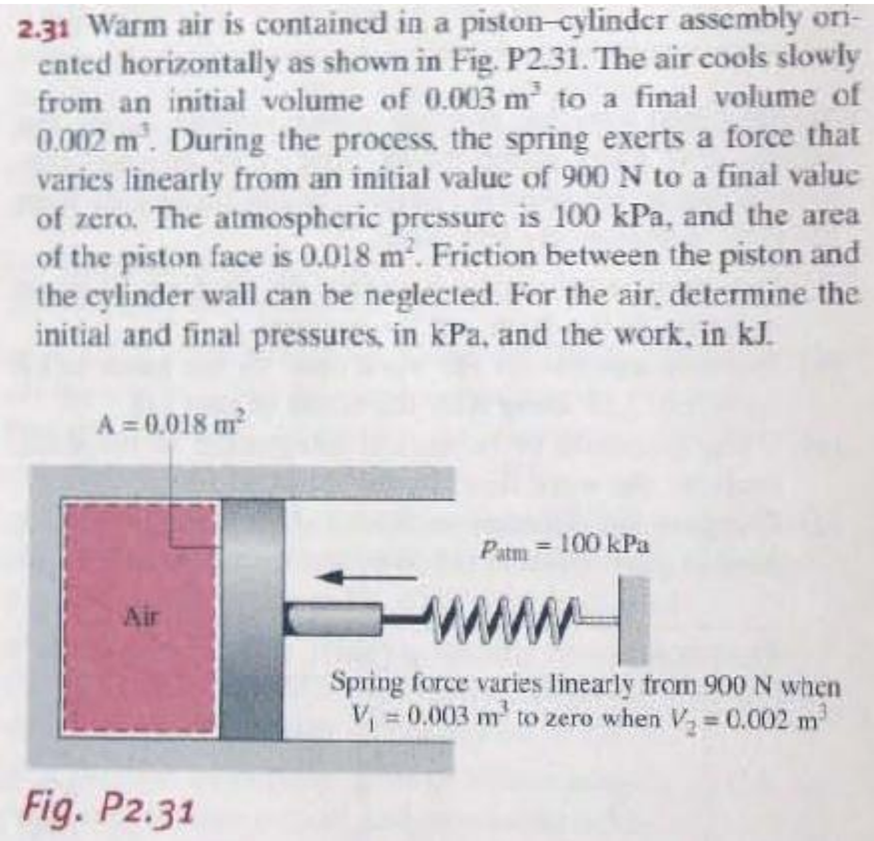
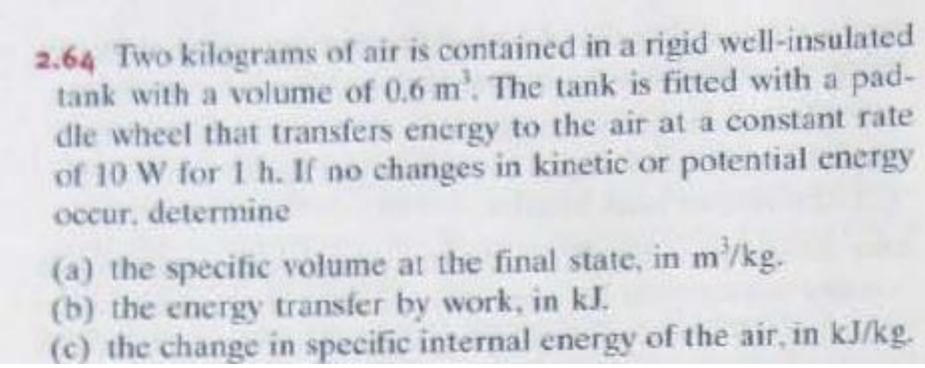


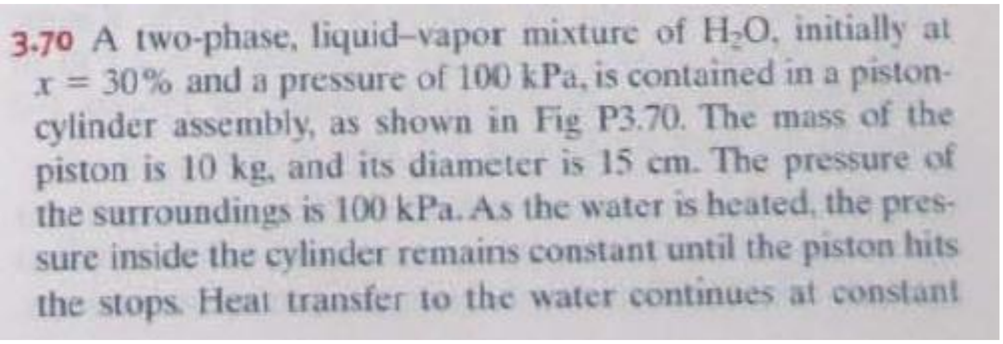
2.31 Warm air is contained in a piston–cylinder assembly oriented horizontally as shown in Fig. P2.31. The air cools slowly from an initial volume of 0.003 m^3 to a final volume of 0.002 m^3. During the process, the spring exerts a force that varies linearly from an initial value of 900 N to a final value of zero. The atmospheric pressure is 100 kPa, and the area of the piston face is 0.018 m^2. Friction between the piston and the cylinder wall can be neglected. For the air, determine the initial and final pressures, in kPa, and the work, in kJ.

Fig. P2.31



2.64 Two kilograms of air is contained in a rigid well-insulated tank with a volume of 0.6 m^3. The tank is fitted with a paddle wheel that transfers energy to the air at a constant rate of 10 W for 1 h. If no changes in kinetic or potential energy occur, determine

(a) the specific volume at the final state, in m^3/kg.
(b) the energy transfer by work, in kJ.
(c) the change in specific internal energy of the air, in kJ/kg.



3.70 A two-phase, liquid–vapor mixture of H_2O, initially at $x = 30\%$ and a pressure of 100 kPa, is contained in a piston-cylinder assembly, as shown in Fig P3.70. The mass of the piston is 10 kg, and its diameter is 15 cm. The pressure of the surroundings is 100 kPa. As the water is heated, the pressure inside the cylinder remains constant until the piston hits the stops. Heat transfer to the water continues at constant volume until the pressure is 150 kPa. Friction between the piston and the cylinder wall and kinetic and potential energy effects are negligible. For the overall process of the water, determine the work and heat transfer, each in kJ.

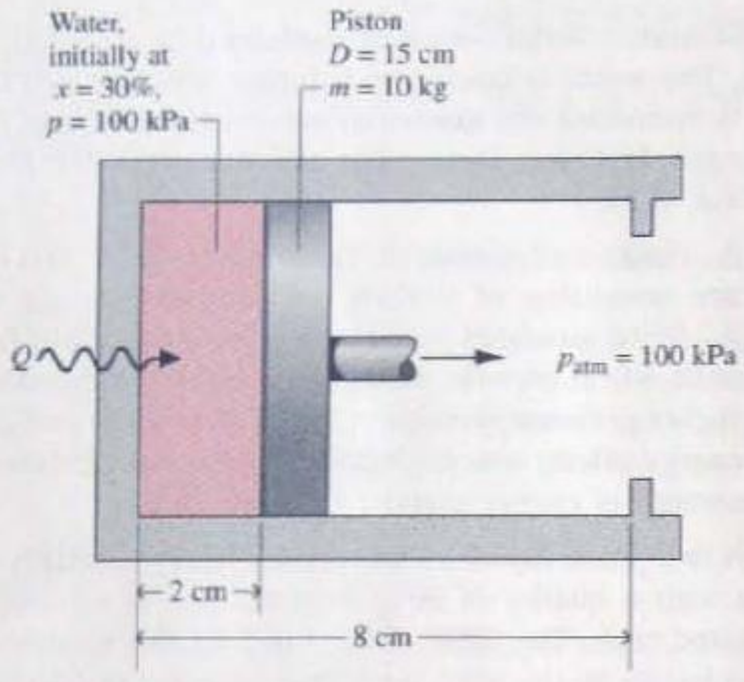


Fig. P3.70

3.125 Two uninsulated, rigid tanks contain air. Initially, tank A holds 1 lb of air at 1440°R, and tank B has 2 lb of air at 900°R. The initial pressure in each tank is 50 lbf/in.^{2} A valve in the line connecting the two tanks is opened and the contents are allowed to mix. Eventually, the contents of the tanks come to equilibrium at the temperature of the surroundings, 520°R. Assuming the ideal gas model, determine the amount of energy transfer by heat, in Btu, and the final pressure, in lbf/in.^{2}

4.45 Steam enters a turbine operating at steady state at 800°F and 500 lbf/in.^{2} and leaves at 0.8 lbf/in.^{2} with a quality of 93%. The turbine develops 15,000 hp, and heat transfer from the turbine to the surroundings occurs at a rate of 2.5×10^6 Btu/h. Neglecting kinetic and potential energy changes from inlet to exit, determine the volumetric flow rate of the steam at the inlet, in ft^3/h.

4.102 A simple steam power plant operates at steady state with water circulating through the components with a mass flow rate of 60 kg/s. Figure P4.102 shows additional data at key points in the cycle. Stray heat transfer and kinetic and potential effects are negligible. Determine (a) the thermal efficiency and (b) the mass flow rate of cooling water through the condenser, in kg/s.

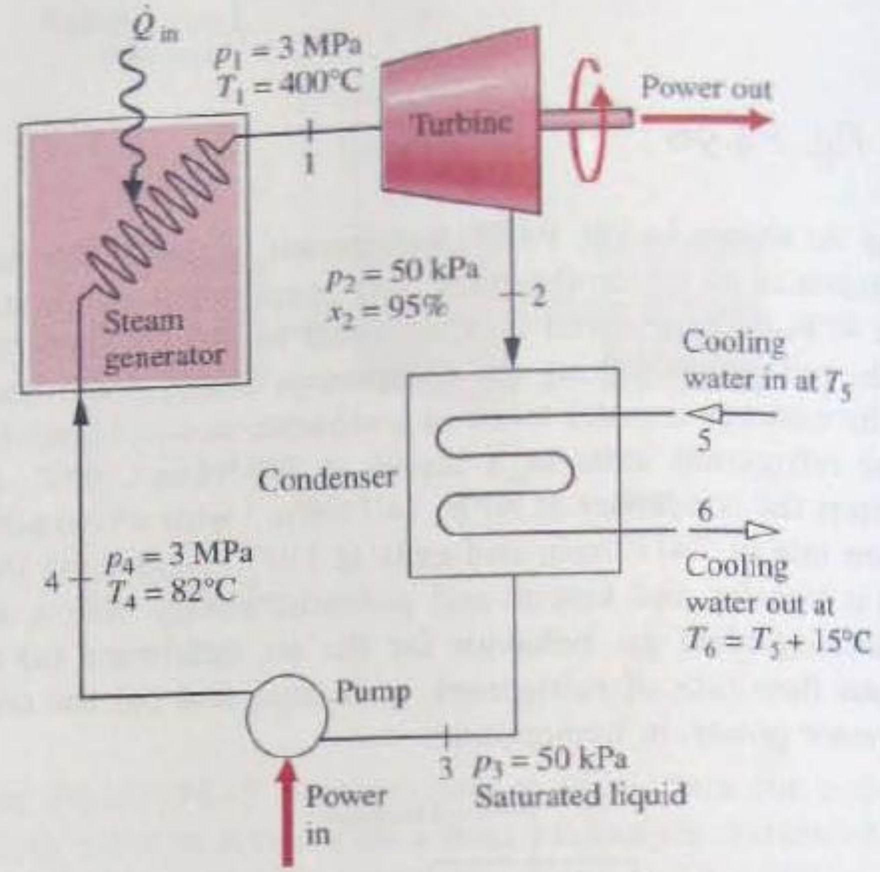
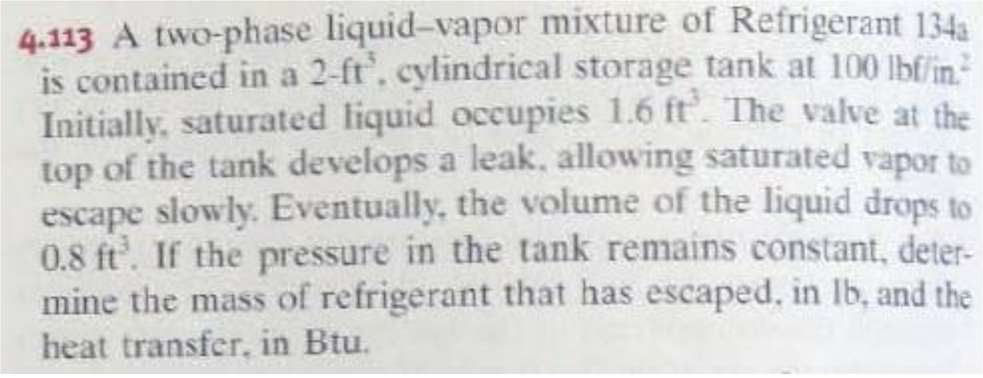
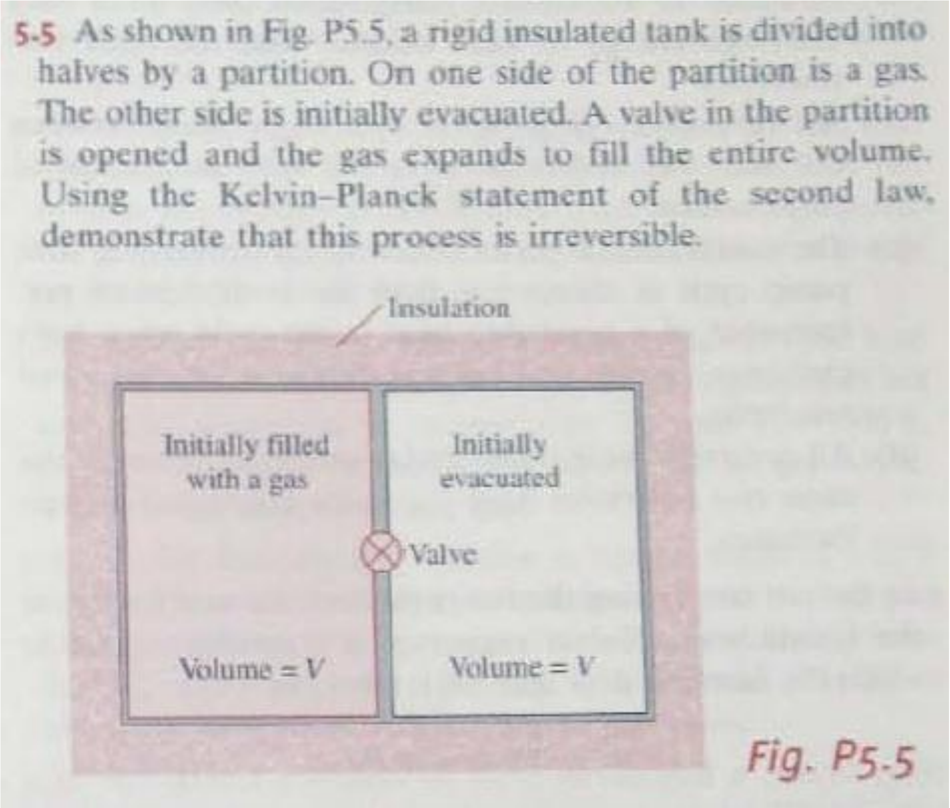


Fig. P4.102

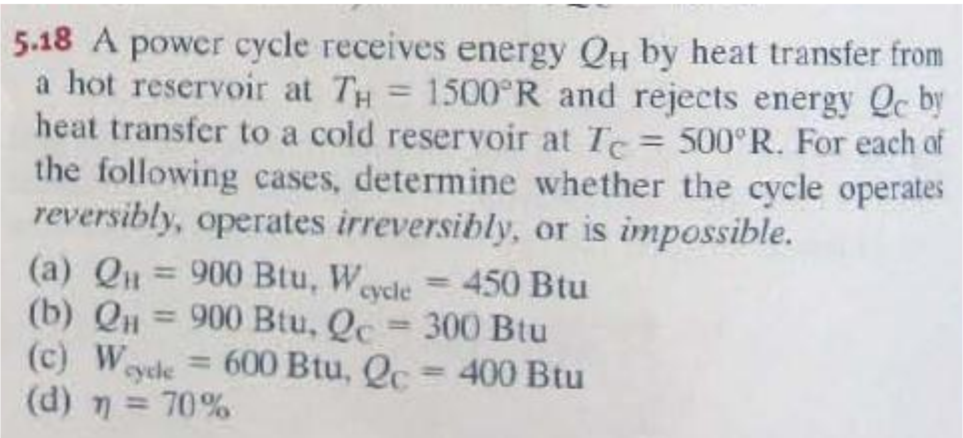


4.113 A two-phase liquid–vapor mixture of Refrigerant 134a is contained in a 2-ft^3, cylindrical storage tank at 100 lbf/in.^{2} Initially, saturated liquid occupies 1.6 ft^3. The valve at the top of the tank develops a leak, allowing saturated vapor to escape slowly. Eventually, the volume of the liquid drops to 0.8 ft^3. If the pressure in the tank remains constant, determine the mass of refrigerant that has escaped, in lb, and the heat transfer, in Btu.



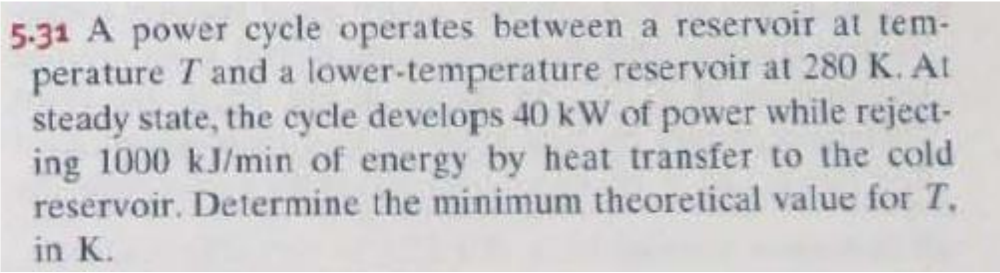
5.5 As shown in Fig. P5.5, a rigid insulated tank is divided into halves by a partition. On one side of the partition is a gas. The other side is initially evacuated. A valve in the partition is opened and the gas expands to fill the entire volume. Using the Kelvin–Planck statement of the second law, demonstrate that this process is irreversible.

Fig. P5-5

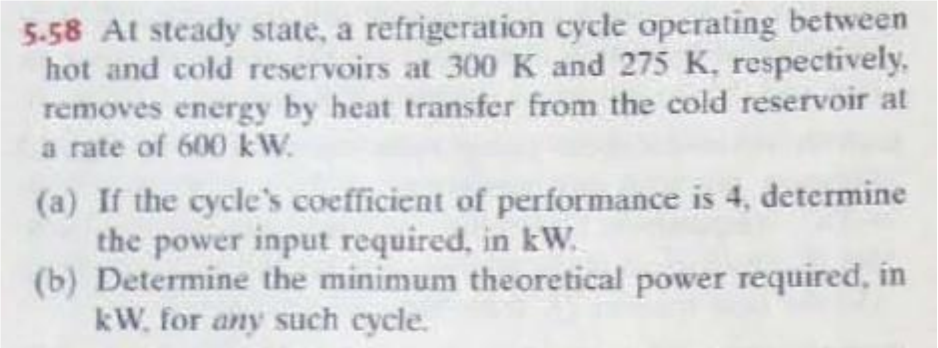


5.18 A power cycle receives energy Q_H by heat transfer from a hot reservoir at $T_H = 1500°R$ and rejects energy Q_C by heat transfer to a cold reservoir at $T_C = 500°R$. For each of the following cases, determine whether the cycle operates *reversibly*, operates *irreversibly*, or is *impossible*.

(a) $Q_H = 900$ Btu, $W_{cycle} = 450$ Btu
(b) $Q_H = 900$ Btu, $Q_C = 300$ Btu
(c) $W_{cycle} = 600$ Btu, $Q_C = 400$ Btu
(d) $\eta = 70\%$



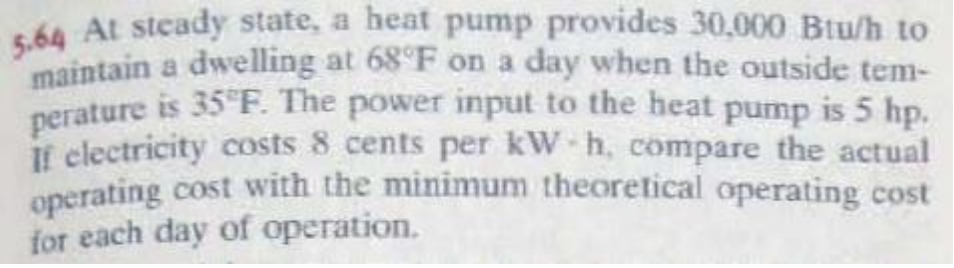
5.31 A power cycle operates between a reservoir at temperature T and a lower-temperature reservoir at 280 K. At steady state, the cycle develops 40 kW of power while rejecting 1000 kJ/min of energy by heat transfer to the cold reservoir. Determine the minimum theoretical value for T, in K.



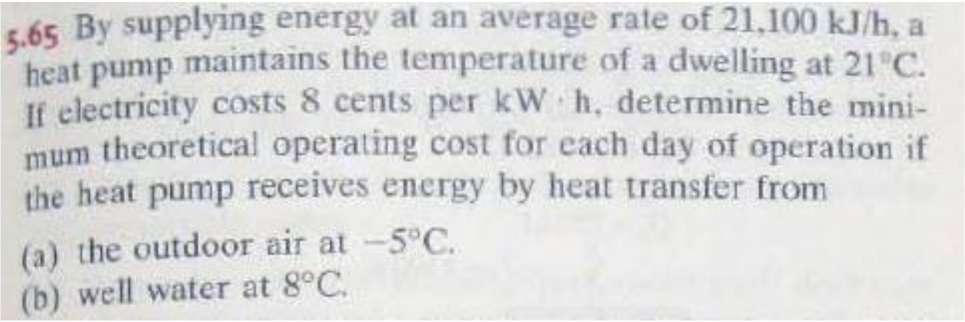
5.58 At steady state, a refrigeration cycle operating between hot and cold reservoirs at 300 K and 275 K, respectively, removes energy by heat transfer from the cold reservoir at a rate of 600 kW.

(a) If the cycle's coefficient of performance is 4, determine the power input required, in kW.

(b) Determine the minimum theoretical power required, in kW, for *any* such cycle.

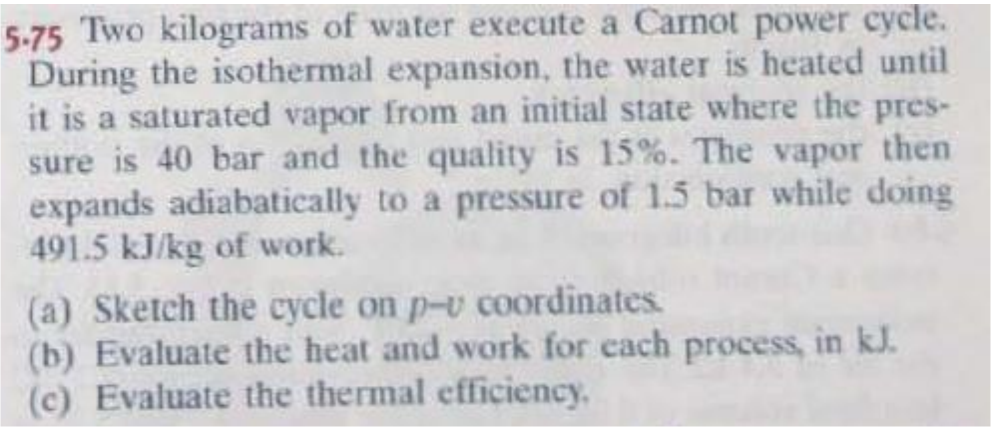


5.64 At steady state, a heat pump provides 30,000 Btu/h to maintain a dwelling at 68°F on a day when the outside temperature is 35°F. The power input to the heat pump is 5 hp. If electricity costs 8 cents per kW · h, compare the actual operating cost with the minimum theoretical operating cost for each day of operation.



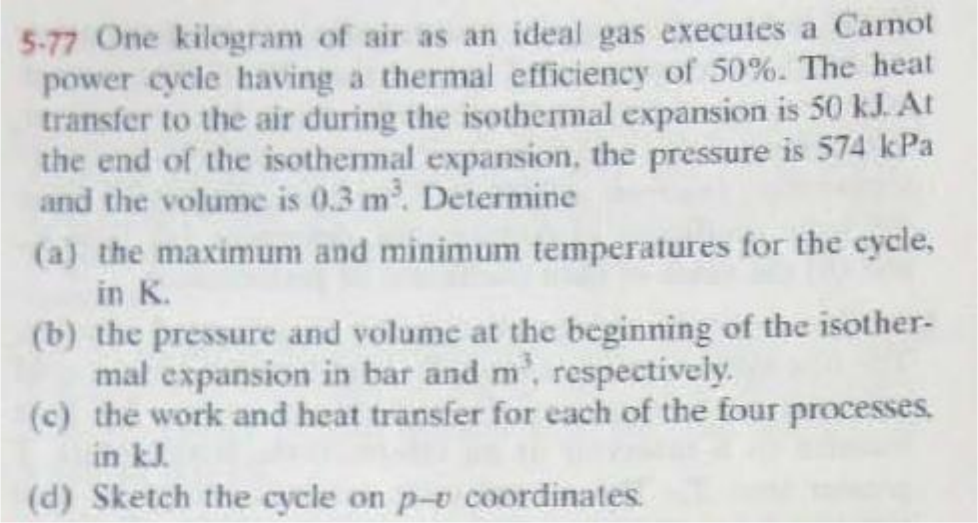
5.65 By supplying energy at an average rate of 21,100 kJ/h, a heat pump maintains the temperature of a dwelling at 21°C. If electricity costs 8 cents per kW · h, determine the minimum theoretical operating cost for each day of operation if the heat pump receives energy by heat transfer from

(a) the outdoor air at −5°C.
(b) well water at 8°C.



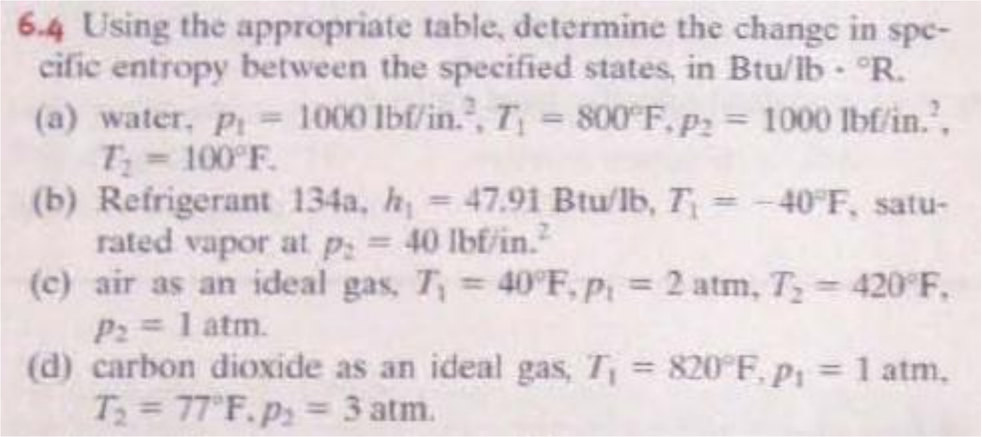
5.75 Two kilograms of water execute a Carnot power cycle. During the isothermal expansion, the water is heated until it is a saturated vapor from an initial state where the pressure is 40 bar and the quality is 15%. The vapor then expands adiabatically to a pressure of 1.5 bar while doing 491.5 kJ/kg of work.

(a) Sketch the cycle on p–v coordinates.
(b) Evaluate the heat and work for each process, in kJ.
(c) Evaluate the thermal efficiency.



5.77 One kilogram of air as an ideal gas executes a Carnot power cycle having a thermal efficiency of 50%. The heat transfer to the air during the isothermal expansion is 50 kJ. At the end of the isothermal expansion, the pressure is 574 kPa and the volume is 0.3 m^3. Determine

(a) the maximum and minimum temperatures for the cycle, in K.
(b) the pressure and volume at the beginning of the isothermal expansion in bar and m^3, respectively.
(c) the work and heat transfer for each of the four processes, in kJ.
(d) Sketch the cycle on p–v coordinates.



6.4 Using the appropriate table, determine the change in specific entropy between the specified states, in Btu/lb · °R.

(a) water, $p_1 = 1000$ lbf/in.^{2}, $T_1 = 800°\text{F}$, $p_2 = 1000$ lbf/in.^{2}, $T_2 = 100°\text{F}$.

(b) Refrigerant 134a, $h_1 = 47.91$ Btu/lb, $T_1 = -40°\text{F}$, saturated vapor at $p_2 = 40$ lbf/in.^{2}

(c) air as an ideal gas, $T_1 = 40°\text{F}$, $p_1 = 2$ atm, $T_2 = 420°\text{F}$, $p_2 = 1$ atm.

(d) carbon dioxide as an ideal gas, $T_1 = 820°\text{F}$, $p_1 = 1$ atm, $T_2 = 77°\text{F}$, $p_2 = 3$ atm.

6.14 One kilogram of water contained in a piston–cylinder assembly, initially at 160°C, 150 kPa, undergoes an isothermal compression process to saturated liquid. For the process, $W = -471.5$ kJ. Determine for the process,

(a) the heat transfer, in kJ.
(b) the change in entropy, in kJ/K.
Show the process on a sketch of the T–s diagram.

6.24 A gas initially at 14 bar and 60°C expands to a final pressure of 2.8 bar in an isothermal, internally reversible process. Determine the heat transfer and the work, each in kJ per kg of gas, if the gas is (a) Refrigerant 134a, (b) air as an ideal gas. Sketch the processes on p–v and T–s coordinates.

6.43 One pound mass of Refrigerant 134a contained within a piston–cylinder assembly undergoes a process from a state where the pressure is 120 lbf/in.^{2} and the quality is 40% to a state where the temperature is 50°F and the refrigerant is saturated liquid. Determine the change in specific entropy of the refrigerant, in Btu/lb · °R. Can this process be accomplished adiabatically?

6.57 An electric water heater having a 200 liter capacity employs an electric resistor to heat water from 23 to 55°C. The outer surface of the resistor remains at an average temperature of 80°C. Heat transfer from the outside of the water heater is negligible and the states of the resistor and the tank holding the water do not change significantly. Modeling the water as incompressible, determine the amount of entropy produced, in kJ/K, for

(a) the water as the system.
(b) the overall water heater including the resistor.

Compare the results of parts (a) and (b), and discuss.

6.82 Air enters an insulated turbine operating at steady state at 6.5 bar, 687°C and exits at 1 bar, 327°C. Neglecting kinetic and potential energy changes and assuming the ideal gas model, determine

(a) the work developed, in kJ per kg of air flowing through the turbine.

(b) whether the expansion is internally reversible, irreversible, or impossible.

6.86 Figure P6.86 provides steady-state operating data for a well-insulated device having steam entering at one location and exiting at another. Neglecting kinetic and potential energy effects, determine (a) the direction of flow and (b) the power output or input, as appropriate, in kJ per kg of steam flowing.

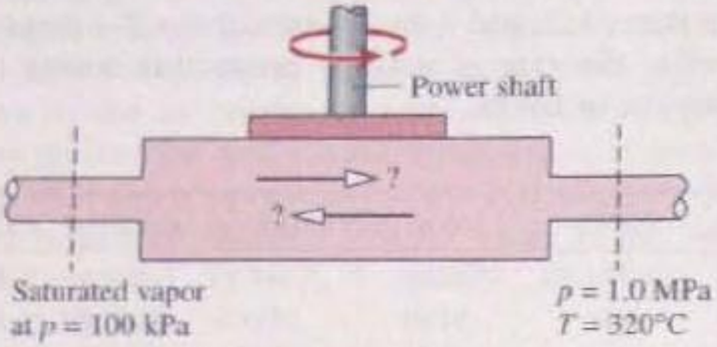
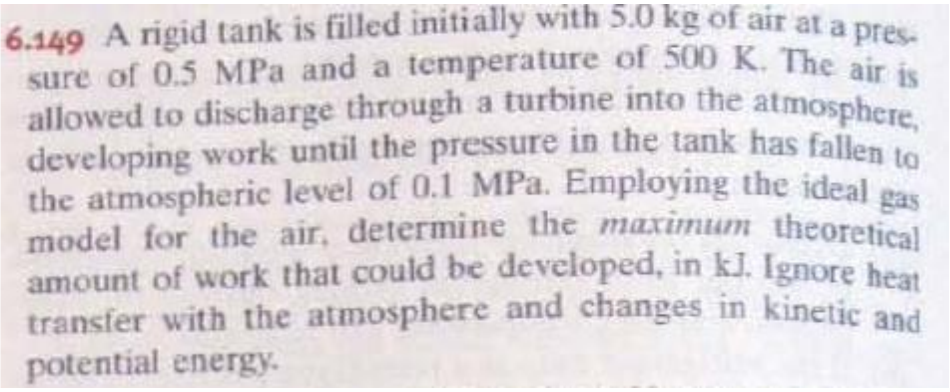
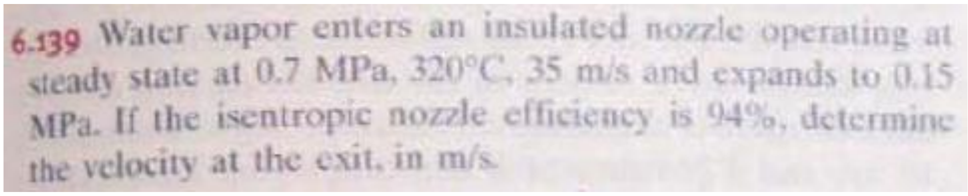


Fig. P6.86

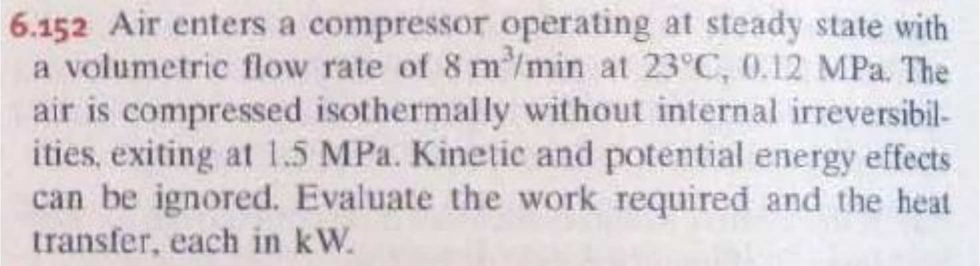
6.97 Air enters a turbine operating at steady state at 500 kPa, 860 K and exits at 100 kPa. A temperature sensor indicates that the exit air temperature is 460 K. Stray heat transfer and kinetic and potential energy effects are negligible, and the air can be modeled as an ideal gas. Determine if the exit temperature reading can be correct. It yes, determine the power developed by the turbine for an expansion between these states, in kJ per kg of air flowing. If no, provide an explanation with supporting calculations.



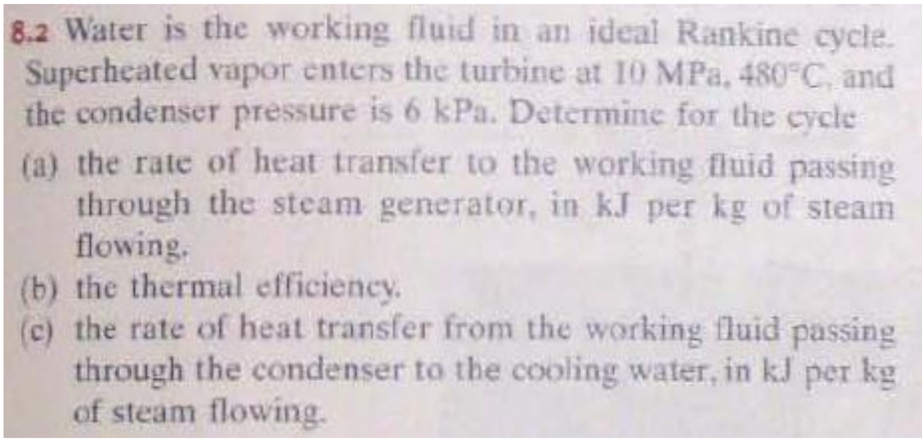
6.149 A rigid tank is filled initially with 5.0 kg of air at a pressure of 0.5 MPa and a temperature of 500 K. The air is allowed to discharge through a turbine into the atmosphere, developing work until the pressure in the tank has fallen to the atmospheric level of 0.1 MPa. Employing the ideal gas model for the air, determine the *maximum* theoretical amount of work that could be developed, in kJ. Ignore heat transfer with the atmosphere and changes in kinetic and potential energy.



6.139 Water vapor enters an insulated nozzle operating at steady state at 0.7 MPa, 320°C, 35 m/s and expands to 0.15 MPa. If the isentropic nozzle efficiency is 94%, determine the velocity at the exit, in m/s.



6.152 Air enters a compressor operating at steady state with a volumetric flow rate of 8 m^3/min at 23°C, 0.12 MPa. The air is compressed isothermally without internal irreversibilities, exiting at 1.5 MPa. Kinetic and potential energy effects can be ignored. Evaluate the work required and the heat transfer, each in kW.

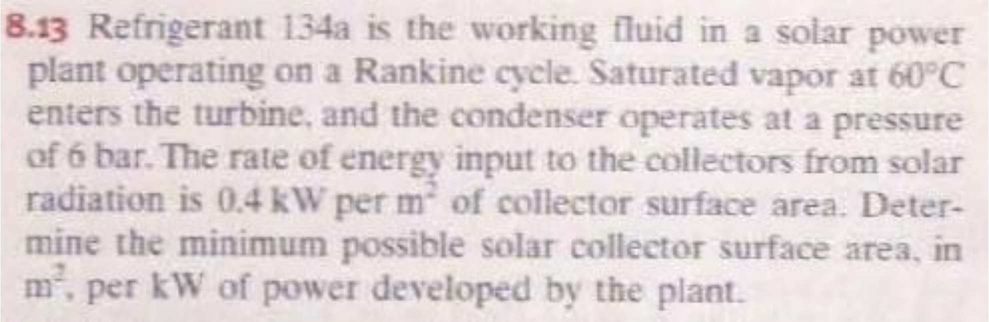


8.2 Water is the working fluid in an ideal Rankine cycle. Superheated vapor enters the turbine at 10 MPa, 480°C, and the condenser pressure is 6 kPa. Determine for the cycle

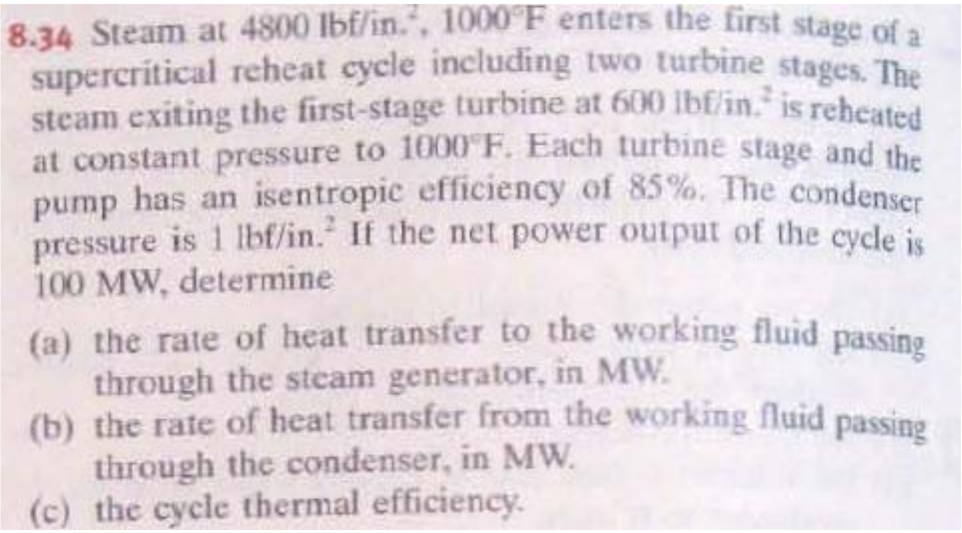
(a) the rate of heat transfer to the working fluid passing through the steam generator, in kJ per kg of steam flowing.

(b) the thermal efficiency.

(c) the rate of heat transfer from the working fluid passing through the condenser to the cooling water, in kJ per kg of steam flowing.



8.13 Refrigerant 134a is the working fluid in a solar power plant operating on a Rankine cycle. Saturated vapor at 60°C enters the turbine, and the condenser operates at a pressure of 6 bar. The rate of energy input to the collectors from solar radiation is 0.4 kW per m^2 of collector surface area. Determine the minimum possible solar collector surface area, in m^2, per kW of power developed by the plant.

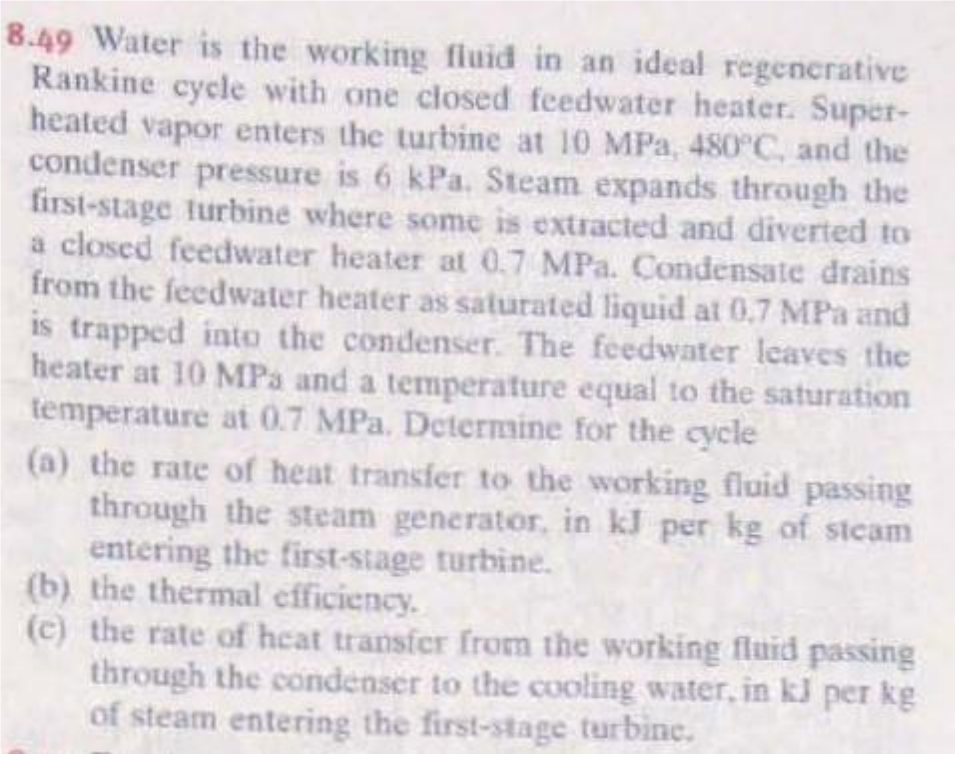


8.34 Steam at 4800 lbf/in.^{2}, 1000°F enters the first stage of a supercritical reheat cycle including two turbine stages. The steam exiting the first-stage turbine at 600 lbf/in.^{2} is reheated at constant pressure to 1000°F. Each turbine stage and the pump has an isentropic efficiency of 85%. The condenser pressure is 1 lbf/in.^{2} If the net power output of the cycle is 100 MW, determine

(a) the rate of heat transfer to the working fluid passing through the steam generator, in MW.

(b) the rate of heat transfer from the working fluid passing through the condenser, in MW.

(c) the cycle thermal efficiency.

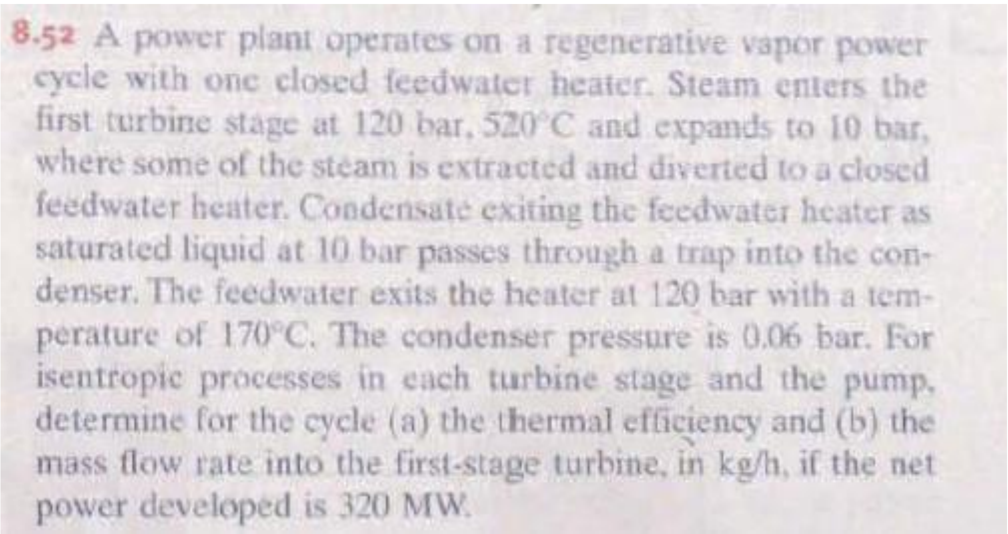


8.49 Water is the working fluid in an ideal regenerative Rankine cycle with one closed feedwater heater. Superheated vapor enters the turbine at 10 MPa, 480°C, and the condenser pressure is 6 kPa. Steam expands through the first-stage turbine where some is extracted and diverted to a closed feedwater heater at 0.7 MPa. Condensate drains from the feedwater heater as saturated liquid at 0.7 MPa and is trapped into the condenser. The feedwater leaves the heater at 10 MPa and a temperature equal to the saturation temperature at 0.7 MPa. Determine for the cycle

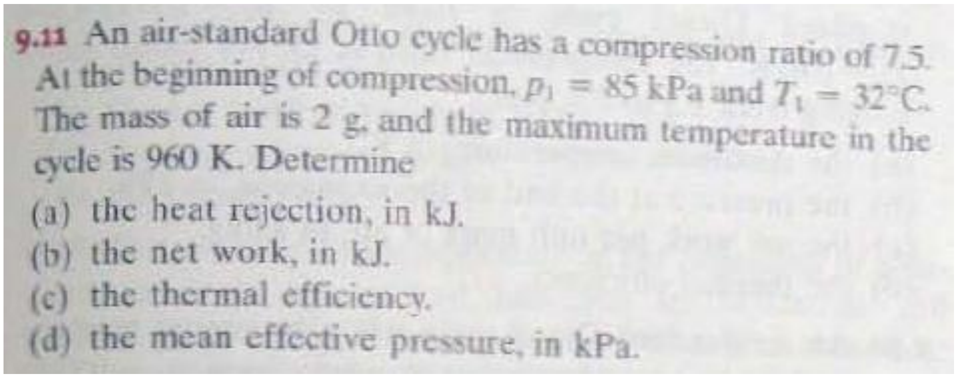
(a) the rate of heat transfer to the working fluid passing through the steam generator, in kJ per kg of steam entering the first-stage turbine.

(b) the thermal efficiency.

(c) the rate of heat transfer from the working fluid passing through the condenser to the cooling water, in kJ per kg of steam entering the first-stage turbine.



8.52 A power plant operates on a regenerative vapor power cycle with one closed feedwater heater. Steam enters the first turbine stage at 120 bar, 520°C and expands to 10 bar, where some of the steam is extracted and diverted to a closed feedwater heater. Condensate exiting the feedwater heater as saturated liquid at 10 bar passes through a trap into the condenser. The feedwater exits the heater at 120 bar with a temperature of 170°C. The condenser pressure is 0.06 bar. For isentropic processes in each turbine stage and the pump, determine for the cycle (a) the thermal efficiency and (b) the mass flow rate into the first-stage turbine, in kg/h, if the net power developed is 320 MW.



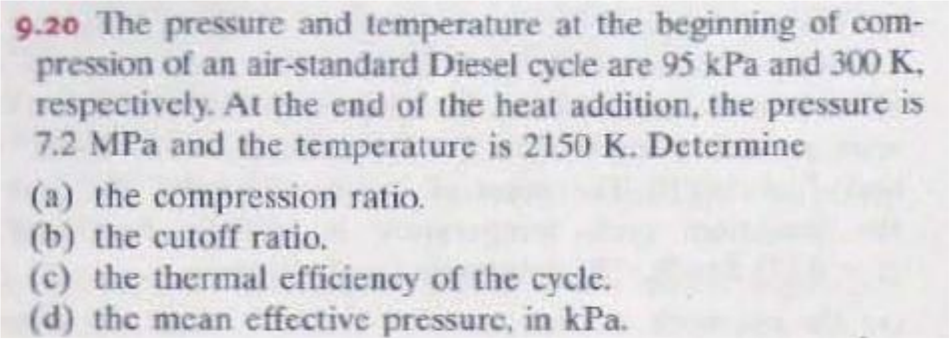
9.11 An air-standard Otto cycle has a compression ratio of 7.5. At the beginning of compression, $p_1 = 85$ kPa and $T_1 = 32°C$. The mass of air is 2 g, and the maximum temperature in the cycle is 960 K. Determine

(a) the heat rejection, in kJ.

(b) the net work, in kJ.

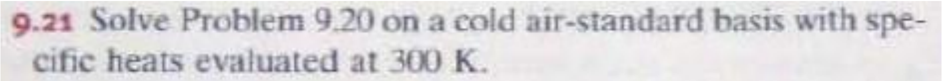
(c) the thermal efficiency.

(d) the mean effective pressure, in kPa.

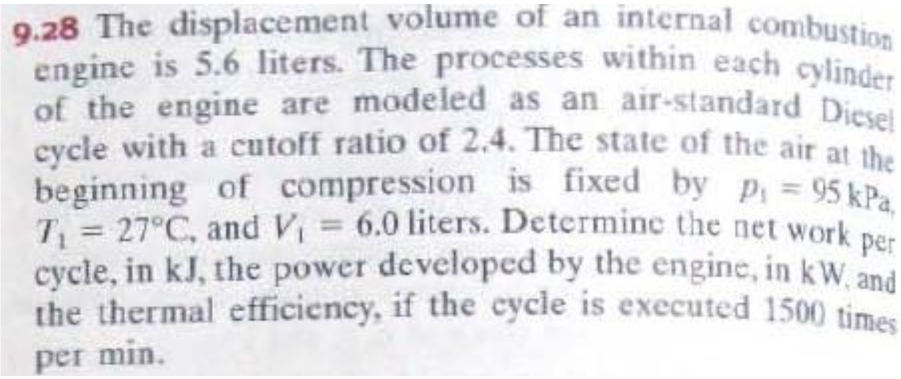


9.20 The pressure and temperature at the beginning of compression of an air-standard Diesel cycle are 95 kPa and 300 K, respectively. At the end of the heat addition, the pressure is 7.2 MPa and the temperature is 2150 K. Determine

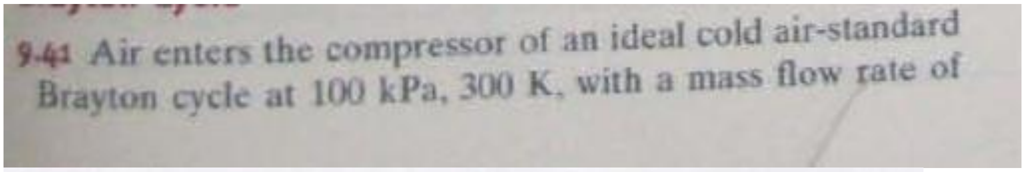
(a) the compression ratio.
(b) the cutoff ratio.
(c) the thermal efficiency of the cycle.
(d) the mean effective pressure, in kPa.

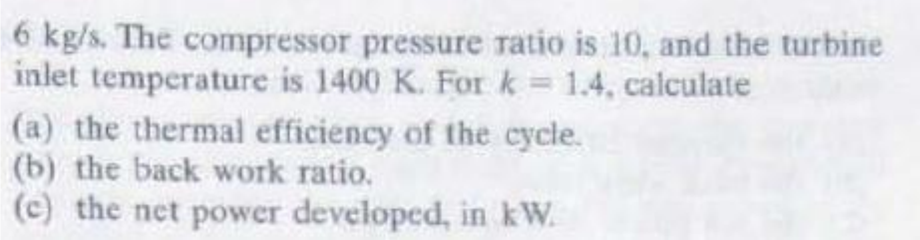


9.21 Solve Problem 9.20 on a cold air-standard basis with specific heats evaluated at 300 K.



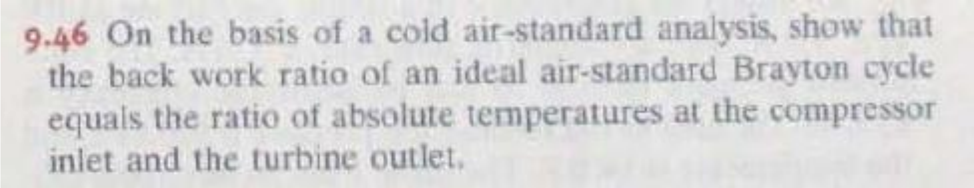
9.28 The displacement volume of an internal combustion engine is 5.6 liters. The processes within each cylinder of the engine are modeled as an air-standard Diesel cycle with a cutoff ratio of 2.4. The state of the air at the beginning of compression is fixed by $p_1 = 95$ kPa, $T_1 = 27°\mathrm{C}$, and $V_1 = 6.0$ liters. Determine the net work per cycle, in kJ, the power developed by the engine, in kW, and the thermal efficiency, if the cycle is executed 1500 times per min.



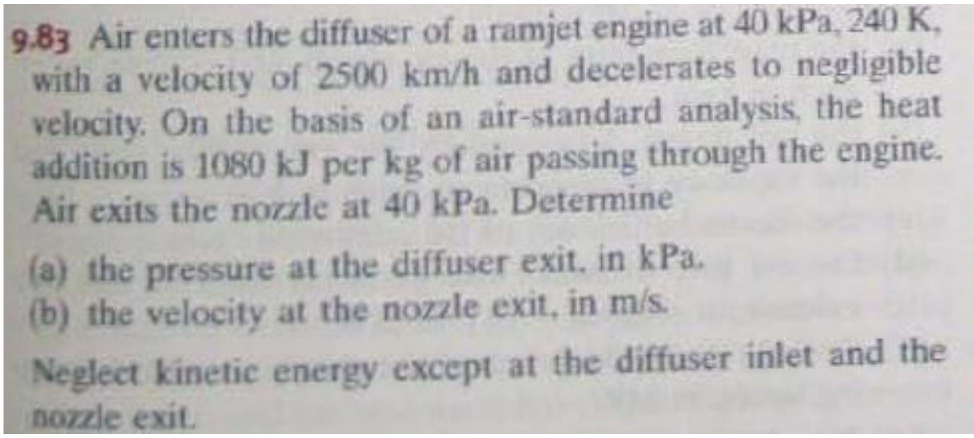


9.41 Air enters the compressor of an ideal cold air-standard Brayton cycle at 100 kPa, 300 K, with a mass flow rate of 6 kg/s. The compressor pressure ratio is 10, and the turbine inlet temperature is 1400 K. For $k = 1.4$, calculate

(a) the thermal efficiency of the cycle.
(b) the back work ratio.
(c) the net power developed, in kW.



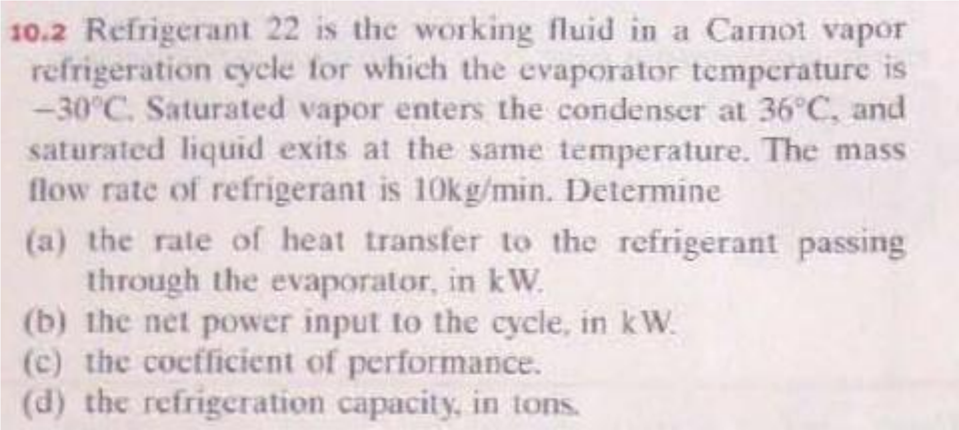
9.46 On the basis of a cold air-standard analysis, show that the back work ratio of an ideal air-standard Brayton cycle equals the ratio of absolute temperatures at the compressor inlet and the turbine outlet.



9.83 Air enters the diffuser of a ramjet engine at 40 kPa, 240 K, with a velocity of 2500 km/h and decelerates to negligible velocity. On the basis of an air-standard analysis, the heat addition is 1080 kJ per kg of air passing through the engine. Air exits the nozzle at 40 kPa. Determine

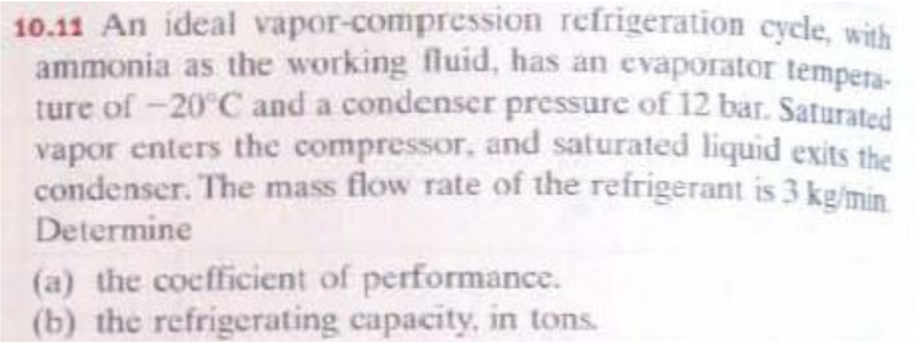
(a) the pressure at the diffuser exit, in kPa.
(b) the velocity at the nozzle exit, in m/s.

Neglect kinetic energy except at the diffuser inlet and the nozzle exit.



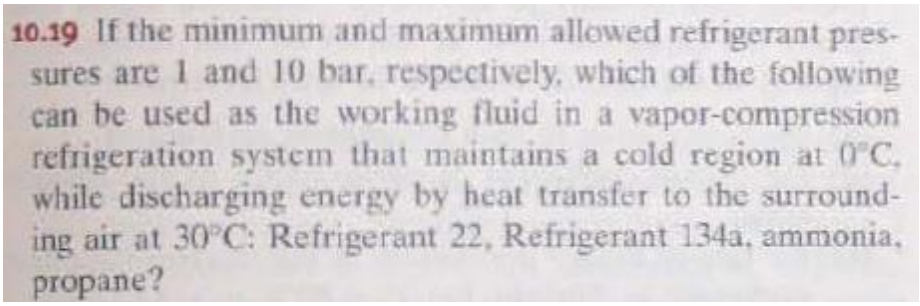
10.2 Refrigerant 22 is the working fluid in a Carnot vapor refrigeration cycle for which the evaporator temperature is −30°C. Saturated vapor enters the condenser at 36°C, and saturated liquid exits at the same temperature. The mass flow rate of refrigerant is 10kg/min. Determine

(a) the rate of heat transfer to the refrigerant passing through the evaporator, in kW.
(b) the net power input to the cycle, in kW.
(c) the coefficient of performance.
(d) the refrigeration capacity, in tons.

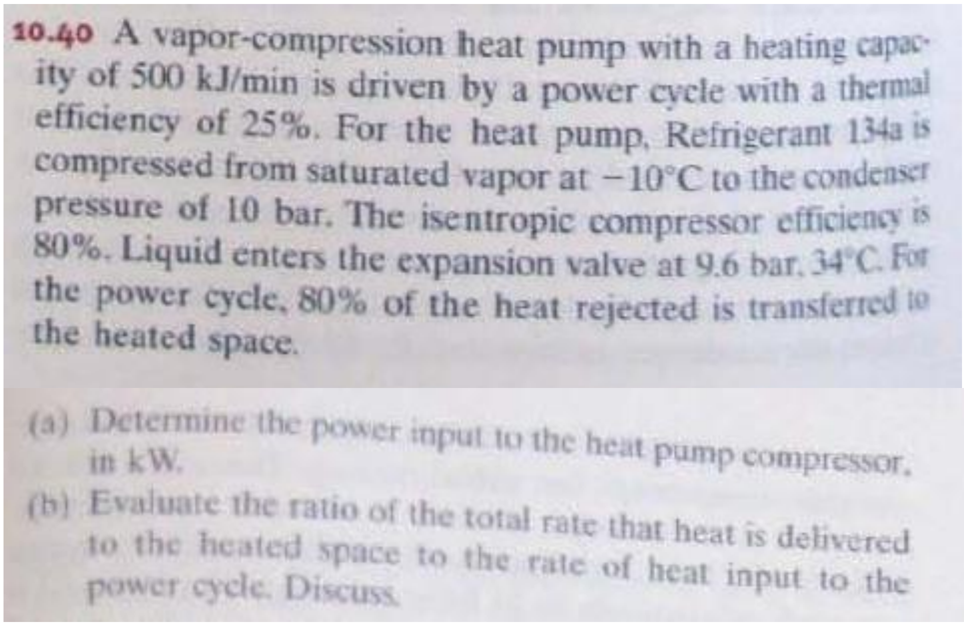


10.11 An ideal vapor-compression refrigeration cycle, with ammonia as the working fluid, has an evaporator temperature of −20°C and a condenser pressure of 12 bar. Saturated vapor enters the compressor, and saturated liquid exits the condenser. The mass flow rate of the refrigerant is 3 kg/min. Determine

(a) the coefficient of performance.
(b) the refrigerating capacity, in tons.



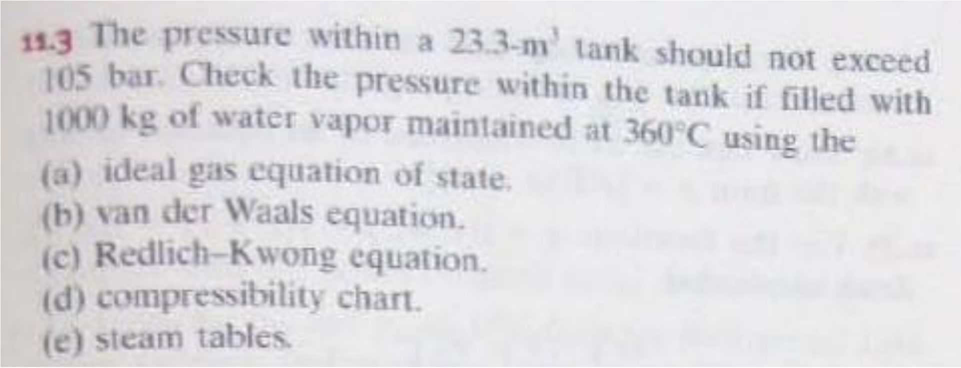
10.19 If the minimum and maximum allowed refrigerant pressures are 1 and 10 bar, respectively, which of the following can be used as the working fluid in a vapor-compression refrigeration system that maintains a cold region at 0°C, while discharging energy by heat transfer to the surrounding air at 30°C: Refrigerant 22, Refrigerant 134a, ammonia, propane?



10.40 A vapor-compression heat pump with a heating capacity of 500 kJ/min is driven by a power cycle with a thermal efficiency of 25%. For the heat pump, Refrigerant 134a is compressed from saturated vapor at −10°C to the condenser pressure of 10 bar. The isentropic compressor efficiency is 80%. Liquid enters the expansion valve at 9.6 bar, 34°C. For the power cycle, 80% of the heat rejected is transferred to the heated space.

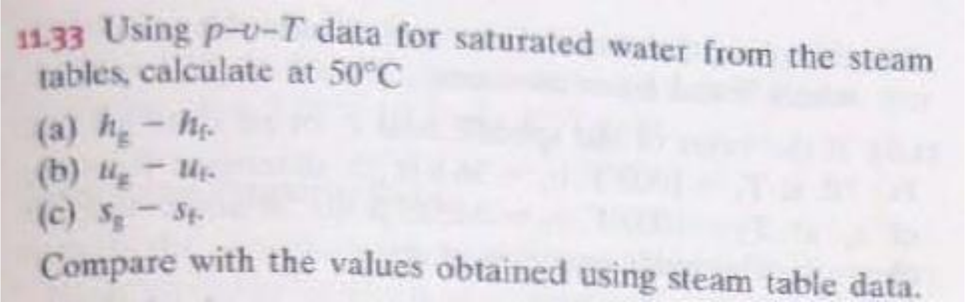
(a) Determine the power input to the heat pump compressor, in kW.

(b) Evaluate the ratio of the total rate that heat is delivered to the heated space to the rate of heat input to the power cycle. Discuss.



11.3 The pressure within a 23.3-m^3 tank should not exceed 105 bar. Check the pressure within the tank if filled with 1000 kg of water vapor maintained at 360°C using the

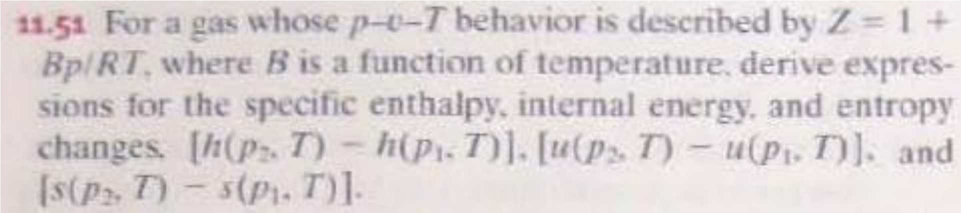
(a) ideal gas equation of state.
(b) van der Waals equation.
(c) Redlich–Kwong equation.
(d) compressibility chart.
(e) steam tables.



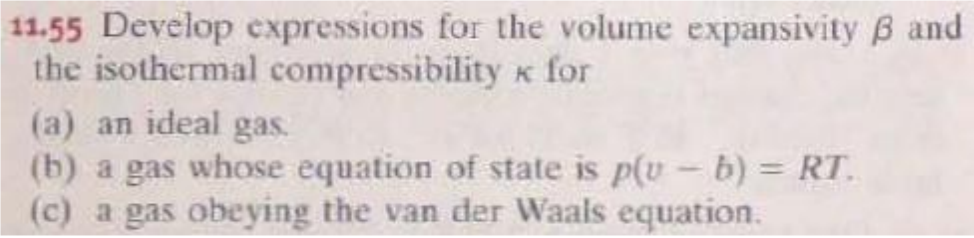
11.33 Using p–v–T data for saturated water from the steam tables, calculate at 50°C

(a) $h_g - h_f$.
(b) $u_g - u_f$.
(c) $s_g - s_f$.

Compare with the values obtained using steam table data.

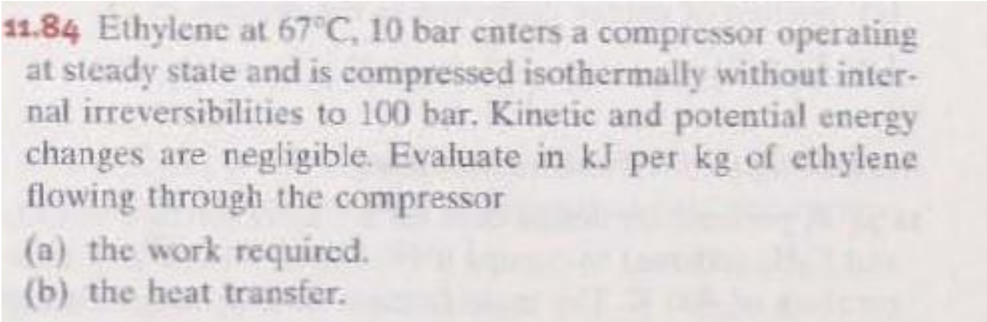


11.51 For a gas whose p–v–T behavior is described by $Z = 1 + Bp/RT$, where B is a function of temperature, derive expressions for the specific enthalpy, internal energy, and entropy changes, $[h(p_2, T) - h(p_1, T)]$, $[u(p_2, T) - u(p_1, T)]$, and $[s(p_2, T) - s(p_1, T)]$.



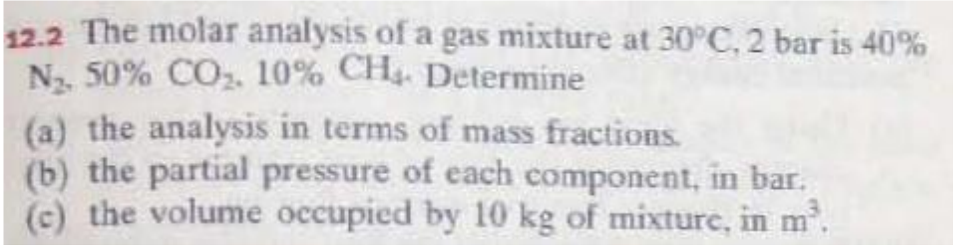
11.55 Develop expressions for the volume expansivity β and the isothermal compressibility κ for

(a) an ideal gas.
(b) a gas whose equation of state is $p(v - b) = RT$.
(c) a gas obeying the van der Waals equation.

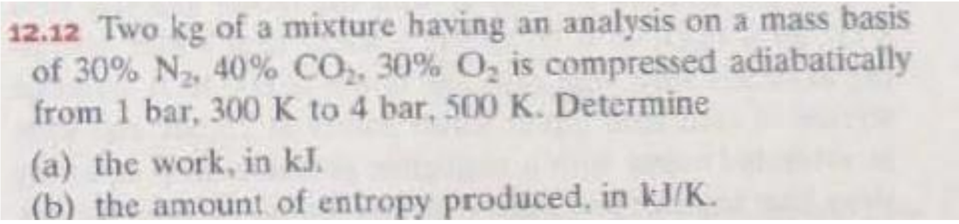


11.84 Ethylene at 67°C, 10 bar enters a compressor operating at steady state and is compressed isothermally without internal irreversibilities to 100 bar. Kinetic and potential energy changes are negligible. Evaluate in kJ per kg of ethylene flowing through the compressor

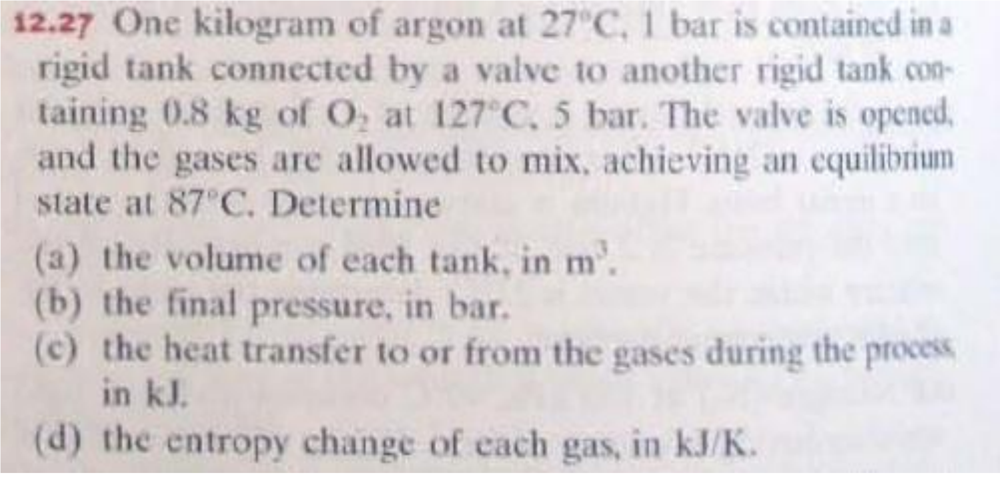
(a) the work required.
(b) the heat transfer.


12.2 The molar analysis of a gas mixture at 30°C, 2 bar is 40% N_2, 50% CO_2, 10% CH_4. Determine

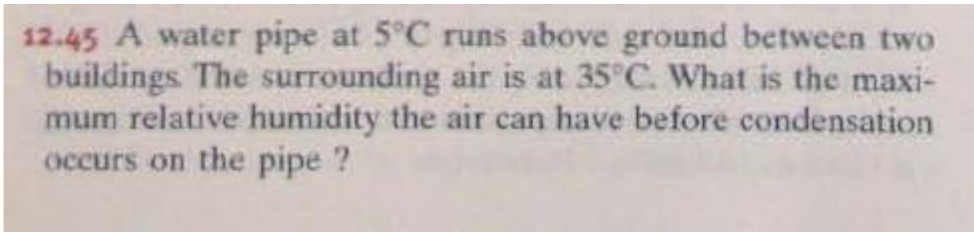
(a) the analysis in terms of mass fractions.
(b) the partial pressure of each component, in bar.
(c) the volume occupied by 10 kg of mixture, in m^3.

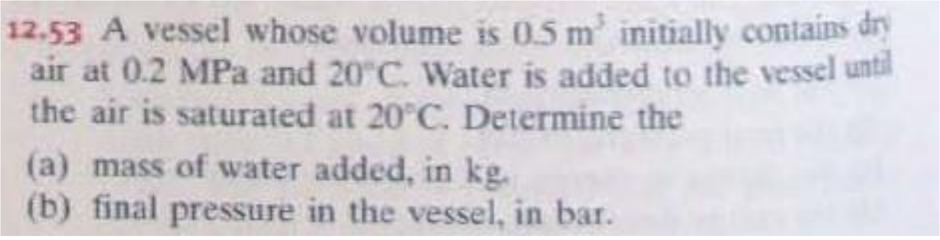

12.12 Two kg of a mixture having an analysis on a mass basis of 30% N_2, 40% CO_2, 30% O_2 is compressed adiabatically from 1 bar, 300 K to 4 bar, 500 K. Determine

(a) the work, in kJ.
(b) the amount of entropy produced, in kJ/K.


12.27 One kilogram of argon at 27°C, 1 bar is contained in a rigid tank connected by a valve to another rigid tank containing 0.8 kg of O_2 at 127°C, 5 bar. The valve is opened, and the gases are allowed to mix, achieving an equilibrium state at 87°C. Determine

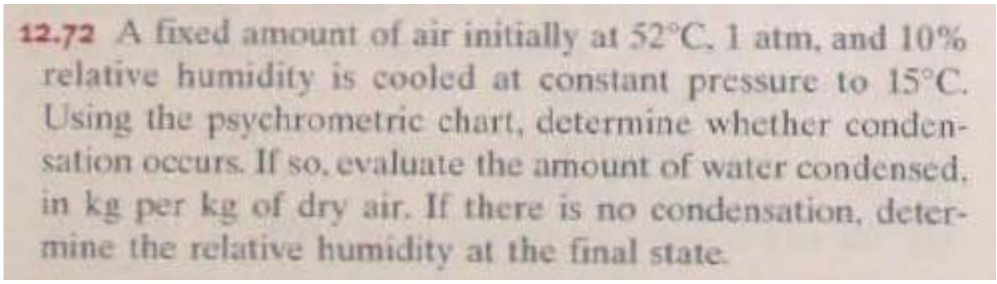
(a) the volume of each tank, in m^3.
(b) the final pressure, in bar.
(c) the heat transfer to or from the gases during the process in kJ.
(d) the entropy change of each gas, in kJ/K.


12.45 A water pipe at 5°C runs above ground between two buildings. The surrounding air is at 35°C. What is the maximum relative humidity the air can have before condensation occurs on the pipe ?

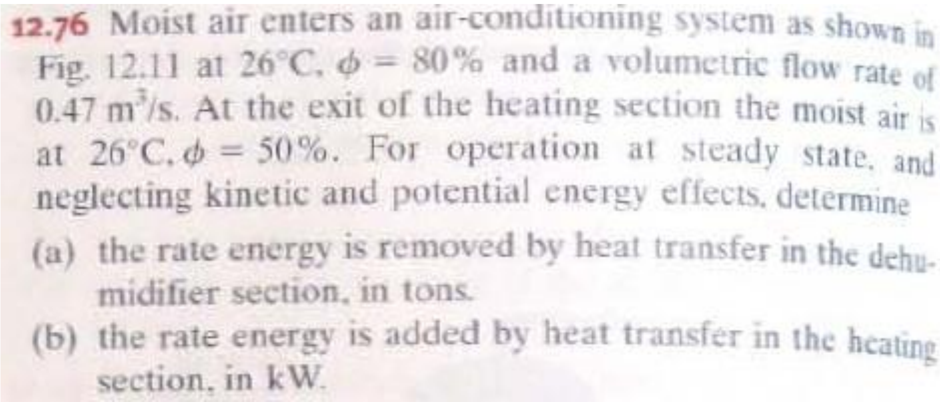


12.53 A vessel whose volume is 0.5 m^3 initially contains dry air at 0.2 MPa and 20°C. Water is added to the vessel until the air is saturated at 20°C. Determine the

(a) mass of water added, in kg.
(b) final pressure in the vessel, in bar.

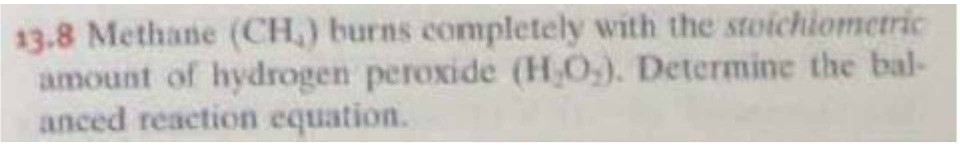


12.72 A fixed amount of air initially at 52°C, 1 atm, and 10% relative humidity is cooled at constant pressure to 15°C. Using the psychrometric chart, determine whether condensation occurs. If so, evaluate the amount of water condensed, in kg per kg of dry air. If there is no condensation, determine the relative humidity at the final state.

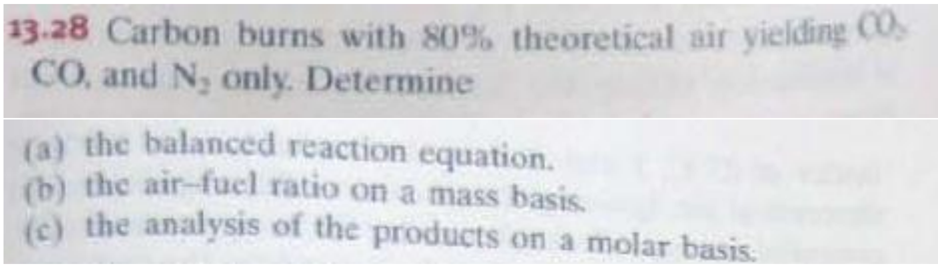


12.76 Moist air enters an air-conditioning system as shown in Fig. 12.11 at 26°C, $\phi = 80\%$ and a volumetric flow rate of 0.47 m^3/s. At the exit of the heating section the moist air is at 26°C, $\phi = 50\%$. For operation at steady state, and neglecting kinetic and potential energy effects, determine

(a) the rate energy is removed by heat transfer in the dehumidifier section, in tons.
(b) the rate energy is added by heat transfer in the heating section, in kW.

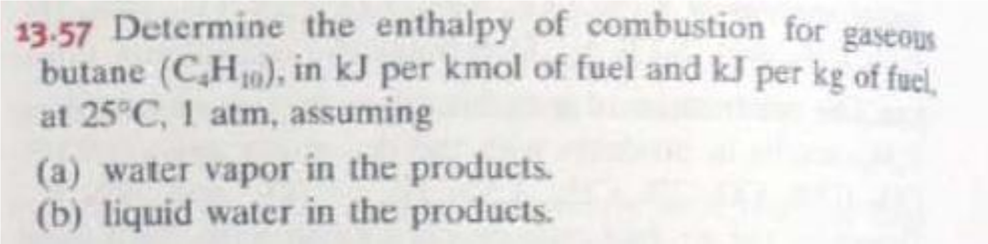


13.8 Methane (CH_4) burns completely with the *stoichiometric* amount of hydrogen peroxide (H_2O_2). Determine the balanced reaction equation.



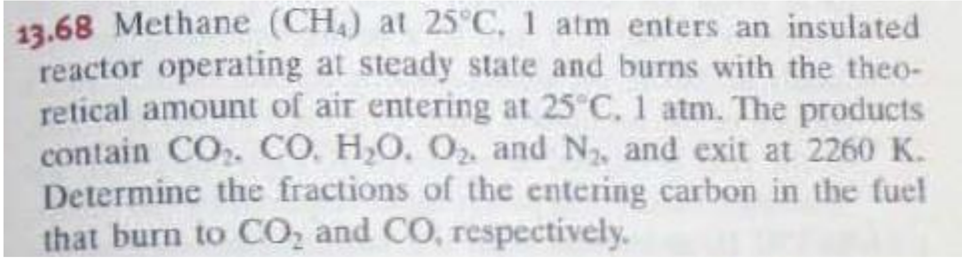
13.28 Carbon burns with 80% theoretical air yielding CO_2, CO, and N_2 only. Determine

(a) the balanced reaction equation.
(b) the air–fuel ratio on a mass basis.
(c) the analysis of the products on a molar basis.

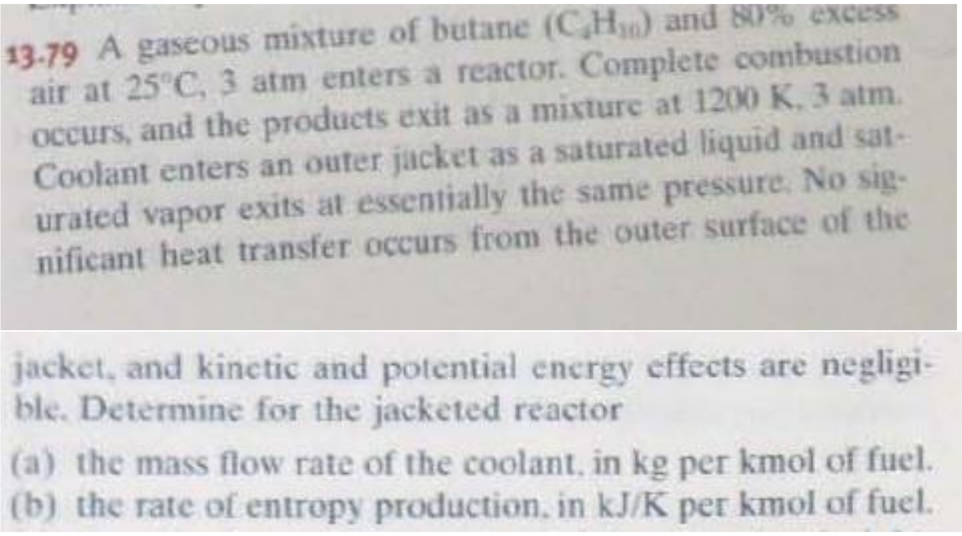


13.57 Determine the enthalpy of combustion for gaseous butane (C_4H_{10}), in kJ per kmol of fuel and kJ per kg of fuel, at 25°C, 1 atm, assuming

(a) water vapor in the products.
(b) liquid water in the products.

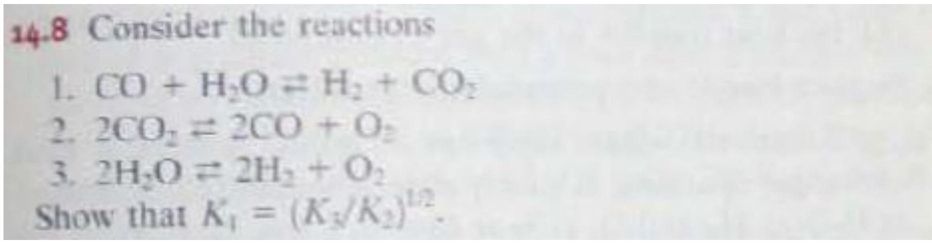


13.68 Methane (CH_4) at 25°C, 1 atm enters an insulated reactor operating at steady state and burns with the theoretical amount of air entering at 25°C, 1 atm. The products contain CO_2, CO, H_2O, O_2, and N_2, and exit at 2260 K. Determine the fractions of the entering carbon in the fuel that burn to CO_2 and CO, respectively.



13.79 A gaseous mixture of butane (C_4H_{10}) and 80% excess air at 25°C, 3 atm enters a reactor. Complete combustion occurs, and the products exit as a mixture at 1200 K, 3 atm. Coolant enters an outer jacket as a saturated liquid and saturated vapor exits at essentially the same pressure. No significant heat transfer occurs from the outer surface of the jacket, and kinetic and potential energy effects are negligible. Determine for the jacketed reactor

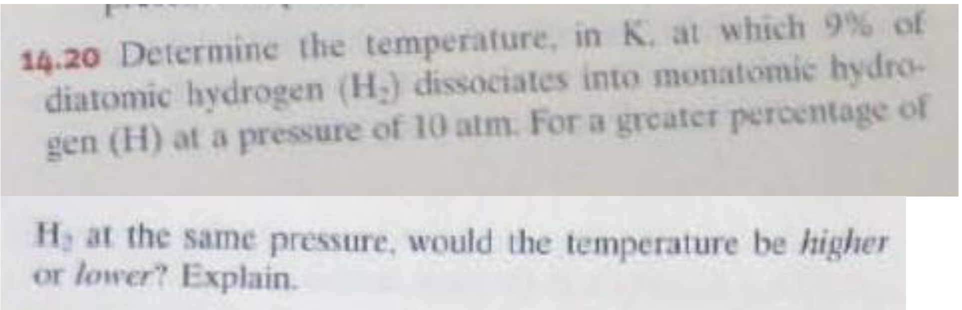
(a) the mass flow rate of the coolant, in kg per kmol of fuel.
(b) the rate of entropy production, in kJ/K per kmol of fuel.



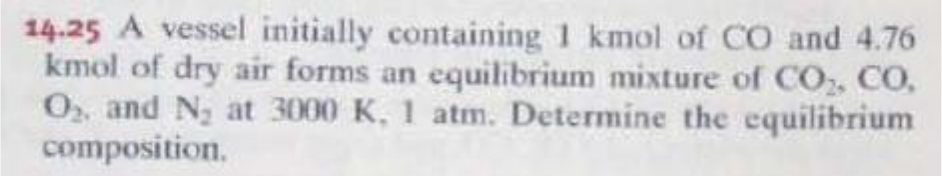
14.8 Consider the reactions

1. $CO + H_2O \rightleftharpoons H_2 + CO_2$
2. $2CO_2 \rightleftharpoons 2CO + O_2$
3. $2H_2O \rightleftharpoons 2H_2 + O_2$

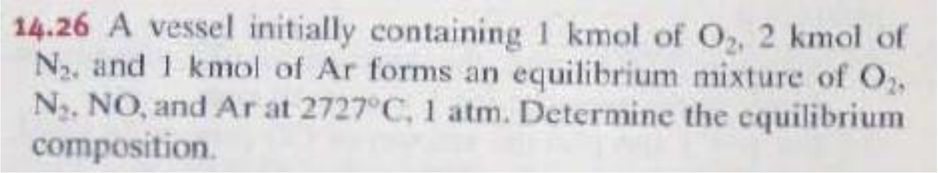
Show that $K_1 = (K_3/K_2)^{1/2}$.



14.20 Determine the temperature, in K, at which 9% of diatomic hydrogen (H_2) dissociates into monatomic hydrogen (H) at a pressure of 10 atm. For a greater percentage of H_2 at the same pressure, would the temperature be *higher* or *lower*? Explain.



14.25 A vessel initially containing 1 kmol of CO and 4.76 kmol of dry air forms an equilibrium mixture of CO_2, CO, O_2, and N_2 at 3000 K, 1 atm. Determine the equilibrium composition.



14.26 A vessel initially containing 1 kmol of O_2, 2 kmol of N_2, and 1 kmol of Ar forms an equilibrium mixture of O_2, N_2, NO, and Ar at 2727°C, 1 atm. Determine the equilibrium composition.