

Thermodynamics Ph.D. Qualifying Exam

Department of Mechanical Engineering

Michigan State University

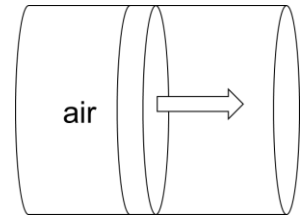
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Directions: Closed book. One sheet of notes allowed. Formula sheet/tables provided. All problems carry equal weight. In order to receive full credit for a solution, you must show all work clearly.

Prepared by: Profs. Brereton and Anthony

1. Air is in a piston-cylinder assembly, initially at $p = 6.75 \text{ bar}$, $T = 600 \text{ K}$, $V = 0.5 \text{ m}^3$. The air is expanded to 1.32 bar in an adiabatic process. The process occurs internally reversibly. You can assume that the air is an ideal gas and that changes in KE and PE for the system are negligible. (10 points)

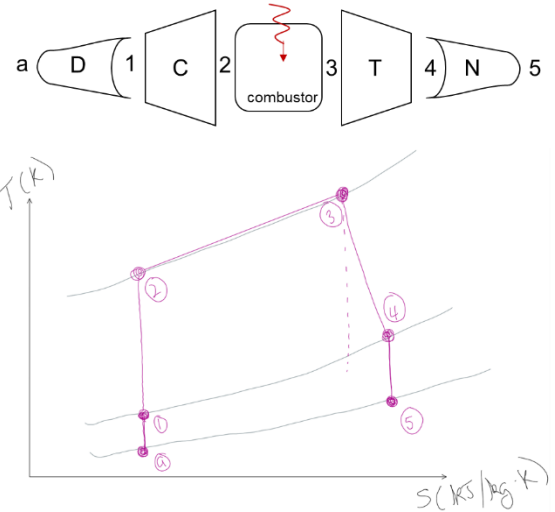
a) What is the final temperature of the air, in K?



b) What is the work done during the process, in kJ?

2. Air enters the diffuser of a turbojet engine with a mass flow rate of 25 kg/s at 30 kPa, 250 K, and a velocity of 142 m/s. Then property data of the air at various states within the engine is listed below. The diffuser, compressor, and nozzle operate internally reversibly, but the turbine has irreversibilities. For the problem, assume ideal gas behavior and air-standard analysis. (10 points)

STATE	p (kPa)	T	h (kJ/kg)	v (m/s)	s° (kJ/kg·K)	If $\Delta s = 0$ p _r (relative pressure)
a	30	250 K	250.05	142	1.51917	.7329
1	38.4	260 K	260.09	0	1.55848	.8405
2	480	532 K	536.01	0	2.28355	10.5
3	480	1120 K	1184.28	0	3.09825	179.7
4	38.4	600 K	607.02	0	2.40902	16.28
5	30	560 K	568.17		2.33685	12.7



- a) The data in the table are for real operation of the turbojet. What is the isentropic efficiency of the turbine, η_T ?

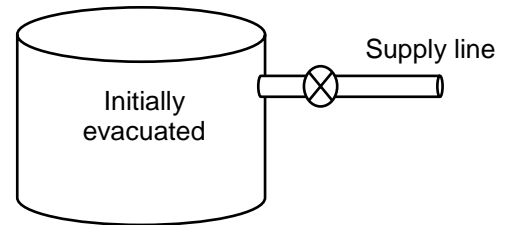
- b) What is the velocity at the nozzle exit for real (irreversible) operation, in m/s?

3. A solar-powered heat pump receives energy as heat from a solar collector at T_H , rejects heat to the surroundings at T_A , and pumps heat from a cold space at T_C , with no other external energy transfers.
- A) If the three heat transfer rates are Q_H , Q_A , and Q_C , find an expression for the minimum ratio Q_H/Q_C , in terms of the three temperatures.

- B) If $T_H = 350\text{ K}$, $T_A = 290\text{ K}$, $T_C = 200\text{ K}$, and $Q_C = 10\text{ kW}$, and each m^2 of the solar collector captures 0.2 kW , what is the minimum solar collector area required?

4. A well-insulated tank whose volume is 0.35 m^3 is initially evacuated. A valve connects the tank to a supply line of H_2O , which is a saturated vapor at 10 bar. The valve is opened and the vapor flows into the tank until the pressure inside is 1.5 bar. There is no work during this process. (10 points)

a) Determine the temperature of the H_2O in the tank when the process is complete ($p = 1.5 \text{ bar}$).



b) Determine the mass of H_2O contained in the tank when the process is complete.

c) Determine the amount of entropy generated in the process (σ_{gen}), in kJ/K .

TABLE A-22

 $T(K)$, h and $u(kJ/kg)$, s° (kJ/kg · K)

Ideal Gas Properties of Air

T	h	u	s°	when $\Delta s = 0$	
				p_r	v_r
350	350.49	250.02	1.85708	2.379	422.2
360	360.58	257.24	1.88543	2.626	393.4
370	370.67	264.46	1.91313	2.892	367.2
380	380.77	271.69	1.94001	3.176	343.4
390	390.88	278.93	1.96633	3.481	321.5
400	400.98	286.16	1.99194	3.806	301.6
410	411.12	293.43	2.01699	4.153	283.3
420	421.26	300.69	2.04142	4.522	266.6
430	431.43	307.99	2.06533	4.915	251.1
440	441.61	315.30	2.08870	5.332	236.8
580	586.04	419.55	2.37348	14.38	115.7
590	596.52	427.15	2.39140	15.31	110.6
600	607.02	434.78	2.40902	16.28	105.8
610	617.53	442.42	2.42644	17.30	101.2

TABLE A-4

Properties of Superheated Water Vapor

T °C	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg · K
$p = 1.5 \text{ bar} = 0.15 \text{ MPa}$ ($T_{\text{sat}} = 111.37^\circ\text{C}$)				
Sat.	1.159	2519.7	2693.6	7.2233
120	1.188	2533.3	2711.4	7.2693
160	1.317	2595.2	2792.8	7.4665
200	1.444	2656.2	2872.9	7.6433
240	1.570	2717.2	2952.7	7.8052
280	1.695	2778.6	3032.8	7.9555
$p = 10.0 \text{ bar} = 1.0 \text{ MPa}$ ($T_{\text{sat}} = 179.91^\circ\text{C}$)				
Sat.	0.1944	2583.6	2778.1	6.5865
200	0.2060	2621.9	2827.9	6.6940
240	0.2275	2692.9	2920.4	6.8817

TABLE A-3

Properties of Saturated Water (Liquid–Vapor): Pressure Table

Pressure Conversions:
1 bar = 0.1 MPa
= 10² kPa

		Specific Volume m ³ /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		Press. bar
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0