Tutorial - 4 (ESO201A)

5–28 The diffuser in a jet engine is designed to decrease the kinetic energy of the air entering the engine compressor without any work or heat interactions. Calculate the velocity at the exit of a diffuser when air at 100 kPa and 30°C enters it with a velocity of 350 m/s and the exit state is 200 kPa and 90°C.

Solution

Air is decelerated in an adiabatic diffuser. The velocity at the exit is to be determined.

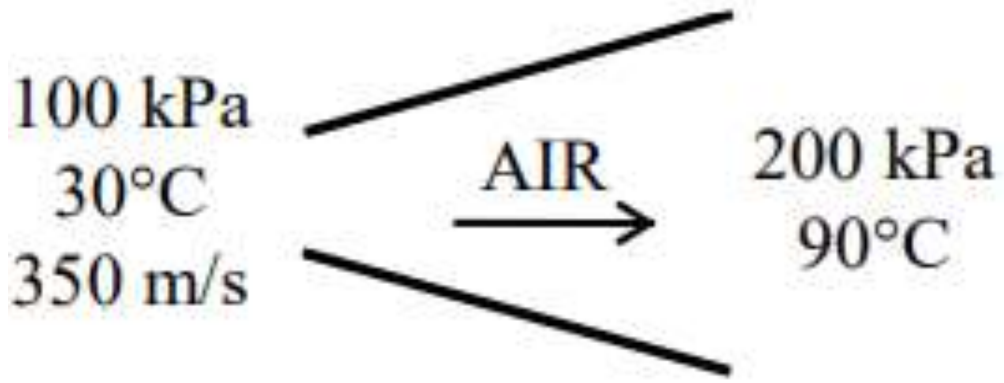
Assumptions **1** This is a steady-flow process since there is no change with time.

2 Air is an ideal gas with constant specific heats.

3 Potential energy changes are negligible.

4 There are no work interactions.

5 The diffuser is adiabatic.



Properties The specific heat of air at the average temperature of (30+90)/2 = 60°C = 333 K is Cp = 1.007 kJ/kg.K (Table A-2b).

TABLE A–2

Ideal–gas specific heats of various common gases (*Continued*)

(*b*) At various temperatures

Temperature, K	c_p kJ/kg·K	c_v kJ/kg·K	k	c_p kJ/kg·K	c_v kJ/kg·K	k	c_p kJ/kg·K	c_v kJ/kg·K	k
	Air			*Carbon dioxide, CO_2*			*Carbon monoxide, CO*		
250	1.003	0.716	1.401	0.791	0.602	1.314	1.039	0.743	1.400
300	1.005	0.718	1.400	0.846	0.657	1.288	1.040	0.744	1.399
350	1.008	0.721	1.398	0.895	0.706	1.268	1.043	0.746	1.398
400	1.013	0.726	1.395	0.939	0.750	1.252	1.047	0.751	1.395
450	1.020	0.733	1.391	0.978	0.790	1.239	1.054	0.757	1.392
500	1.029	0.742	1.387	1.014	0.825	1.229	1.063	0.767	1.387
550	1.040	0.753	1.381	1.046	0.857	1.220	1.075	0.778	1.382
600	1.051	0.764	1.376	1.075	0.886	1.213	1.087	0.790	1.376
650	1.063	0.776	1.370	1.102	0.913	1.207	1.100	0.803	1.370
700	1.075	0.788	1.364	1.126	0.937	1.202	1.113	0.816	1.364
750	1.087	0.800	1.359	1.148	0.959	1.197	1.126	0.829	1.358
800	1.099	0.812	1.354	1.169	0.980	1.193	1.139	0.842	1.353
900	1.121	0.834	1.344	1.204	1.015	1.186	1.163	0.866	1.343
1000	1.142	0.855	1.336	1.234	1.045	1.181	1.185	0.888	1.335
	Hydrogen, H_2			*Nitrogen, N_2*			*Oxygen, O_2*		
250	14.051	9.927	1.416	1.039	0.742	1.400	0.913	0.653	1.398
300	14.307	10.183	1.405	1.039	0.743	1.400	0.918	0.658	1.395
350	14.427	10.302	1.400	1.041	0.744	1.399	0.928	0.668	1.389
400	14.476	10.352	1.398	1.044	0.747	1.397	0.941	0.681	1.382
450	14.501	10.377	1.398	1.049	0.752	1.395	0.956	0.696	1.373
500	14.513	10.389	1.397	1.056	0.759	1.391	0.972	0.712	1.365
550	14.530	10.405	1.396	1.065	0.768	1.387	0.988	0.728	1.358
600	14.546	10.422	1.396	1.075	0.778	1.382	1.003	0.743	1.350
650	14.571	10.447	1.395	1.086	0.789	1.376	1.017	0.758	1.343
700	14.604	10.480	1.394	1.098	0.801	1.371	1.031	0.771	1.337
750	14.645	10.521	1.392	1.110	0.813	1.365	1.043	0.783	1.332
800	14.695	10.570	1.390	1.121	0.825	1.360	1.054	0.794	1.327
900	14.822	10.698	1.385	1.145	0.849	1.349	1.074	0.814	1.319
1000	14.983	10.859	1.380	1.167	0.870	1.341	1.090	0.830	1.313

Source of Data: Kenneth Wark, *Thermodynamics,* 4th ed. (New York: McGraw–Hill, 1983), p. 783, Table A-4M. Originally published in *Tables of Thermal Properties of Gases,* NBS Circular 564, 1955.

Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take diffuser as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2)$$

$$h_1 + V_1^2/2 = h_2 + V_2^2/2$$

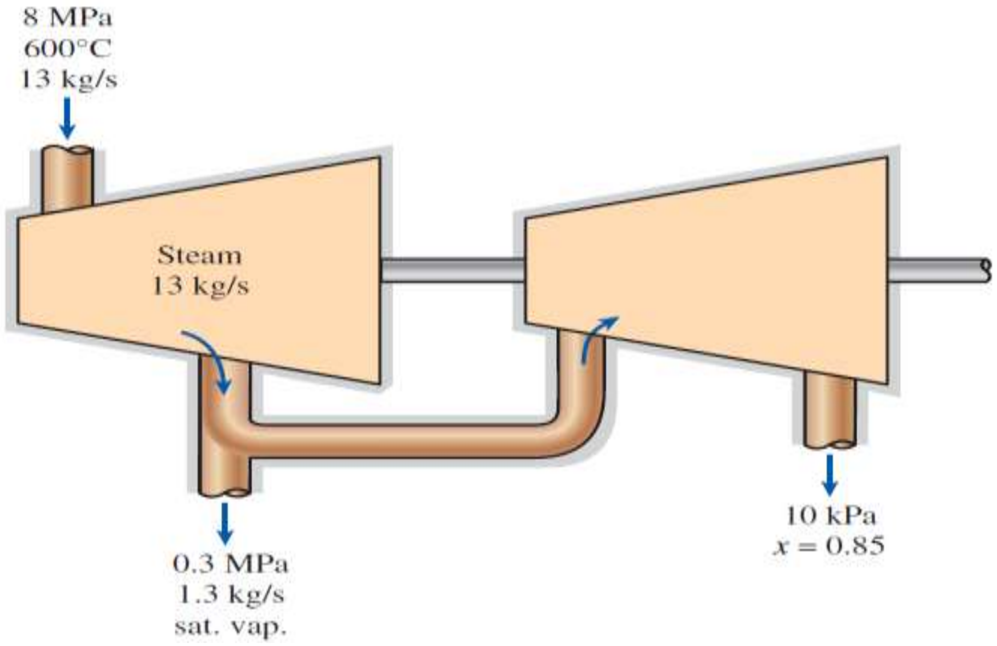
Solving for exit velocity,

$$V_2 = \left[V_1^2 + 2(h_1 - h_2)\right]^{0.5} = \left[V_1^2 + 2c_p(T_1 - T_2)\right]^{0.5}$$

$$= \left[(350 \text{ m/s})^2 + 2(1.007 \text{ kJ/kg}\cdot\text{K})(30-90)\text{K}\left(\frac{1000 \text{ m}^2/\text{s}^2}{1 \text{ kJ/kg}}\right)\right]^{0.5}$$

$$= \mathbf{40.7 \, m/s}$$

5-55 Steam enters a steady-flow turbine with a mass flow rate of 13 kg/s at 600°C, 8 MPa, and a negligible velocity. The steam expands in the turbine to **a saturated vapor** at 300 kPa where 10 percent of the steam is removed for some other use. The remainder of the steam continues to expand to the turbine exit where the pressure is 10 kPa and **quality is 85 percent**. If the turbine is adiabatic, determine the rate of work done by the steam during this process.



Solution

Steam expands in a two-stage adiabatic turbine from a specified state to another state. Some steam is extracted at the end of the first stage. The power output of the turbine is to be determined.

Assumptions *1. This is a steady-flow process since there is no change with time.*

2. Kinetic and potential energy changes are negligible.

3. The turbine is adiabatic and thus heat transfer is negligible.

Properties From the steam tables (Tables A-5 and A-6)

$$\left.\begin{array}{l} P_1 = 8\ \text{MPa} \\ T_1 = 600^\circ\text{C} \end{array}\right\} h_1 = 3642.4\ \text{kJ/kg}$$

(from Superheated tables)

$$\left.\begin{array}{l} P_2 = 0.3\ \text{MPa} \\ x_2 = 1 \end{array}\right\} h_2 = 2724.9\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_3 = 10\ \text{kPa} \\ x_2 = 0.85 \end{array}\right\} \begin{array}{l} h_3 = h_f + x h_{fg} \\ \quad = 191.81 + (0.85)(2392.1) = 2225.1\ \text{kJ/kg} \end{array}$$

TABLE A–6

Superheated water (*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 4.0 MPa (250.35°C)				P = 4.5 MPa (257.44°C)				P = 5.0 MPa (263.94°C)			
Sat.	0.04978	2601.7	2800.8	6.0696	0.04406	2599.7	2798.0	6.0198	0.03945	2597.0	2794.2	5.9737
275	0.05461	2668.9	2887.3	6.2312	0.04733	2651.4	2864.4	6.1429	0.04144	2632.3	2839.5	6.0571
300	0.05887	2726.2	2961.7	6.3639	0.05138	2713.0	2944.2	6.2854	0.04535	2699.0	2925.7	6.2111
350	0.06647	2827.4	3093.3	6.5843	0.05842	2818.6	3081.5	6.5153	0.05197	2809.5	3069.3	6.4516
400	0.07343	2920.8	3214.5	6.7714	0.06477	2914.2	3205.7	6.7071	0.05784	2907.5	3196.7	6.6483
450	0.08004	3011.0	3331.2	6.9386	0.07076	3005.8	3324.2	6.8770	0.06332	3000.6	3317.2	6.8210
500	0.08644	3100.3	3446.0	7.0922	0.07652	3096.0	3440.4	7.0323	0.06858	3091.8	3434.7	6.9781
600	0.09886	3279.4	3674.9	7.3706	0.08766	3276.4	3670.9	7.3127	0.07870	3273.3	3666.9	7.2605
700	0.11098	3462.4	3906.3	7.6214	0.09850	3460.0	3903.3	7.5647	0.08852	3457.7	3900.3	7.5136
800	0.12292	3650.6	4142.3	7.8523	0.10916	3648.8	4140.0	7.7962	0.09816	3646.9	4137.7	7.7458
900	0.13476	3844.8	4383.9	8.0675	0.11972	3843.3	4382.1	8.0118	0.10769	3841.8	4380.2	7.9619
1000	0.14653	4045.1	4631.2	8.2698	0.13020	4043.9	4629.8	8.2144	0.11715	4042.6	4628.3	8.1648
1100	0.15824	4251.4	4884.4	8.4612	0.14064	4250.4	4883.2	8.4060	0.12655	4249.3	4882.1	8.3566
1200	0.16992	4463.5	5143.2	8.6430	0.15103	4462.6	5142.2	8.5880	0.13592	4461.6	5141.3	8.5388
1300	0.18157	4680.9	5407.2	8.8164	0.16140	4680.1	5406.5	8.7616	0.14527	4679.3	5405.7	8.7124
	P = 6.0 MPa (275.59°C)				P = 7.0 MPa (285.83°C)				P = 8.0 MPa (295.01°C)			
Sat.	0.03245	2589.9	2784.6	5.8902	0.027378	2581.0	2772.6	5.8148	0.023525	2570.5	2758.7	5.7450
300	0.03619	2668.4	2885.6	6.0703	0.029492	2633.5	2839.9	5.9337	0.024279	2592.3	2786.5	5.7937
350	0.04225	2790.4	3043.9	6.3357	0.035262	2770.1	3016.9	6.2305	0.029975	2748.3	2988.1	6.1321
400	0.04742	2893.7	3178.3	6.5432	0.039958	2879.5	3159.2	6.4502	0.034344	2864.6	3139.4	6.3658
450	0.05217	2989.9	3302.9	6.7219	0.044187	2979.0	3288.3	6.6353	0.038194	2967.8	3273.3	6.5579
500	0.05667	3083.1	3423.1	6.8826	0.048157	3074.3	3411.4	6.8000	0.041767	3065.4	3399.5	6.7266
550	0.06102	3175.2	3541.3	7.0308	0.051966	3167.9	3531.6	6.9507	0.045172	3160.5	3521.8	6.8800
600	0.06527	3267.2	3658.8	7.1693	0.055665	3261.0	3650.6	7.0910	0.048463	3254.7	3642.4	7.0221
700	0.07355	3453.0	3894.3	7.4247	0.062850	3448.3	3888.3	7.3487	0.054829	3443.6	3882.2	7.2822
800	0.08165	3643.2	4133.1	7.6582	0.069856	3639.5	4128.5	7.5836	0.061011	3635.7	4123.8	7.5185
900	0.08964	3838.8	4376.6	7.8751	0.076750	3835.7	4373.0	7.8014	0.067082	3832.7	4369.3	7.7372
1000	0.09756	4040.1	4625.4	8.0786	0.083571	4037.5	4622.5	8.0055	0.073079	4035.0	4619.6	7.9419
1100	0.10543	4247.1	4879.7	8.2709	0.090341	4245.0	4877.4	8.1982	0.079025	4242.8	4875.0	8.1350
1200	0.11326	4459.8	5139.4	8.4534	0.097075	4457.9	5137.4	8.3810	0.084934	4456.1	5135.5	8.3181
1300	0.12107	4677.7	5404.1	8.6273	0.103781	4676.1	5402.6	8.5551	0.090817	4674.5	5401.0	8.4925

TABLE A–5

Saturated water—Pressure table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071

TABLE A–6

Superheated water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 0.01 MPa (45.81°C)*				P = 0.05 MPa (81.32°C)			
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931
50	14.867	2443.3	2592.0	8.1741				
100	17.196	2515.5	2687.5	8.4489	3.4187	2511.5	2682.4	7.6953
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659
500	35.680	3132.9	3489.7	9.8998	7.1338	3132.6	3489.3	9.1566
600	40.296	3303.3	3706.3	10.1631	8.0577	3303.1	3706.0	9.4201
700	44.911	3480.8	3929.9	10.4056	8.9813	3480.6	3929.7	9.6626
800	49.527	3665.4	4160.6	10.6312	9.9047	3665.2	4160.4	9.8883
900	54.143	3856.9	4398.3	10.8429	10.8280	3856.8	4398.2	10.1000
1000	58.758	4055.3	4642.8	11.0429	11.7513	4055.2	4642.7	10.3000
1100	63.373	4260.0	4893.8	11.2326	12.6745	4259.9	4893.7	10.4897
1200	67.989	4470.9	5150.8	11.4132	13.5977	4470.8	5150.7	10.6704
1300	72.604	4687.4	5413.4	11.5857	14.5209	4687.3	5413.3	10.8429
	P = 0.20 MPa (120.21°C)				P = 0.30 MPa (133.52°C)			
Sat.	0.88578	2529.1	2706.3	7.1270	0.60582	2543.2	2724.9	6.9917
150	0.95986	2577.1	2769.1	7.2810	0.63402	2571.0	2761.2	7.0792
200	1.08049	2654.6	2870.7	7.5081	0.71643	2651.0	2865.9	7.3132
250	1.19890	2731.4	2971.2	7.7100	0.79645	2728.9	2967.9	7.5180
300	1.31623	2808.8	3072.1	7.8941	0.87535	2807.0	3069.6	7.7037
400	1.54934	2967.2	3277.0	8.2236	1.03155	2966.0	3275.5	8.0347
500	1.78142	3131.4	3487.7	8.5153	1.18672	3130.6	3486.6	8.3271
600	2.01302	3302.2	3704.8	8.7793	1.34139	3301.6	3704.0	8.5915
700	2.24434	3479.9	3928.8	9.0221	1.49580	3479.5	3928.2	8.8345
800	2.47550	3664.7	4159.8	9.2479	1.65004	3664.3	4159.3	9.0605
900	2.70656	3856.3	4397.7	9.4598	1.80417	3856.0	4397.3	9.2725
1000	2.93755	4054.8	4642.3	9.6599	1.95824	4054.5	4642.0	9.4726
1100	3.16848	4259.6	4893.3	9.8497	2.11226	4259.4	4893.1	9.6624
1200	3.39938	4470.5	5150.4	10.0304	2.26624	4470.3	5150.2	9.8431
1300	3.63026	4687.1	5413.1	10.2029	2.42019	4686.9	5413.0	10.0157

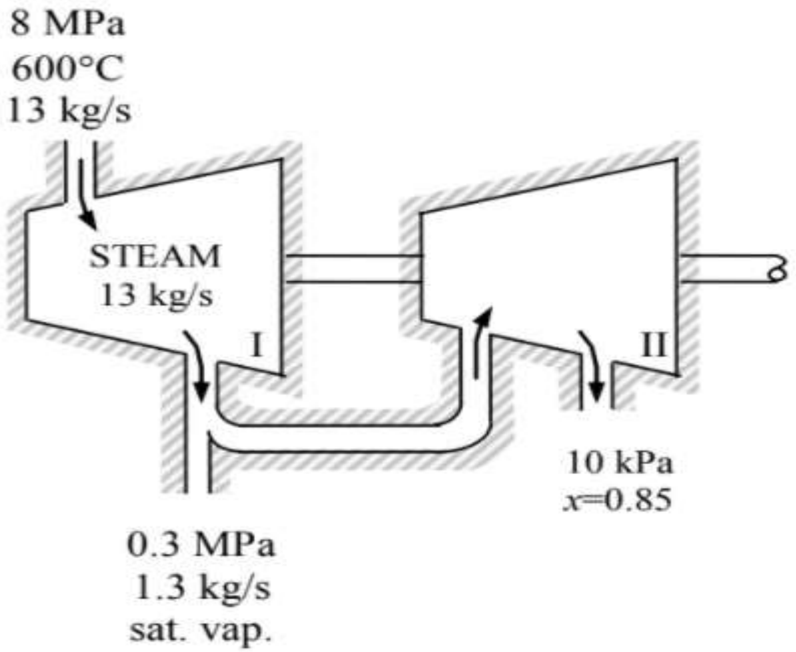
Analysis We take the entire turbine, including the connection part between the two stages, as the system, which is a control volume since mass crosses the boundary. Noting that one fluid stream enters the turbine and two fluid streams leave, the energy balance for this steady flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3 + \dot{W}_{out}$$

$$\dot{W}_{out} = \dot{m}_1 (h_1 - 0.1 h_2 - 0.9 h_3)$$



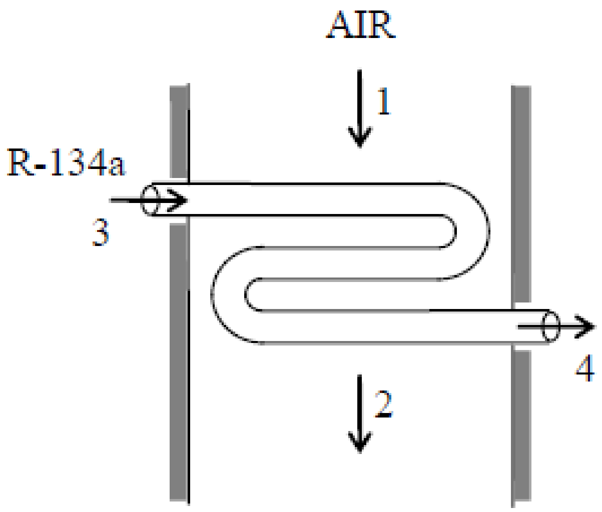
Substituting, the power output of the turbine is

$\dot{W}_{out} = \dot{m}_1(h_1 - 0.1h_2 - 0.9h_3)$

= (13 kg/s)(3642.4 - 0.1×2724.9 - 0.9×2225.1) kJ/kg

= 17,776 kW = **17.8 MW**

5-81 Refrigerant-134a at 1 MPa and 90°C is to be cooled to 1 MPa and 30°C in a condenser by air. The air enter: at 100 kPa and 27°C with a volume flow rate of 600 m^3/min and leave at 95 kPa and 60°C. Determine the mass flow rate of the refrigerant.



Solution

Refrigerant-134a is to be cooled by air in the condenser. For a specified volume flow rate of air, the mass flow rate of the refrigerant is to be determined

Assumptions

1. This is a steady-flow process since there is no change with time.

2. Kinetic and potential energy changes are negligible.

3 .There are no work interactions.

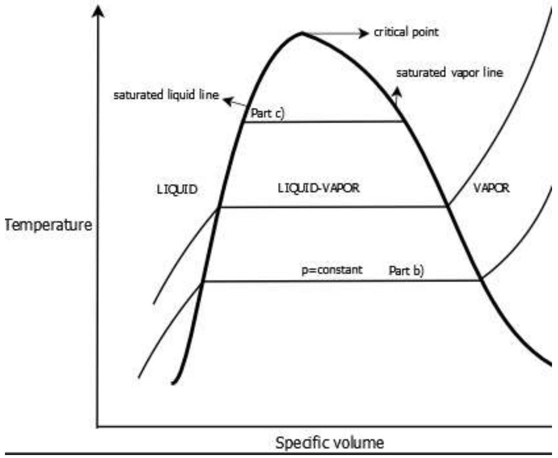
4. Heat loss from the device to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid.

5. Air is an ideal gas with constant specific heats at room temperature.

Properties

The gas constant of air is 0.287 kPa.m3 /kg.K . The constant pressure specific heat of air is cp = 1.005 kJ/kg·°C .

The enthalpies of the R-134a at the inlet and the exit states are



$$\left.\begin{array}{l} P_3 = 1\ \text{MPa} \\ T_3 = 90°\text{C} \end{array}\right\} h_3 = 324.66\ \text{kJ/kg}$$

(From A-13-superheated table)

$$\left.\begin{array}{l} P_4 = 1\ \text{MPa} \\ T_4 = 30°\text{C} \end{array}\right\} h_4 \cong h_{f@30°C} = 93.58\ \text{kJ/kg}$$

(From A-11 saturated temp table)

Analysis The inlet specific volume and the mass flow rate of air are

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300\ \text{K})}{100\ \text{kPa}} = 0.861\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{600\ \text{m}^3/\text{min}}{0.861\ \text{m}^3/\text{kg}} = 696.9\ \text{kg/min}$$

We take the entire heat exchanger as the system, which is a control volume. The mass and energy balances for this steady-flow system can be expressed in the rate form as

Mass balance (for each fluid stream):

$$\dot{m}_{in} - \dot{m}_{out} = \Delta\dot{m}_{system}^{\nearrow 0\ (steady)} = 0 \rightarrow \dot{m}_{in} = \dot{m}_{out} \rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}_a \text{ and } \dot{m}_3 = \dot{m}_4 = \dot{m}_R$$

Energy balance (for the entire heat exchanger):

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{system}^{\nearrow 0\ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4 \quad (\text{since } \dot{Q} = \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

Combining the two,

$$\dot{m}_a(h_2 - h_1) = \dot{m}_R(h_3 - h_4)$$

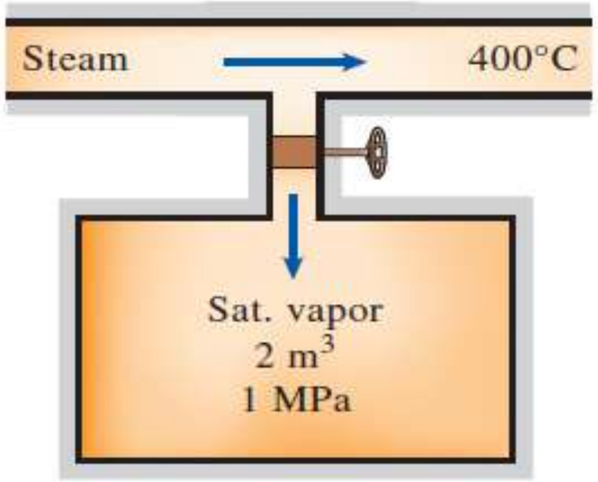
Solving for $\dot{m}_R$:

$$\dot{m}_R = \frac{h_2 - h_1}{h_3 - h_4}\dot{m}_a \cong \frac{c_p(T_2 - T_1)}{h_3 - h_4}\dot{m}_a$$

Substituting,

$$\dot{m}_R = \frac{(1.005\ \text{kJ/kg}\cdot{}^\circ\text{C})(60 - 27)^\circ\text{C}}{(324.66 - 93.58)\ \text{kJ/kg}}(696.9\ \text{kg/min}) = \mathbf{100.0\ kg/min}$$

5-112 A $2m^3$ rigid insulated tank initially containing **saturated water vapor at 1 MPa** is connected through a valve to a supply line that carries steam at 400^0C. Now the valve is opened, and steam is allowed to flow slowly into the tank until the pressure in the tank rises to 2 MPa. At this instant the tank temperature is measured to be 300^0C. Determine the mass of the steam that has entered and the pressure of the steam in the supply line.



Solution: Steam flowing in a supply line is allowed to enter into an insulated tank until a specified state is achieved in the tank. The mass of the steam that has entered and the pressure of the steam in the supply line are to be determined.

Assumptions

1. This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process since the state of fluid entering the tank remains constant.
2. Kinetic and potential energies are negligible.
3. Take 1→initial state of system, 2→ final state of system; i→ incoming steam entering tank

The initial and final properties of steam are obtained from the steam table:

P_1= 1MPa=1000kPa

x_1=1 (since saturated vapour: given)

V_1=0.19436m^3/kg

U_1=2582.8kJ/kg

TABLE A–5

Saturated water—Pressure table (*Concluded*)

		Specific volume, m³/kg		Internal energy, kJ/kg			
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51
1100	184.06	0.001133	0.17745	779.78	1805.7	2585.5	781.03
1200	187.96	0.001138	0.16326	796.96	1790.9	2587.8	798.33
1300	191.60	0.001144	0.15119	813.10	1776.8	2589.9	814.59
1400	195.04	0.001149	0.14078	828.35	1763.4	2591.8	829.96
1500	198.29	0.001154	0.13171	842.82	1750.6	2593.4	844.55
1750	205.72	0.001166	0.11344	876.12	1720.6	2596.7	878.16
2000	212.38	0.001177	0.099587	906.12	1693.0	2599.1	908.47
2250	218.41	0.001187	0.088717	933.54	1667.3	2600.9	936.21
2500	223.95	0.001197	0.079952	958.87	1643.2	2602.1	961.87
3000	233.85	0.001217	0.066667	1004.6	1598.5	2603.2	1008.3
3500	242.56	0.001235	0.057061	1045.4	1557.6	2603.0	1049.7
4000	250.35	0.001252	0.049779	1082.4	1519.3	2601.7	1087.4
5000	263.94	0.001286	0.039448	1148.1	1448.9	2597.0	1154.5
6000	275.59	0.001319	0.032449	1205.8	1384.1	2589.9	1213.8
7000	285.83	0.001352	0.027378	1258.0	1323.0	2581.0	1267.5

- P_2= 2 MPa (2000kPa), T_1=300^0 C
- v_2= 0.12551 m^3/kg, u_2=2773.2 kJ/kg

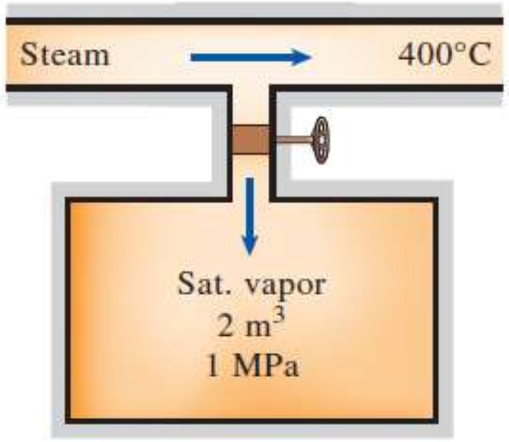
	P = 1.60 MPa (201.37°C)				P = 1.80 MPa (207.11°C)				P = 2.00 MPa (212.38°C)			
Sat.	0.12374	2594.8	2792.8	6.4200	0.11037	2597.3	2795.9	6.3775	0.09959	2599.1	2798.3	6.3390
225	0.13293	2645.1	2857.8	6.5537	0.11678	2637.0	2847.2	6.4825	0.10381	2628.5	2836.1	6.4160
250	0.14190	2692.9	2919.9	6.6753	0.12502	2686.7	2911.7	6.6088	0.11150	2680.3	2903.3	6.5475
300	0.15866	2781.6	3035.4	6.8864	0.14025	2777.4	3029.9	6.8246	0.12551	2773.2	3024.2	6.7684
350	0.17459	2866.6	3146.0	7.0713	0.15460	2863.6	3141.9	7.0120	0.13860	2860.5	3137.7	6.9583
400	0.19007	2950.8	3254.9	7.2394	0.16849	2948.3	3251.6	7.1814	0.15122	2945.9	3248.4	7.1292
500	0.22029	3120.1	3472.6	7.5410	0.19551	3118.5	3470.4	7.4845	0.17568	3116.9	3468.3	7.4337
600	0.24999	3293.9	3693.9	7.8101	0.22200	3292.7	3692.3	7.7543	0.19962	3291.5	3690.7	7.7043
700	0.27941	3473.5	3920.5	8.0558	0.24822	3472.6	3919.4	8.0005	0.22326	3471.7	3918.2	7.9509
800	0.30865	3659.5	4153.4	8.2834	0.27426	3658.8	4152.4	8.2284	0.24674	3658.0	4151.5	8.1791
900	0.33780	3852.1	4392.6	8.4965	0.30020	3851.5	4391.9	8.4417	0.27012	3850.9	4391.1	8.3925
1000	0.36687	4051.2	4638.2	8.6974	0.32606	4050.7	4637.6	8.6427	0.29342	4050.2	4637.1	8.5936
1100	0.39589	4256.6	4890.0	8.8878	0.35188	4256.2	4889.6	8.8331	0.31667	4255.7	4889.1	8.7842
1200	0.42488	4467.9	5147.7	9.0689	0.37766	4467.6	5147.3	9.0143	0.33989	4467.2	5147.0	8.9654
1300	0.45383	4684.8	5410.9	9.2418	0.40341	4684.5	5410.6	9.1872	0.36308	4684.2	5410.3	9.1384

Analysis

- We take **the tank as the system,** which is a **control volume** since mass crosses the boundary. Noting that the microscopic energies of flowing and nonflowing fluids are represented by enthalpy h and internal energy u, respectively, the mass and energy balances for this uniform-flow system can be expressed as

Mass balance

- m_{in}-m_{out}=Δm_{system} so m_i= m_2-m_1
- **Energy balance**: E_{in}-E_{out}=ΔE_{system}
- $m_i h_i$=$m_2 u_2$-$m_1 u_1$ (Since Q=KE=PE=0)

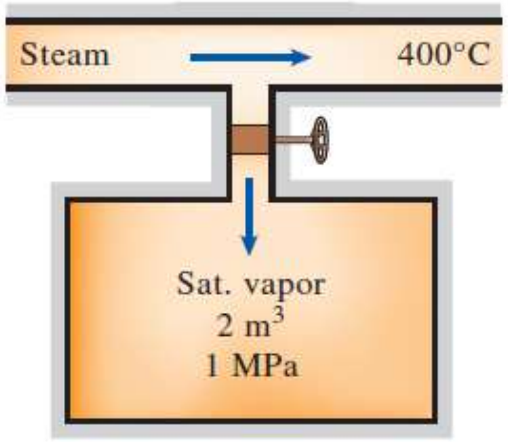


- $m_1 = V_{tank}/v_1 = 2/0.19436 = 10.29kg$
- $m_2 = V_{tank}/v_2 = 2/0.12551 = 15.94kg$
- $m_i = m_2 - m_1 = 15.94 - 10.29 = 5.645kg$
- Therefore, $m_i h_i = m_2 u_2 - m_1 u_1$
- $5.645hi = (15.94*2773.2) - (10.29*2582.8)$
- So, hi=3122.7kJ/kg

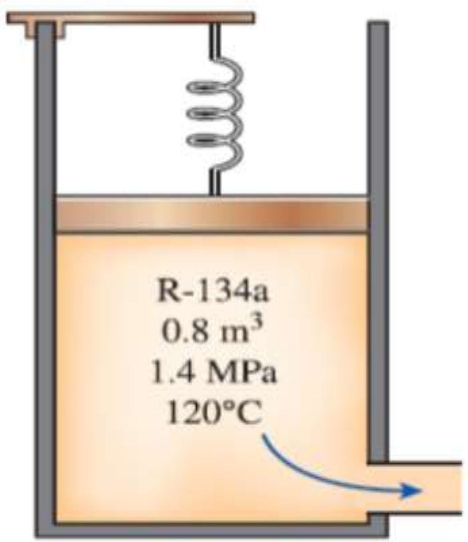
(also given that Ti=400^0C, so superheated state)

→Look @ superheated tables for which P hi is coming close to calculated value at 400^0C

So, Pi=8931kPa (determined from EES)



5-134 An insulated vertical piston-cylinder device initially contains 0.8 m^3 of refrigerant- 134a at 1.4 MPa and 120°C. A linear spring at this point applies full force to the piston. A valve connected to the cylinder is now opened, and refrigerant is allowed to escape. The spring unwinds as the piston moves down, and the pressure and volume drop to 0.7 MPa and 0.5 m^3 at the end of the process. Determine (a) the amount of refrigerant that has escaped and (b) the final temperature of the refrigerant.



Solution

An insulated piston-cylinder device with a linear spring is applying force to the piston. A valve at the bottom of the cylinder is opened, and refrigerant is allowed to escape. The amount of refrigerant that escapes and the final temperature of the refrigerant are to be determined

Assumptions

1. This is an unsteady process since the conditions within the device are changing during the process, but it can be analyzed as a uniform-flow process assuming that the state of fluid leaving the device remains constant.
2. Kinetic and potential energies are negligible.

Properties

The initial properties of R-134a are (Tables A-11 through A-13)

$$\left.\begin{array}{l} P_1 = 1.4\ \text{MPa} \\ T_1 = 120°\text{C} \end{array}\right\} \begin{array}{l} v_1 = 0.02039\ \text{m}^3/\text{kg} \\ u_1 = 323.57\ \text{kJ/kg} \\ h_1 = 352.11\ \text{kJ/kg} \end{array}$$

	P = 1.20 MPa (T_{sat} = 46.29°C)				P = 1.40 MPa (T_{sat} = 52.40°C)				P = 1.60 MPa (T_{sat} = 57.88°C)			
Sat.	0.016715	253.81	273.87	0.9130	0.014107	256.37	276.12	0.9105	0.012123	258.47	277.86	0.9078
50	0.017201	257.63	278.27	0.9267								
60	0.018404	267.56	289.64	0.9614	0.015005	264.46	285.47	0.9389	0.012372	260.89	280.69	0.9163
70	0.019502	277.21	300.61	0.9938	0.016060	274.62	297.10	0.9733	0.013430	271.76	293.25	0.9535
80	0.020529	286.75	311.39	1.0248	0.017023	284.51	308.34	1.0056	0.014362	282.09	305.07	0.9875
90	0.021506	296.26	322.07	1.0546	0.017923	294.28	319.37	1.0364	0.015215	292.17	316.52	1.0194
100	0.022442	305.80	332.73	1.0836	0.018778	304.01	330.30	1.0661	0.016014	302.14	327.76	1.0500
110	0.023348	315.38	343.40	1.1118	0.019597	313.76	341.19	1.0949	0.016773	312.07	338.91	1.0795
120	0.024228	325.03	354.11	1.1394	0.020388	323.55	352.09	1.1230	0.017500	322.02	350.02	1.1081
130	0.025086	334.77	364.88	1.1664	0.021155	333.41	363.02	1.1504	0.018201	332.00	361.12	1.1360
140	0.025927	344.61	375.72	1.1930	0.021904	343.34	374.01	1.1773	0.018882	342.05	372.26	1.1632
150	0.026753	354.56	386.66	1.2192	0.022636	353.37	385.07	1.2038	0.019545	352.17	383.44	1.1900
160	0.027566	364.61	397.69	1.2449	0.023355	363.51	396.20	1.2298	0.020194	362.38	394.69	1.2163
170	0.028367	374.78	408.82	1.2703	0.024061	373.75	407.43	1.2554	0.020830	372.69	406.02	1.2421
180	0.029158	385.08	420.07	1.2954	0.024757	384.10	418.76	1.2807	0.021456	383.11	417.44	1.2676

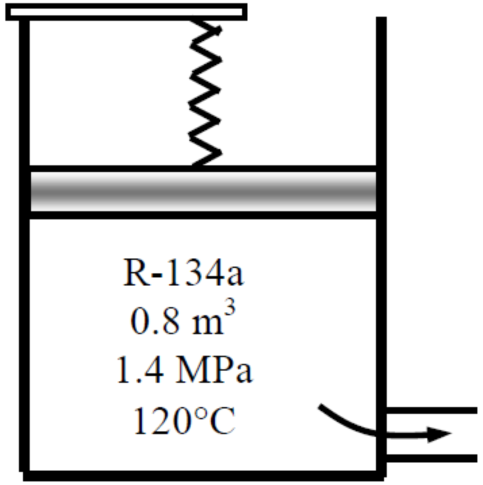
Analysis We take the tank as the system, which is a control volume since mass crosses the boundary. Noting that the microscopic energies of flowing and nonflowing fluids are represented by enthalpy *h* and internal energy *u*, respectively, the mass and energy balances for this uniform-flow system can be expressed as

Mass balance: $m_{\text{in}} - m_{\text{out}} = \Delta m_{\text{system}} \rightarrow m_e = m_1 - m_2$

Energy balance:

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$W_{\text{b,in}} - m_e h_e = m_2 u_2 - m_1 u_1 \quad (\text{since } Q \cong ke \cong pe \cong 0)$$



The initial mass and the relations for the final and exiting masses are

$$m_1 = \frac{V_1}{v_1} = \frac{0.8\ \text{m}^3}{0.02039\ \text{m}^3/\text{kg}} = 39.24\ \text{kg}$$

$$m_2 = \frac{V_2}{v_2} = \frac{0.5\ \text{m}^3}{v_2}$$

$$m_e = m_1 - m_2 = 39.24 - \frac{0.5\ \text{m}^3}{v_2}$$

Noting that the spring is linear, the boundary work can be determined from

$$W_{\mathrm{b,in}} = \frac{P_1 + P_2}{2}(V_1 - V_2) = \frac{(1400 + 700)\ \mathrm{kPa}}{2}(0.8 - 0.5)\mathrm{m}^3 = 315\ \mathrm{kJ}$$

Substituting the energy balance,

$$315 - \left(39.24 - \frac{0.5\ \mathrm{m}^3}{v_2}\right)h_e = \left(\frac{0.5\ \mathrm{m}^3}{v_2}\right)u_2 - (39.24\ \mathrm{kg})(323.57\ \mathrm{kJ/kg}) \qquad \text{(Eq. 1)}$$

where the enthalpy of exiting fluid is assumed to be the average of initial and final enthalpies of the refrigerant in the cylinder. That is,

$$h_e = \frac{h_1 + h_2}{2} = \frac{(352.11\ \mathrm{kJ/kg}) + h_2}{2}$$

Final state properties of the refrigerant (*h*2, u2, and v2) are all functions of final pressure (known) and temperature (unknown). The solution may be obtained by a trial-error approach by trying different final state temperatures until Eq. (1) is satisfied. Thus, we obtain

$T_2 =$ **96.2°C**, $m_e =$ **26.8 kg,** $h_2 = 334.51$ kJ/kg,

$u_2 = 306.43$ kJ/kg, $v_2 = 0.04011\ \mathrm{m}^3/\mathrm{kg}$, $m_2 = 12.47$ kg