Time spent on problems:

Problem 1:

Problem 2:

Problem 3:

Problem 4:

Problem 5:

Problem 6:

Problem 7:

16.050 Thermal Energy

Do all problems. Please use a separate sheet of paper for each problem.

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1. During a certain cyclic process a system receives 100 kJ of heat from a reservoir while it is discharging 60 kJ of heat to a sink. Two work quantities are noted during this process. One is an input work of 15 kJ. Find the other work quantity. Also find the net work and state if this is done on or by the system.

2. A system is capable of executing a cyclic process as indicated in the pV sketch; it may be executed either clockwise *abca* or counterclockwise *adca*. (**a**) When going clockwise to state *c*, 80 kJ of heat flow to the system and 35 kJ of work are done by it. Returning to state *a* from *c*, 60 kJ of heat flow from the system. Find the work along the path *ca*. (**b**) When going counterclockwise to state *c*, 70 kJ of heat flow to the system. Find the work during the process *adc*.
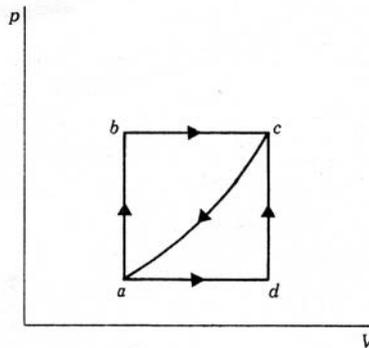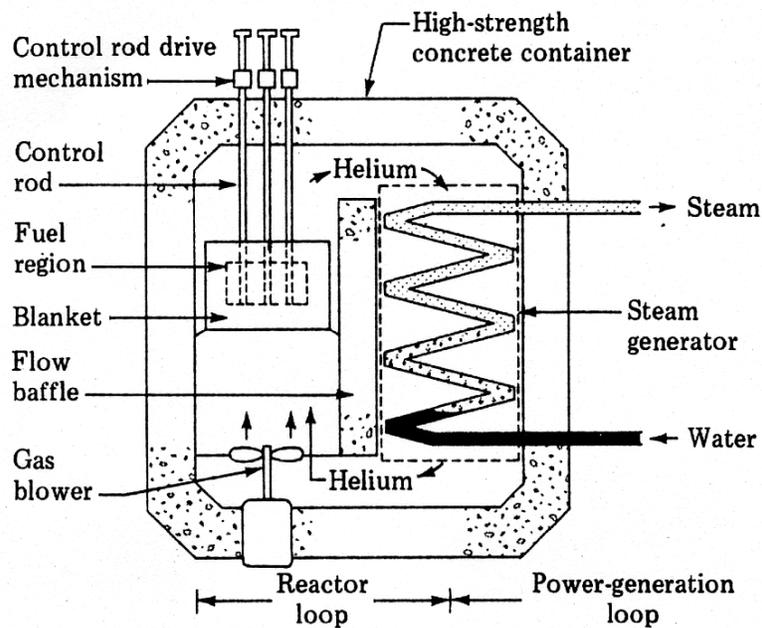

Problem 2

3. By how much does the temperature of the airflow through a nozzle change when it is accelerated from an inlet velocity of 10 m/s to an exit velocity of 90 m/s? How much heat per kg air would need to be transferred to the airflow if the temperature was kept constant during the acceleration? The flow through the nozzle can be assumed adiabatic and frictionless. Model the air as a diatomic gas mixture containing 78.1% N_2, 20.9% O_2 and 1.0% Ar.

4. 10 kg of air contained in a piston cylinder apparatus at 5 bar, 300K, expands isothermally until the pressure is 1 bar. Determine:

    (i)   the work done.
    (ii)   the internal energy change of the air.
    (iii) the heat transfer.

    Assume that air behaves as an ideal gas and pressure variation is gradual and continuous.

5. The figure shows a gas-cooled fast breeder reactor. Helium enters the steam generator at a temperature of 640ºC with a flow are of 1x10⁶ kg/h. It leaves at a temperature of 330ºC. Water enters the steam generator at 40ºC, 21x10⁶ N/m² (h = 185 kJ/kg). The steam leaves at a pressure of 20 x 10⁶ N/m², 550ºC. The water inlet pipe has a 0.1m diameter, and the steam exit pipe is 0.18m in diameter and 6 m above the inlet. Heat losses can be neglected. Assuming that kinetic energies are negligible, determine the steam-flow rate and the flow velocities at the inlet and exit. Comment on the validity of the above assumption and bolster your statement with an appropriate error estimate. Use the perfect-gas equation of state for the helium, and tabulated properties for steam.
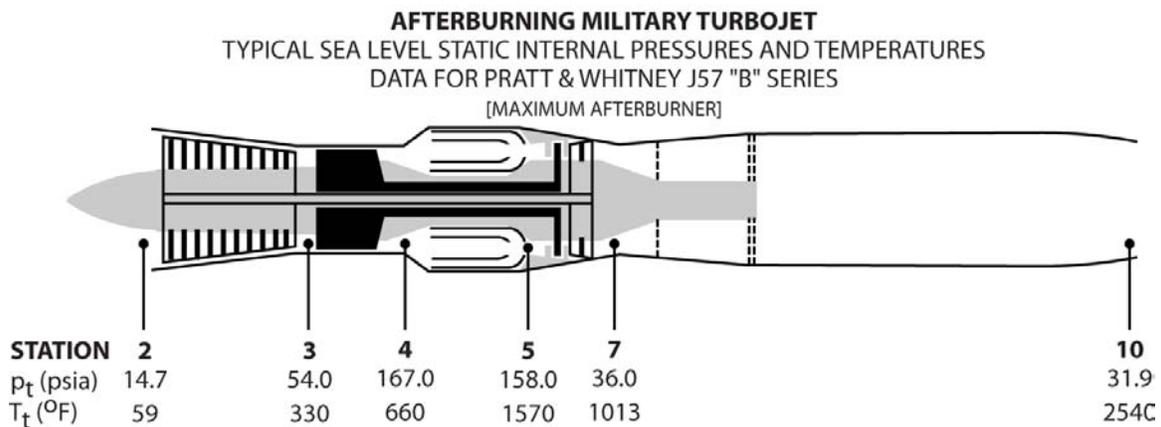

Problem 5

Temperature, °C

P, MPa (T_sat, °C)	Property	250	300	350	400	450	500	550	600	650	700	750	800	900
2 (212.4)	v, m³/kg	0.1114	0.1255	0.1386	0.1512	0.1635	0.1757	0.1877	0.1996	0.2114	0.2232	0.2350	0.2467	0.2700
	u, kJ/kg	2679.6	2772.6	2859.8	2945.2	3030.4	3116.2	3203.0	3290.9	3380.2	3471.0	3563.2	3657.0	3849.3
	h, kJ/kg	2902.5	3023.5	3137.0	3247.6	3357.5	3467.6	3578.3	3690.1	3803.1	3917.5	4033.2	4150.4	4389.4
	s, kJ/(kg·K)	6.5461	6.7672	6.9571	7.1279	7.2853	7.4325	7.5713	7.7032	7.8290	7.9496	8.0656	8.1774	8.3903
3 (233.9)	v, m³/kg	0.07058	0.08114	0.09053	0.09936	0.1079	0.1162	0.1244	0.1324	0.1404	0.1484	0.1563	0.1641	0.1798
	u, kJ/kg	2644.0	2750.0	2843.7	2932.7	3020.4	3107.9	3196.0	3285.0	3375.2	3466.6	3559.4	3653.6	3846.5
	h, kJ/kg	2855.8	2993.5	3115.3	3230.8	3344.0	3456.5	3569.1	3682.3	3796.5	3911.7	4028.2	4146.0	4385.9
	s, kJ/(kg·K)	6.2880	6.5398	6.7436	6.9220	7.0842	7.2346	7.3757	7.5093	7.6364	7.7580	7.8747	7.9871	8.2008
4 (250.4)	v, m³/kg		0.05884	0.06645	0.07341	0.08003	0.08643	0.09269	0.09885	0.1049	0.1109	0.1169	0.1229	0.1347
	u, kJ/kg		2725.3	2826.6	2919.9	3010.1	3099.5	3189.0	3279.1	3370.1	3462.1	3555.5	3650.1	3843.6
	h, kJ/kg		2960.7	3092.4	3213.5	3330.2	3445.2	3559.7	3674.4	3789.8	3905.9	4023.2	4141.6	4382.3
	s, kJ/(kg·K)		6.3622	6.5828	6.7698	6.9371	7.0908	7.2343	7.3696	7.4981	7.6206	7.7381	7.8511	8.0655
6 (275.6)	v, m³/kg		0.03616	0.04223	0.04739	0.05214	0.05665	0.06101	0.06525	0.06942	0.07352	0.07758	0.08160	0.08958
	u, kJ/kg		2667.2	2789.6	2892.8	2988.9	3082.2	3174.6	3266.9	3359.6	3453.2	3547.6	3643.1	3837.8
	h, kJ/kg		2884.2	3043.0	3177.2	3301.8	3422.1	3540.6	3658.4	3776.2	3894.3	4013.1	4132.7	4375.3
	s, kJ/(kg·K)		6.0682	6.3342	6.5415	6.7201	6.8811	7.0296	7.1685	7.2996	7.4242	7.5433	7.6575	7.8735
8 (295.1)	v, m³/kg		0.02426	0.02995	0.03432	0.03817	0.04175	0.04516	0.04845	0.05166	0.05481	0.05791	0.06097	0.06702
	u, kJ/kg		2590.9	2747.7	2863.8	2966.7	3064.3	3159.8	3254.4	3349.6	3444.0	3539.6	3636.1	3832.1
	h, kJ/kg		2785.0	2987.3	3138.3	3272.0	3398.3	3521.0	3642.0	3762.3	3882.5	4002.5	4123.8	4368.3
	s, kJ/(kg·K)		5.7914	6.1309	6.3642	6.5559	6.7248	6.8786	7.0214	7.1553	7.2821	7.4027	7.5182	7.7359
10 (311.1)	v, m³/kg			0.02242	0.02641	0.02975	0.03279	0.03564	0.03837	0.04101	0.04358	0.04611	0.04859	0.05349
	u, kJ/kg			2699.2	2832.4	2943.3	3045.8	3144.5	3241.7	3338.2	3434.7	3531.5	3629.0	3826.3
	h, kJ/kg			2923.4	3096.5	3240.8	3373.6	3500.9	3625.3	3748.3	3870.5	3992.6	4114.9	4361.2
	s, kJ/(kg·K)			5.9451	6.2127	6.4197	6.5974	6.7569	6.9037	7.0406	7.1696	7.2919	7.4086	7.6280
12 (324.8)	v, m³/kg			0.01721	0.02108	0.02412	0.02680	0.02929	0.03164	0.03390	0.03610	0.03824	0.04034	0.04447
	u, kJ/kg			2641.1	2798.3	2918.8	3026.6	3128.9	3228.7	3327.2	3425.3	3523.4	3621.8	3820.6
	h, kJ/kg			2847.6	3051.2	3208.2	3348.2	3480.3	3608.3	3734.0	3858.4	3982.3	4105.9	4354.2
	s, kJ/(kg·K)			5.7604	6.0754	6.3006	6.4879	6.6535	6.8045	6.9445	7.0757	7.1998	7.3178	7.5390

P, MPa (T_sat, °C)	Property	400	450	500	550	600	650	700	750	800	850	900	950	1000
15 (342.2)	v, m³/kg	0.01565	0.01845	0.02080	0.02293	0.02491	0.02680	0.02861	0.03037	0.03210	0.03379	0.03546	0.03711	0.03875
	u, kJ/kg	2740.7	2879.5	2996.5	3104.7	3208.6	3310.4	3410.9	3511.0	3611.0	3711.2	3811.9	3913.2	4015.4
	h, kJ/kg	2975.4	3156.2	3308.5	3448.6	3582.3	3712.3	3840.1	3966.6	4092.4	4218.0	4343.8	4469.9	4596.6
	s, kJ/(kg·K)	5.8819	6.1412	6.3451	6.5207	6.6784	6.8232	6.9580	7.0848	7.2048	7.3192	7.4288	7.5340	7.6356
20 (365.8)	v, m³/kg	0.00994	0.01270	0.01477	0.01656	0.01818	0.01969	0.02113	0.02251	0.02385	0.02516	0.02645	0.02771	0.02897
	u, kJ/kg	2619.2	2806.2	2942.8	3062.3	3174.0	3281.5	3386.5	3490.0	3592.7	3695.1	3797.4	3900.0	4003.1
	h, kJ/kg	2818.1	3060.1	3238.2	3393.4	3537.6	3675.3	3809.1	3940.3	4069.8	4198.3	4326.4	4454.3	4582.5
	s, kJ/(kg·K)	5.5548	5.9025	6.1409	6.3356	6.5056	6.6591	6.8002	6.9317	7.0553	7.1723	7.2839	7.3907	7.4933
22.088 (374.136)	v, m³/kg	0.00818	0.01104	0.01305	0.01475	0.01627	0.01768	0.01901	0.02029	0.02152	0.02272	0.02389	0.02505	0.02619
	u, kJ/kg	2552.9	2772.1	2919.0	3043.9	3159.1	3269.1	3376.1	3481.0	3585.0	3688.3	3791.4	3894.5	3998.0
	h, kJ/kg	2733.7	3015.9	3207.2	3369.6	3518.4	3659.6	3796.0	3929.2	4060.3	4190.1	4319.1	4447.9	4576.6

Problem 5 Steam Table

6. At a birthday party the host notices that one of the party balloons is 0.2m in diameter instead of 0.3m. Assume that the balloon contains air at a pressure of 150kPa and a temperature of 280K and that pressure is directly proportional to the diameter of the balloon. In order to increase the diameter to 0.3m the host attaches the balloon to a valve connected to an air line flowing air at 300kPa and 300K. The valve is opened allowing air to flow into the balloon until the temperature inside reaches 290K. How much work and heat is transferred to the balloon during the process?

7. The schematic below shows the Pratt & Whitney J57 afterburning turbojet engine. The mass flow through the engine is 75 kg/s. The specific heat of air in the compressor is c_{pC} = 1000 J/kgK.

   a) What is the power needed to drive the low-pressure and the high-pressure compressors?

   b) Find the specific heat of the combustion gas through the turbine.

   c) When the afterburner is lit, find the heat transferred and the pressure drop in the afterburner.

   d) Assuming that the flow expands adiabatically and reversibly to ambient pressure at the exit of the afterburner, find the exit velocity (assume a perfect gas and use the c_p for the combustion gas found in b).

   e) If the flight velocity is 150 m/s find the thrust.

AFTERBURNING MILITARY TURBOJET
TYPICAL SEA LEVEL STATIC INTERNAL PRESSURES AND TEMPERATURES
DATA FOR PRATT & WHITNEY J57 "B" SERIES
[MAXIMUM AFTERBURNER]

STATION	2	3	4	5	7	10
p_t (psia)	14.7	54.0	167.0	158.0	36.0	31.9
T_t (°F)	59	330	660	1570	1013	2540

Problem 7