CM

ROSE-HULMAN
INSTITUTE OF TECHNOLOGY

Name

ME301 – Applications of Thermodynamics

Exam 2

Oct 31, 2019

Circle section: **01** [3rd Mertz] **02** [3rd Thom] **03** [4th Thom] **04** [3rd Cloutier] **05** [4th Cloutier]

Rules:
- Closed book/notes exam.
- Two help sheets allowed. (8-1/2 x 11" sheets of paper, one side, handwritten; may not contain worked out example problems)
- Maple, Excel, and MATLAB are allowed on your laptop, but nothing may be prepared before the exam.
- Either open property tables (hardcopies) or open Property Calculator Programs on your laptop.

Instructions:
- Show all work for complete credit.
- Work in symbols first, plugging in numbers and performing calculations last.

Problem 1	________/ 26
Problem 2	________/ 38
Problem 3	________/ 36
Total	________/100

PROBLEM 1 [26 points]

(a) **True | False** For a thermodynamic cycle, $w_{\text{net,out}} = q_{\text{net,in}}$.

True | False A power cycle is always oriented counterclockwise on a *p-v* diagram.

True | False For the components comprising an ideal gas mixture, the mole fractions and mass fractions are related by $mf_i = y_i M_i$.

True | False $w_{\text{net,out}} > 0$ for a refrigeration cycle.

True | False Increasing the boiler pressure in a Rankine cycle tends to increase the cycle's thermal efficiency.

True | False The throttling process in a refrigeration cycle is internally reversible.

True | False A refrigeration cycle is always oriented clockwise on a *T-s* diagram.

True | False By Dalton's Model, each component of an ideal gas mixture behaves as an ideal gas as if it were alone at the temperature and volume of the mixture.

True | False For an ideal gas, specific volume is a function of temperature only, $v = v(T)$.

(b) An ideal vapor-compression refrigeration cycle operates with a heat transfer rate out of the condenser of $\dot{Q}_{\text{out}} = 105$ kW and a heat transfer rate into the evaporator of $\dot{Q}_{\text{in}} = 83$ kW. Find the coefficient of performance (COP) assuming:

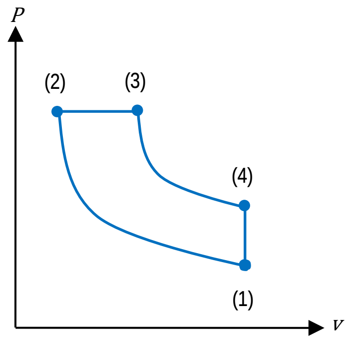
i. the cycle functions as a refrigerator.

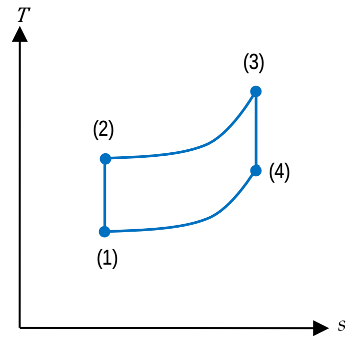
ii. the cycle functions as a heat pump.

PROBLEM 2 [38 points]

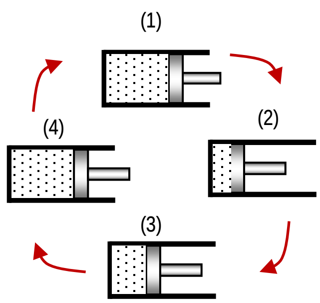
A closed-system/periodic cycle consists of the following processes:

(1)→(2) Reversible, adiabatic compression
(2)→(3) Constant pressure heat addition
(3)→(4) Reversible, adiabatic expansion
(4)→(1) Constant volume heat rejection





The cycle operates with a compression ratio of $r = v_1/v_2 = 18.2$. Other state information and some energy transfers are given in the tables. **Assume an air-standard cycle** with R_a=0.287 kJ/kg-K.



(You do not need to fill in all property values.)

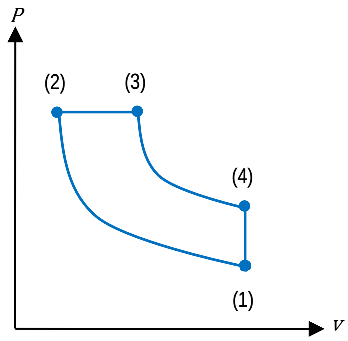
State	T [K]	P [kPa]	h [kJ/kg]	u [kJ/kg]	s^o [kJ/kg·K]	P_r	v_r
1	380	100	380.77	271.69	1.94	3.176	343.4
2							
3	1900		2127.40	1581.81	3.735	1655	3.295
4	896	235.9	929.16	671.25	2.843	73.03	34.77

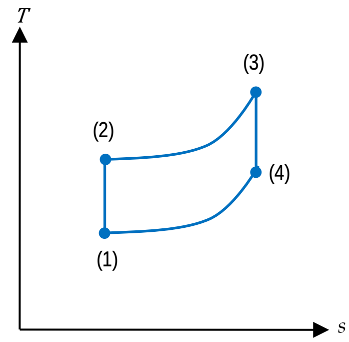
	q_{in}[kJ/kg]	w_{in}[kJ/kg]
1→2	?	?
2→3	966.33	?
3→4	0	-910.56
4→1	-399.6	0

(a) Find the temperature and pressure at state (2), T_2 and P_2.
(b) Find the unknown values of heat transfer per unit mass, $q_{A\rightarrow B}$, and the work per unit mass, $w_{A\rightarrow B}$ for the cycle.
(c) Find the cycle efficiency.

PROBLEM 2 [cont'd]

(1)→(2) Reversible, adiabatic compression
(2)→(3) Constant pressure heat addition
(3)→(4) Reversible, adiabatic expansion
(4)→(1) Constant volume heat rejection





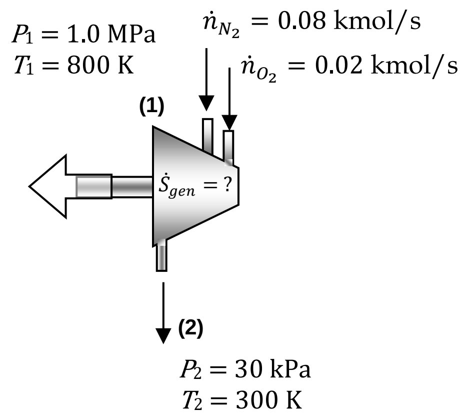
	q_{in} [kJ/kg]	w_{in} [kJ/kg]
1→2	?	?
2→3	966.33	?
3→4	0	-910.56
4→1	-399.6	0

(You do not need to fill in all property values.)

State	T [K]	P [kPa]	h [kJ/kg]	u [kJ/kg]	s^o [kJ/kg·K]	P_r	v_r
1	380	100	380.77	271.69	1.94	3.176	343.4
2							
3	1900		2127.40	1581.81	3.735	1655	3.295
4	896	235.9	929.16	671.25	2.843	73.03	34.77

PROBLEM 2 [cont'd]

Problem 3 [36 points]



An adiabatic turbine has a stream of nitrogen and a stream of oxygen both at a temperature of 800 K and a pressure of 1.0 MPa entering the turbine. The nitrogen has a molar flow rate of $\dot{n}_{N_2} = 0.08$ kmol/s and the oxygen has a molar flow rate of $\dot{n}_{O_2} = 0.02$ kmol/s. The exit of the turbine is a mixture of the inlet gasses at a pressure of 30 kPa at a temperature of 300 K.

Assuming ideal gas behavior with variable specific heats, find the rate of entropy generation in the turbine in kW/K.

Length

1 ft = 12 in = 0.3048 m = 1/3 yd
1 m = 100 cm = 1000 mm = 39.37 in = 3.2808 ft
1 mile = 5280 ft = 1609.3 m

Mass

1 kg = 1000 g = 2.2046 lbm
1 lbm = 16 oz = 0.45359 kg
1 slug = 32.174 lbm

Temperature Values

(T/K) = (T/°R) / 1.8
(T/K) = (T/°C) + 273.15
(T/°C) = [(T/°F) – 32]/1.8
(T/°R) = 1.8(T/K)
(T/°R) = (T/°F) + 459.67
(T/ °F) = 1.8(T/°C) + 32

Temperature Differences

$(\Delta T/{}^{\circ}R) = 1.8(\Delta T/K)$

$(\Delta T/{}^{\circ}R) = (\Delta T/{}^{\circ}F)$

$(\Delta T/K) = (\Delta T/{}^{\circ}C)$

Volume

1 m^3 = 1000 L = 10^6 cm^3 =10^6 mL = 35.315 ft^3
= 264.17 gal
1 ft^3 = 1728 in^3 = 7.4805 gal = 0.028317 m^3
1 gal = 0.13368 ft^3 = 0.0037854 m^3

Volumetric Flow Rate

1 m^3/s = 35.315 ft^3/s = 264.17 gal/s
1 ft^3/s = 1.6990 m^3/min = 7.4805 gal/s
= 448.83 gal/min

Force

1 N = 1 kg·m/s^2 = 0.22481 lbf
1 lbf = 1 slug·ft/s^2 = 32.174 lbm·ft/s^2
= 4.4482 N

Pressure

1 atm = 101.325 kPa = 1.01325 bar
= 14.696 lbf/in^2
1 bar = 100 kPa = 10^5 Pa
1 Pa = 1 N/m^2 = 10^{-3} kPa
1 lbf/in^2 = 6.8947 kPa = 6894.7 N/m^2 ;
[lbf/in^2 = "psi"]

Energy

1 J = 1 N·m = 1 Pa·m^3
1 kJ = 1000 J = 737.56 ft·lbf = 0.94782 Btu
1 Btu = 1.0551 kJ = 778.17 ft·lbf
1 ft·lbf = 1.3558 J

Energy Transfer Rate

1 kW = 1 kJ/s = 737.56 ft·lbf/s = 1.3410 hp = 0.94782 Btu/s
1 Btu/s = 1.0551 kW = 1.4149 hp
= 778.17 ft·lbf/s
1 hp = 550 ft·lbf/s = 0.74571 kW
= 0.70679 Btu/s

Specific Energy

1 kJ/kg = 1000 m^2/s^2
1 Btu/lbm = 25037 ft^2/s^2
1 ft·lbf /lbm = 32.174 ft^2/s^2

Other useful information	SI	USCS
Universal Ideal Gas Constant: $\bar{R}$	= 8.314 kJ/(kmol-K)	= 1545 (ft-lbf)/(lbmol-R) = 1.986 Btu/(lbmol-R)
Acceleration of Gravity: g	= 9.810 m/s^2	= 32.174 ft/s^2