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In class we did

11-3
11-7
11-9
11-25
11-26
11-28
Example-1
Example-2

They are all in attached PDF

Problems and Solutions

11-1. Equations of state for a single component can be any of the following, *except*:

(a) the ideal gas law, $Pv = RT$

(b) the ideal gas law modified by insertion of a compressibility factor, $Pv = ZRT$

(c) any relationship interrelating three or more state functions

(d) a mathematical expression defining a path between states

(e) relationships mathematically interrelating thermodynamic properties of the material

Solution

All *except* (d) are correct. The ideal gas law is the simplest equation of state; it is often applied to real gases by using a compressibility factor Z. Any relationships that interrelate thermodynamic state function data are equations of state. Answer (d) expresses the path of a process between states rather than a relationship between variables at a single point or state. The answer is (d).

11-2. On the Mollier diagram for steam, which of the numbered lines represents a line of constant pressure?

(a) Line 1

(b) Line 2

(c) Line 3

(d) Line 4

(e) Line 5

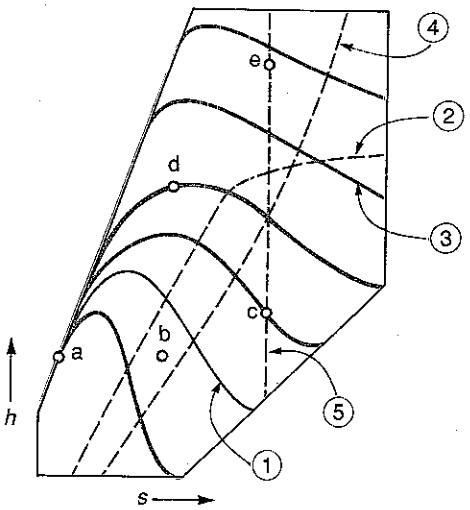


Fig. 11-2

Solution

(a) constant moisture 100 – x% or quality x% (Line 1)

(b) constant temperature, °F (Line 2)

(c) constant superheat, °F (Line 3)

(d) constant pressure, psia (Line 4)

(e) constant entropy, BTU/lb °R (Line 5)

Horizontal lines are constant enthalpy or total heat content. The answer is (d).

11-3.

Saturated Property Table

T, °F	P, psia	v_f, ft^3	v_g ft^3	h_f BTU/lb	h_g, BTU/lb	s_f, BTU/lb°R	s_g, BTU/lb°R
40	51.7	0.0116	0.774	17.3	81.4	0.0375	0.166
80	98.9	0.0123	0.411	26.4	85.3	0.0548	0.164
120	172	0.0132	0.233	36.0	88.6	0.0717	0.162

Given the above data for Freon 12, what is its state at 40 °F and 25 psia?

(a) saturated liquid (d) saturated vapor
(b) superheated vapor (e) vapor-liquid mixture
(c) compressed liquid

Solution

At 40 °F equilibrium between liquid and gas exists at 51.7 psia. Below 51.7 psia superheated vapor exists, and above 51.7 psia only pressurized liquid exists. The answer is (b).

11-4. Using the previous Freon 12 data table, what is its entropy in BTU/lb °R at 120 °F and 80% quality?

(a) 0.057 (d) 28.8
(b) 0.144 (e) none of these
(c) 0.186

Solution

At 120 °F, $s_f = 0.0717$ and $s_{fg} = 0.162 - 0.0717 = 0.090$. Here s_f is saturated liquid at 0% quality and s_g is saturated vapor of 100% quality. Thus s at 80% quality $= s_f + (0.80)\ s_{fg} = 0.0717 + (0.80)(0.090) = 0.144$ BTU/lb °R. The answer is (b).

11-5. Using the previous Freon 12 data table, what is its latent heat (heat of vaporization) in BTU/lb at 80 °F?

(a) 0.219 (d) 58.9
(b) 0.423 (e) none of these
(c) 26.4

Solution

Here, $h_{fg} = h_g - h_f = 85.3 - 26.4 = 58.9$ BTU/lb
The answer is (d).

11-6. A nonflow (closed) system contains 1 pound of an ideal gas ($C_p = 0.24$, $C_v = 0.17$). The gas temperature is increased by 10 °F while 5 BTU of work are done by the gas. What is the heat transfer in BTU?

(a) −3.3 (d) +7.4
(b) −2.6 (e) none of these
(c) +6.7

Solution

The thermodynamic sign convention is + for heat in and + for work out of a system. Apply the first law for a closed system and an ideal gas working fluid:

$$\Delta U = mC_v\,\Delta T = q - w$$

$$0.17(10) = q - (+5), \quad 1.7 = q - 5, \quad q = 6.7$$

The answer is (c).

11-7. Shaft work of –15 BTU/lb and heat transfer of –10 BTU/lb change the enthalpy of a system by

(a) –25 BTU/lb
(b) –15 BTU/lb
(c) –10 BTU/lb
(d) –5 BTU/lb
(e) +5 BTU/lb

Solution

The first law applied to a flow system is

$$h = q - w_s = -10 - (-15) = +5$$

The answer is (e).

11-8. A quantity of 55,000 gallons of water passes through a heat exchanger and absorbs 28,000,000 BTUs. The exit temperature is 110 °F. The entrance water temperature in °F is nearest to:

(a) 49
(b) 56
(c) 68
(d) 73
(e) 82

Solution

For liquid water, $C_p = 1.0$ BTU/(lb °F)

$$Q = mC_p\Delta T = mC_p(T_2 - T_1)$$

$$28{,}000{,}000 = (55{,}000\ \text{gal})\left(\frac{8.33\ \text{lb}}{\text{gallon}}\right)(1.0)(110 - T_1)$$

$$61.1 = 110 - T_1 \quad T_1 = 48.9\ ^\circ\text{F}$$

The answer is (a).

11-9. A fluid at 100 psia has a specific volume of 4 ft^3/lb and enters an apparatus with a velocity of 500 ft/sec. Heat radiation losses in the apparatus are equal to 10 BTU/lb of fluid supplied. The fluid leaves the apparatus at 20 psia with a specific volume of 15 ft^3/lb and a velocity of 1000 ft/sec. In the apparatus, the shaft work done by the fluid is equal to 195,000 ft-lbf/lbm. Does the internal energy of the fluid increase or decrease, and how much is the change?

(a) 230 BTU/lb (increase)
(b) 244 BTU/lb (increase)
(c) 250 BTU/lb (decrease)
(d) 257 BTU/lb (decrease)
(e) 294 BTU/lb (decrease)

Solution

The basis of the calculation will be: 1 lbm

Use the thermodynamic sign convention that heat in and work out are positive. The first law energy balance for the flow system: $h_2 + KE_2 - h_1 - KE_1 = Q - W_s$. Since the working fluid is unspecified and the internal energy change is desired, use the definition $h = u + Pv$.

$$u_2 + P_2v_2 + KE_2 - u_1 - P_1v_1 - KE_1 = Q - W_s$$

or

$$u_2 - u_1 = Q - W_s + P_1v_1 + KE_1 - P_2v_2 - KE_2$$

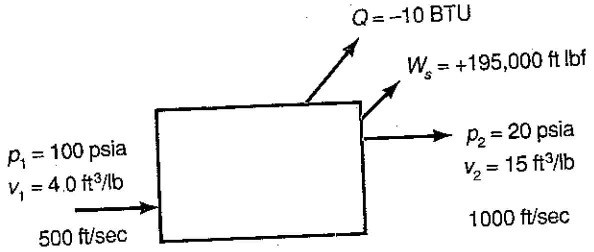


Fig. 11-9

Now calculate numerical values for all terms except $u_2 - u_1$:

$$P_2v_2 = \frac{20(144)(15)}{778} = 55.5\ \text{BTU/lb} \quad P_1v_1 = \frac{100(144)(4.0)}{778} = 74.0\ \text{BTU/lb}$$

$$KE_2 = \frac{V^2}{2gJ} = \frac{(1000)^2}{(64.4)(778)} = 20.0\ \text{BTU/lb}$$

$$KE_1 = \frac{V^2}{2gJ} = \frac{(500)^2}{(64.4)(778)} = 5.0\ \text{BTU/lb}$$

$$W_s = \frac{195{,}000\ \text{ft-lbf}}{\text{lbm}} \times \frac{\text{BTU}}{778\ \text{ft-lbf}} = +250.6\ \text{BTU/lb}$$

Therefore,

$u_2 - u_1 = -10 - 250.6 + 74.0 + 5.0 - 55.5 - 20.0 = -257.1$ BTU/lb (decrease)

The answer is (d).

11-10. Exhaust steam from a turbine exhausts into a surface condenser at a mass flow rate of 8000 lb/hr, 2 psia and 92% quality. Cooling water enters the condenser at 74 °F and leaves at the steam inlet temperature.

Properties of Saturated Water (US units): Temperature Table

v, ft³/lb; u and h, BTU/lb; s, BTU/(lb)(°R)

		Specific volume		Internal energy		Enthalpy			Entropy	
Temp. °F T	Press psia P	Sat liquid v_f	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
74	0.4158	0.01606	763.5	42.09	1035.0	42.09	1051.7	1093.8	0.08215	2.0526

11-25. A Carnot engine operating between 70 °F and 2000 °F is modified solely by raising the high temperature by 150 °F and raising the low temperature by 100 °F. Which of the following statements is *false*?

(a) The thermodynamic efficiency is increased.

(b) More work is done during the isothermal expansion

(c) More work is done during the isentropic compression.

(d) More work is done during the reversible adiabatic expansion

(e) More work is done during the isothermal compression.

Solution

The Carnot cycle efficiency is originally

$$\eta = \frac{T_H - T_L}{T_H - 0} = \frac{2460\ ^\circ\mathrm{R} - 530\ ^\circ\mathrm{R}}{2460\ ^\circ\mathrm{R}} = 0.785$$

After the change

$$\eta = \frac{2610 - 630}{2610} = 0.759 \text{ (efficiency is reduced)}$$

On the T-s and P-V diagrams in Fig. 11-25 the original cycle is shown as ABCD, and the modified cycle is shown as A′B′C′D′.

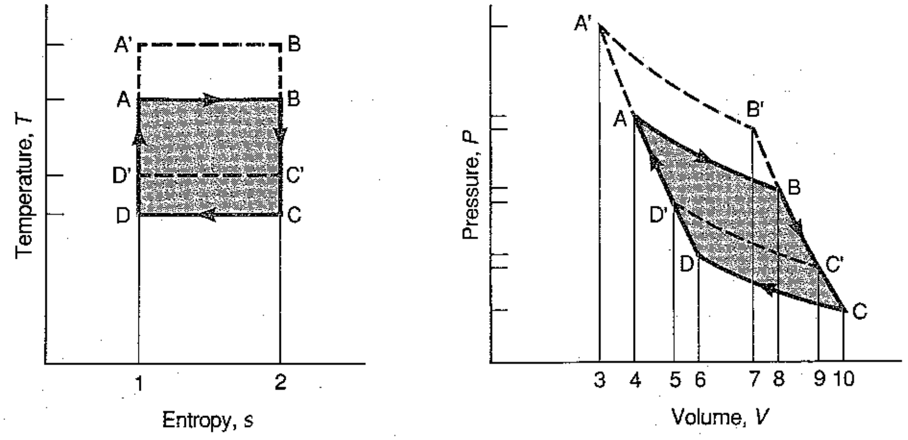


Fig. 11-25

Compare the work done during the isothermal expansion (A to B vs. A′ to B′):

Original: area A–B–8–4

Modified: area A′–B′–7–3 is larger

Compare the work done during the isentropic compression (D to A vs. D′ to A′):

Original: area D–A–4–6

Modified: area D′–A′–3–5 is larger

Compare the work during the reversible (isentropic) expansion (B to C vs. B′ to C′):

Original: area B–C–10–8

Modified: area B′–C′–9–7 is larger

Compare the work during the isothermal compression (C to D vs. C′ to D′):

Original: area C–D–6–10

Modified: area C′–D′–5–9 is larger

Statements (b), (c), (d), and (e) are correct. The answer is (a).

11-26. In the ideal heat pump system represented in Fig. 11-26, the expansion valve 4–1 performs the process that is located on the *T*-*s* diagram between points

(a) A and B

(b) B and C

(c) C and D

(d) D and E

(e) E and A

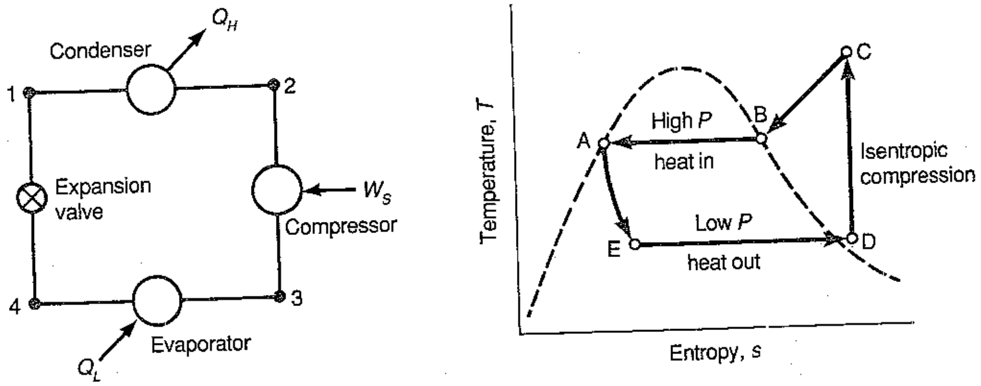


Fig. 11-26

Solution

The vapor compression reversed Rankine cycle is conducted counterclockwise on both the schematic and *T*-*s* diagrams. Numbers on the schematic and letters on the *T*-*s* diagram are related: 1 = A, 2 = B, 3 = D, and 4 = E Process C–B–A occurs in the condenser between 2 and 1 The expansion process A–E occurs between 1–4 The answer is (e).

11-27. Which air-standard power cycle do the *P*-*V* and *T*-*s* diagrams in Fig. 11-27 represent?

(a) Otto cycle

(b) Reheat cycle

(c) Carnot cycle

(d) Rankine cycle

(e) Brayton cycle

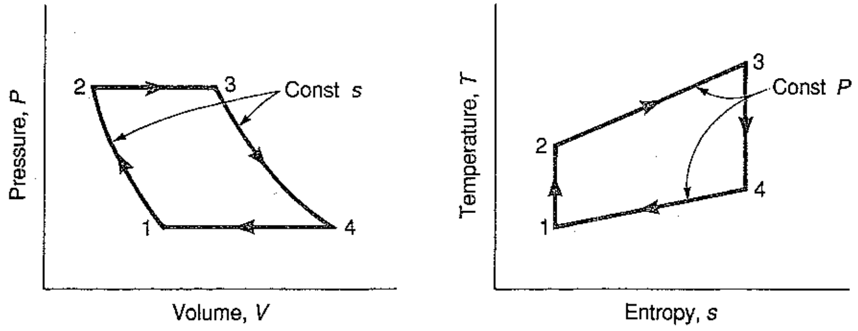


Fig 11-27

Solution

The Brayton cycle is applied to the simple open-cycle gas turbine wherein intake air is compressed (1–2), combustion supplies thermal energy (2–3), and combustion products expand and drive the turbine (3–4) and exhaust at 4. The answer is (e)

11-28. Data in the table describe two states of a working fluid that exist at two locations in a piece of hardware.

	P, psia	v, ft^3/lb	T, °F	h, BTU/lb	s, BTU/(lb °F)
State 1	25	0.011	20	19.2	0.0424
State 2	125	0.823	180	203.7	0.3649

Which of the following statements about the path from State 1 to 2 is *false*?

(a) The path results in an expansion

(b) The path determines the amount of work done.

(c) The path is indeterminate from these data.

(d) The path requires that energy be added in the process.

(e) The path is reversible and adiabatic.

Solution

The large volume and entropy changes indicate a change from a condensed phase to a vapor phase. Temperature, pressure, and enthalpy increases require an energy input. The path from 1 to 2 is indeterminate since no information on intermediate states is given. Work is always path dependent. The entropy increase means the process cannot be reversible and adiabatic (isentropic). The answer is (e)

11-29. Name the process that has no heat transfer.

(a) Isentropic

(b) Isothermal

(c) Quasistatic

(d) Reversible

(e) Polytropic

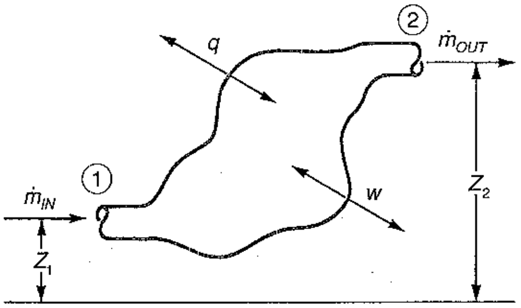


Fig. 11-2

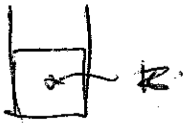
The thermodynamic sign convention for heat and work is that q_{in} is positive and w_{out} is positive. This is the normal flow of heat and work in an engine or power plant

Care must be taken to keep the units consistent. For example, the normal units for internal energy, heat and work are kJ/kg or BTU/lbm. In the S.I. system, $V^2/2g_c$ and Zg/g_c must be divided by 1000—in the U.S. system by 778. Remember that g_c in the S.I. system has a value of 1 but is 32.2 in the U.S. system.

The first law is the most popular one by far in solving thermodynamics problems!

Example 1

A piston-cylinder contains 5 kg of air. During a compression process 100 kJ of heat is removed while 250 kJ of work is done on the air. Find the change in internal energy of the air.



Solution

The system is a closed system since the mass is fixed. So

$u_1 + q = u_2 + w$

Here, $q = -100$ kJ, since heated leaving a system is negative, and $w = -250$ kJ, since work done *on* a system is negative. Thus

$$u_2 - u_1 = -100 - (-250) = 150 \text{ kJ}, \quad \text{or} \quad \frac{150}{5} = 30 \text{ kJ/kg}$$

Example 2

Heated air enters a turbine at a flow rate of 5 kg/s. The entering and leaving conditions are shown in the table below. The heat loss from the turbine is 50 kW. Find the power produced

	Inlet	Exit
Pressure, kPa	1000	100
Temperature, °K	800	500
Velocity, m/s	100	200
Specific internal energy, kJ/kg	137	85
Specific volume, m³/kg	0.23	1.44
Elevation, m	3	10

Solution

The system has mass flowing across the boundaries so it is an open system.

$$u_1 + p_1 v_1 + \frac{Z_1 g}{g_c} + \frac{V_1^2}{2g_c} + q = u_2 + p_2 v_2 + \frac{Z_2 g}{g_c} + \frac{V_2^2}{2g_c} + w$$

$$w = (u_1 - u_2) + (p_1 v_1 - p_2 v_2) + \frac{(Z_1 - Z_2)g}{g_c} + \frac{V_1^2 - V_2^2}{2g_c} + q$$

$$= (137 - 85) + (1000 \times 0.23 - 100 \times 1.44) + \frac{(3-10)}{1000} \times \frac{9.81}{1.0} + \frac{100^2 - 200^2}{2 \times 1 \times 1000}$$

$$= 52 + 86 - 0.069 - 15 = 122.9 \frac{\text{kJ}}{\text{kg}}$$

$$\dot{w} = w \times \dot{m} = 122.9 \times 5 = 615 \text{ kW}$$

PROPERTIES OF PURE SUBSTANCES

Use of Steam Tables

Property tables for substances that go through a phase change during normal thermodynamic processes, such as H_2O, R-12 and NH_3, are divided into three groups:

- Saturated Tables. These show the properties (v, u, h, s) of the saturated liquid and saturated vapor. For convenience, there are usually two sets; one using T as the entering argument and one using P. The highest temperature/pressure entry is usually the critical point. The quality x is needed to define properties in the mixture region.
- Superheated Tables. These show the properties (v, u, h, s) as a function of T and P in the superheated area to the right of the saturated vapor curve and are usually grouped by pressure. *Any two* properties (v, u, h, s, T, P) may be used to define the state. The saturated state is usually noted. At moderate pressures and temperatures well away from saturation, perfect gas relationships may be used as an approximation.
- Subcooled or Compressed Liquid Tables. These tables show properties (v, u, h, and s) as a function of T and P in the area to the left of the saturated liquid curve and are usually grouped by pressure. As with the Superheated Tables, any two properties may be used to define the state, and the saturated state is usually noted. For points in the region that are below the tabulated pressures, the properties are approximated as those of the saturated liquid at the same temperature (v, u, h and s are weak functions of pressure).

The procedure for finding the state-point properties for given data where the condition of the substances is not defined is best done in a structured manner: