

Thermodynamics

Caution: Students please read before starting

- (1) You should be provided with a set of thermodynamics properties tables for use during this exam.
- (2) The exam consists of three (3) problems, each starting on a new page. Check NOW to verify that your exam is complete.

If you are missing the properties tables or any of the three (3) exam problems, stop work NOW and advise your proctor immediately.

Problem 1

An ideal gas of mass m and gas constant R at pressure P_1 and temperature T_1 is compressed in a polytropic process to pressure $P_2 = 2P_1$. The polytropic exponent is $n = 1/2$. The gas is isothermally expanded back to $P_3 = P_2$. The gas then undergoes an isobaric process to return to P_1 and T_1 .

(a) Find T_2 in terms of T_1 .

(b) Find the work of each process in the cycle (${}_1W_2$, ${}_2W_3$, and ${}_3W_1$) and total cycle work (W_{cycle}) in terms of P_1 , T_1 , m , and R . Is work done on or by this system?

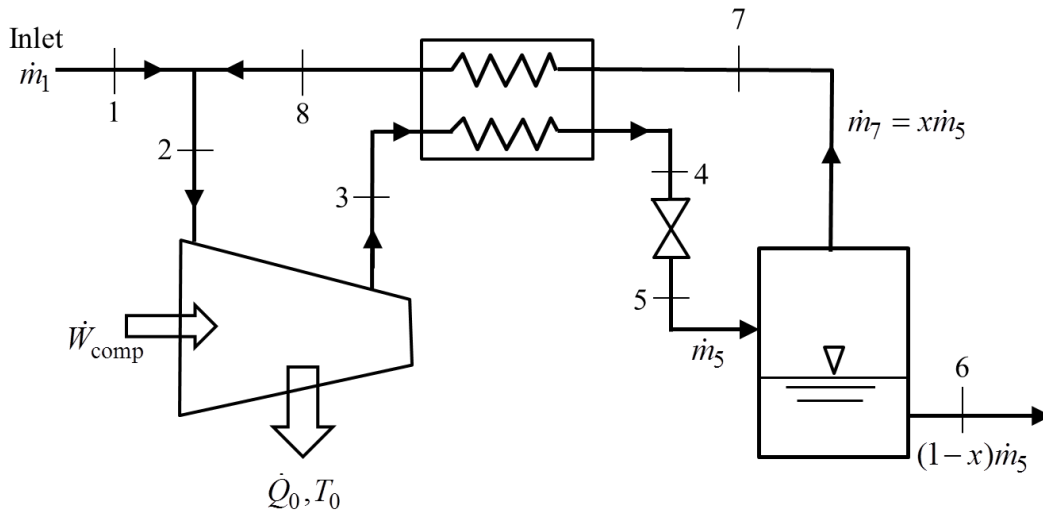
(c) Sketch the cycle in the P - v plane.

Problem 2

A 1 lbm charge of finely chopped steel wool with specific heat of 0.1 Btu/lbm-°R is placed into a well-insulated cylinder-piston mechanism containing 0.2 lbm of an ideal gas at 100 psia. The initial temperature of the ideal gas and metal wool is 520°R. The ideal gas and wool then experience a very slow process through which the piston transfers 28 Btu of work to the ideal gas. Calculate the final pressure of the gas. Assume the ideal gas has the following properties: $c_v = 0.2$ Btu/lbm-°R, $R = 0.07$ Btu/lbm-°R.

Problem 3

A Linde-Hampson cycle shown below is used to produce liquid nitrogen (N_2) from pure N_2 gas with a flow rate $\dot{m}_1 = 0.02$ kg/s, as shown in the following. Assume that states 1, 2, and 8 are at atmospheric conditions: $p_0 = 100$ kPa = 0.1 MPa and $T_0 = 300$ K.



The N_2 gas is compressed isothermally from state 2 to state 3 at $p_3 = 10$ MPa, while transferring heat to the ambient at a rate \dot{Q}_0 . The compressor may be assumed reversible. After the compressor, the nitrogen is cooled to state 4 in a heat exchanger. Neglect pressure drops of the fluid through the pipelines in the heat exchanger.

From state 4 to state 5 is a throttling process where the pressure is reduced to $p_5 = 0.1$ MPa = p_0 and the temperature is reduced to $T_5 = T_{sat}(p_0) = 77.3$ K. The two-phase mixture at state 5 goes into a separation tank, from which saturated liquid is withdrawn at state 6 with a flow rate $\dot{m}_6 = (1-x)\dot{m}_5$ and saturated vapor (state 7) is sent to the heat exchanger. Assume that the valve and separator, as well as the exposed pipes, are perfectly insulated. If needed, make additional assumptions yourself.

Answer the following questions. You may refer to the following property tables.

- (1) Schematically draw all the states and processes in a T - s diagram. Assume that the temperature of state 4 is above the critical temperature.
- (2) Find the value x and determine the specific enthalpy at state 4, h_4 .

- (3) Assuming, $T_4 = 158 \text{ K}$, $s_4 = 1.94 \text{ kJ/kg-K}$, calculate the entropy generation rate in the heat exchanger.
- (4) Determine the required compressor power, \dot{W}_{comp} .

Necessary nitrogen property table:

State	2	3	6 Sat. liquid	7 Sat. vapor
Temperature (K)	300	300	77.3	77.3
Pressure (MPa)	0.1	10	0.1	0.1
Specific Enthalpy (kJ/kg)	462	444	29.3	229
Specific Entropy (kJ/kg-K)	4.42	3.01	0.42	2.99