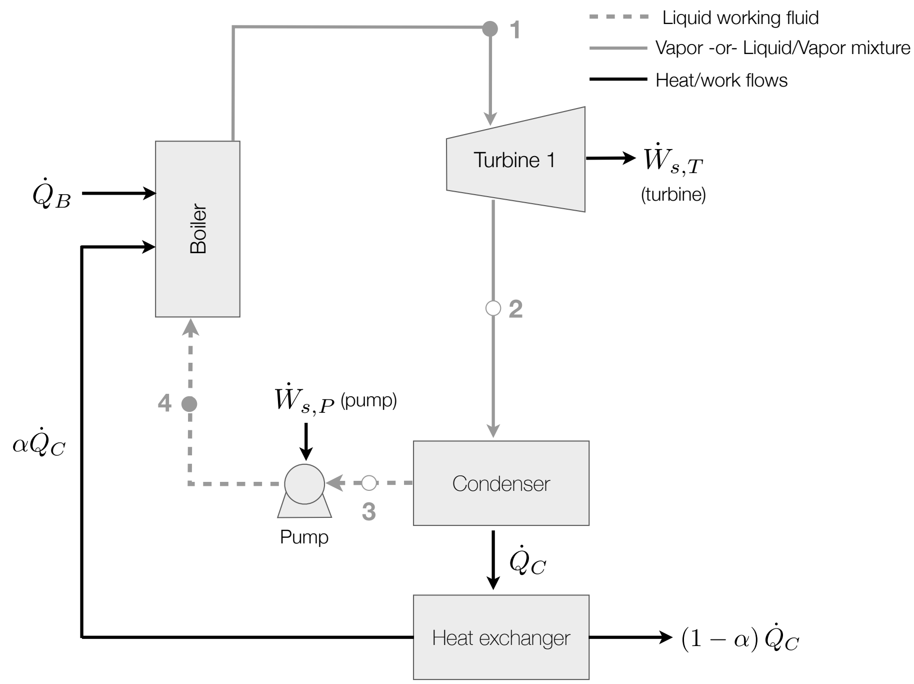

Figure 1: Schematic of the unit operations of a modified organic Rankine cycle in which a fraction of the heat from the condenser is recycled to the boiler through a heat exchanger.

1. (30 pt) The Organic Rankine Cycle (ORC) is an *open* four step thermodynamic process used to generate power that uses organic compounds as working fluids (Fig. 1). In the cycle, path $\mathcal{P}_{ij}$ connects operating point $\mathcal{O}_i$ to $\mathcal{O}_j$:

   $\mathcal{P}_{41}$ $(4 \rightarrow 1)$: *isobaric* heating in a boiler from operating point $\mathcal{O}_4$ to $\mathcal{O}_1$

   $\mathcal{P}_{12}$ $(1 \rightarrow 2)$: *adiabatic* expansion in a turbine from operating point $\mathcal{O}_1$ to $\mathcal{O}_2$

   $\mathcal{P}_{23}$ $(2 \rightarrow 3)$: *isobaric* cooling in a condenser from operating point $\mathcal{O}_2$ to $\mathcal{O}_3$

   $\mathcal{P}_{34}$ $(3 \rightarrow 4)$: *adiabatic* compression in a pump from operating point $\mathcal{O}_3$ to $\mathcal{O}_4$

   Nomenclature: $\dot{W}_{s,T}$ denotes the rate of turbine shaft work (units: kJ s^{-1}); $\dot{W}_{s,P}$ denotes the rate of pump shaft work (units: kJ s^{-1}); $\dot{Q}_B$ denotes the rate of heat input/output to/from the boiler (units: kJ s^{-1}); $\dot{Q}_C$ denotes the rate of heat input/output to/from the condenser (units: kJ s^{-1})

   Assume: (i) the cycle operates at steady-state; (ii) the working fluid (HFC-134A) has a mass flow rate of $\dot{m}$ = 2.25 kg s^{-1}; (iii) *neglect* the enthalpy and temperature change from the pump (assume $T_3 \simeq T_4$ and $H_3 \simeq H_4$); (iv) neglect changes in the kinetic and potential energy in the system and streams; (v) the turbine efficiency η_T = 85%.

a) (12 pt) Compute the missing state values in Table 1.

b) (12 pt) Compute the missing values in Table 2 without heat recycle (α = 0).

c) (3 pt) Compute the ideal organic Rankine cycle efficiency: $\eta = -\dot{W}_{net}/\dot{Q}_B$ if there is no heat recycle (α = 0).

d) (3 pt) Compute the ideal organic Rankine cycle efficiency if α = 0.33. Does the efficiency increase, decrease or stay the same when compared with c)?

Table 1: State table for the ideal Rankine cycle problem with heat recycle.

$\mathcal{O}$	T (^{o}C)	P (MPa/kPa)	H (kJ kg^{-1})	S (kJ kg^{-1} K^{-1})	Quality θ
$\mathcal{O}_1$	80.0	2.0 MPa		1.75	1.0
$\mathcal{O}_2$		29.41 kPa		1.75	
$\mathcal{O}_3$					
$\mathcal{O}_4$				0.7428	0.0

Table 2: Heat and work table for the Rankine cycle problem with heat recycle (α = 0).

Path	$\dot{Q}$ (kW)	(ideal) $\dot{W}_s$ (kW)	(actual) $\dot{W}_s^*$ (kW)
$\mathcal{P}_{12}$	0		
$\mathcal{P}_{23}$		0	0
$\mathcal{P}_{34}$	N/A	N/A	N/A
$\mathcal{P}_{41}$		0	0
Cycle			N/A

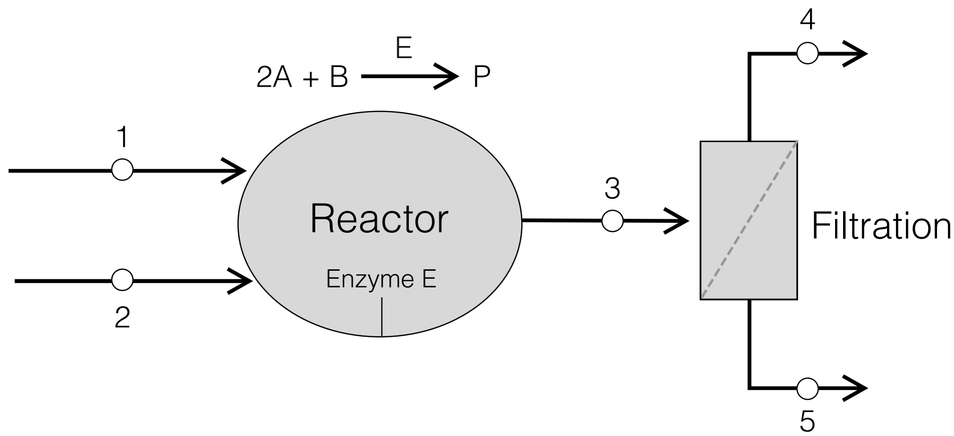

Figure 2: Starting material(s) A and B are converted to product P by enzyme E in a well-mixed reactor with volume V. The reactor is well insulated. The output from the reactor is fed into a filtration unit that separates reactants and products.

2. (20 pt) Consider the reaction/separation process shown in Fig. 2. In a well-mixed and well-insulated reactor, starting material(s) A and B are converted to the product P by enzyme E. The enzyme E is immobilized in the reactor (does not flow out) and is stable. Downstream of the reactor, a filtration device separates unreacted starting material(s) A and B from product P.

   Assume: (i) the reactor and filtration units operate at steady-state; (ii) let species (A, B, P) have indexes $(1, 2, 3)$; (iii) there is no product in the input streams

   a) (16 pt) Compute the missing values in Table 3 if the open extent of reaction $\dot{\epsilon}_1$ was measured to be 26.8 mmol min^{-1}.

   b) (2 pt) Derive an expression for the fractional conversion of species i, denoted by $f_i \geq 0$ for the reactor configuration shown in Fig. 2.

   c) (2 pt) Using the expression from b), compute the fractional conversion for species A and B.

Table 3: State table for the reaction/filtration problem; $\dot{n}_{s,T}$ denotes the total mole flow rate in stream s, $x_{s,1}$ denotes the mole fraction of component 1 (A) in stream s, $x_{s,2}$ denotes the mole fraction of component 2 (B) in stream s, and $x_{s,3}$ denotes the mole fraction of component 3 (P) in stream s.

Stream i	$\dot{n}_{s,T}$ (mmol/min)	$x_{s,1}$	$x_{s,2}$	$x_{s,3}$
1	95	1.0	0.0	0.0
2	45	0.11	0.89	0.0
3				
4				
5	59.54	0.77	0.22	0.01