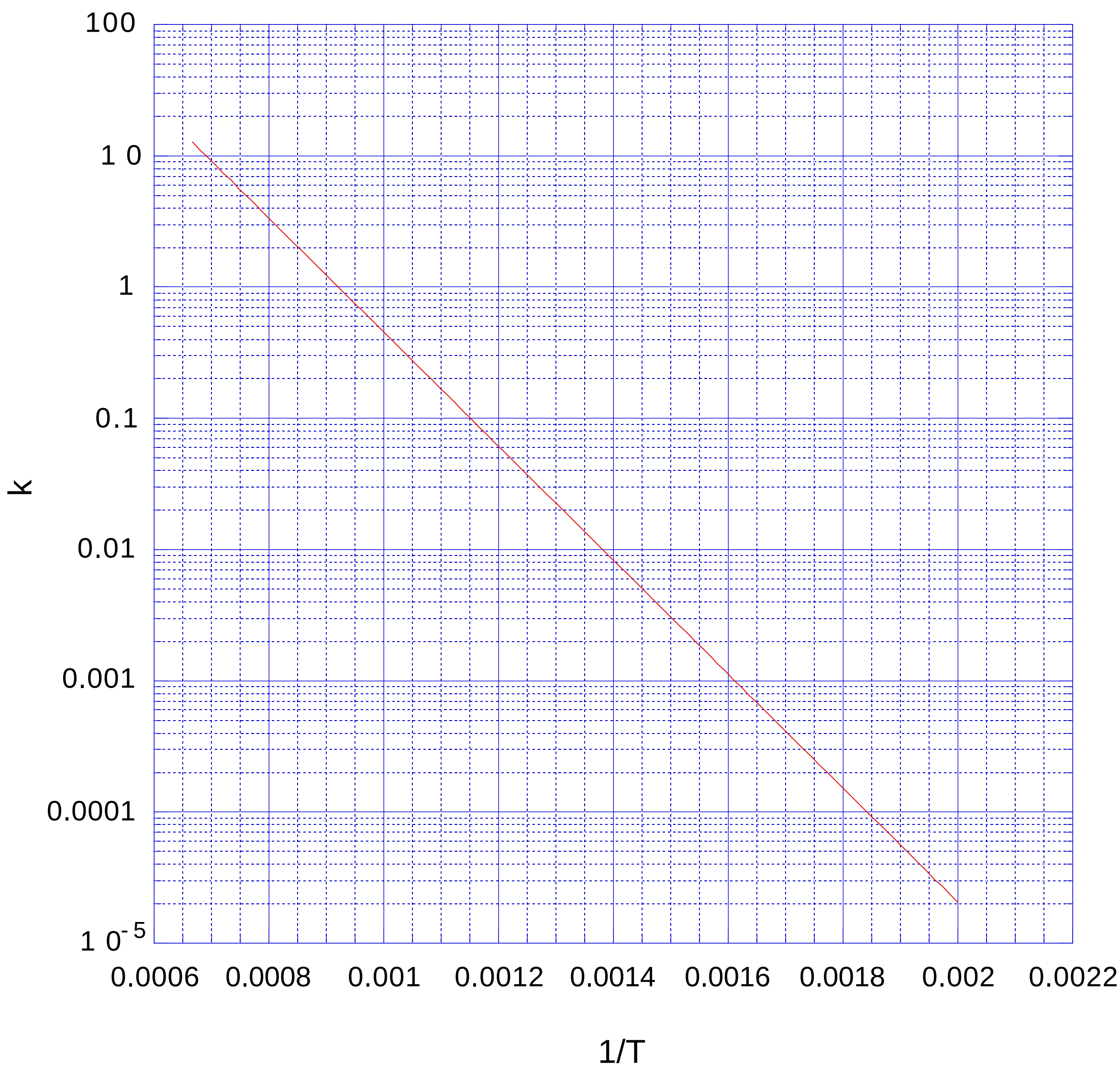
1. A series of measurements were made in Platt of the rate at which plastic tumblers are dropped on the floor and broken as a function of the absolute temperature of the french fries. The data were plotted as the rate, k, in tumblers/second (on a logarithmic scale) versus the reciprocal of the absolute temperature, T, in °R. A straight-line fit of the data is plotted below.



(a) Do any of the following models fit the data?

$$k = \frac{a}{T} + b\,,\ k = ae^{bT}\,,\ k = aT^b\,,\ k = ae^{b/T}\,,\ \sin 10^k = \tanh\frac{a}{T+b}$$

(b) For this study what are the values of a and b?

2. An inventor has approached a venture capitalist with a plan to manufacture dry ice in a low-temperature catalytic reactor. The plans call for using dimerized

carbon vapor, C_2, and air as feedstocks. The feed to the process is 100 mol/h of dimerized carbon vapor and 25% excess air. The feed is mixed with recycled carbon, oxygen, and nitrogen. The resultant mixture is fed into the catalytic reactor where some of the carbon and oxygen react to form dry ice, $CO_2(s)$. The reactor products are fed to a separator where all of the dry ice is removed. One quarter of the recycled-gas stream is bled off as a purge stream with a composition of 92% N_2, 7% O_2, and the remainder C_2 The venture capitalist has hired you as a consultant and has asked you (among other things) to:

(a) Draw and label the PFD for the process.

(b) Calculate the fractional conversion of C_2 in the reaction vessel.

(c) Calculate the fractional conversion of C_2 for the overall process.

3. A and B react according to the equation $2A + 3B \rightarrow 4C$. A mixture of 100 kmol/s of A, 30% excess B and 5 kmol/s of inerts is fed to a processing plant. The feed is mixed with a recycle stream. The resultant stream is fed to a reaction vessel where the A is 20% converted. The output from the reactor is fed to a distillation column. The distillate is 80% C, 2% I, with the balance being B. The bottoms are recycled. Half of the B, half of the inerts, and all of the C entering the distillation column exit in the distillate.

   (a) Draw and label the PFD for the process.

   (b) What is the extent of reaction for the process?

   (c) What is the fractional conversion of B in the reaction vessel?

4. A and B react according to the equation $2A + 3B \rightarrow 3C$. A mixture of 100 kmol/s of A, excess B and 5 kmol/s of inerts is fed to a processing plant. The feed is mixed with a recycle stream. The resultant stream is fed to a reaction vessel where the A is 20% converted. The output from the reactor is fed to a distillation column. The distillate is 75% C, 2.5% I, with the balance being B. The bottoms are recycled. Half of the B, half of the inerts, and all of the C entering the distillation column exit in the distillate.

   (a) Draw and label the PFD for the process.

   (b) What is the percent excess B fed to the process?

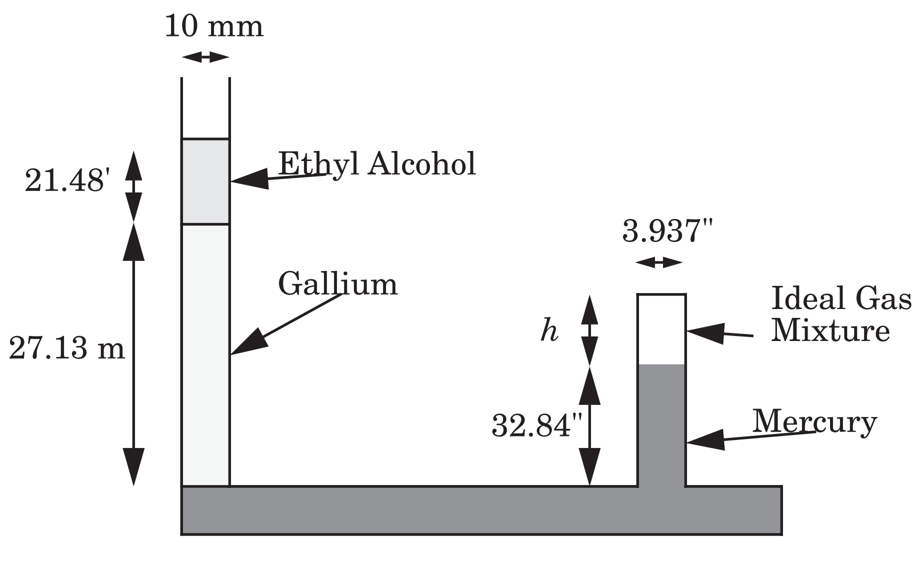
   (c) What is the fractional conversion of B in the reaction vessel?

5. Extremely low oxygen partial pressures are often established by mixing CO and CO_2 and letting the mixture equilibrate. What is the partial pressure of oxygen

that results from mixing one mole of CO and one mole of CO_2 at one atm and heating to 727°C at constant pressure? Data: $CO + \frac{1}{2}O_2 = CO_2$, $\ln K = 23.52$ at 727°C.

6. At one elevation in an iron blast furnace the temperature is 1000 K and the pressure is 2 bar. A mixture of CO and CO_2 is in equilibrium with metallurgical coke (assume pure graphite).
   (a) What are the partial pressures of CO and CO_2 in the system?
   (b) Given the results of part (a), what is the partial pressure of O_2 in the system?

7. A rather perturbed but not completely mad scientist has designed a device for reacting ideal gases. A cylinder that is sealed at the top but open at the bottom contains the reacting gases. The open bottom is attached to a mercury reservoir. Normally some fraction of the cylinder is filled with mercury. Attached to another part of the mercury reservoir is a cylinder whose top end is open to the atmosphere and whose bottom end opens into the mercury reservoir. This column is usually filled with some combination of liquids. The dimensions of the cylinders and columns are given in the drawing. The entire system is at 31.05°C.



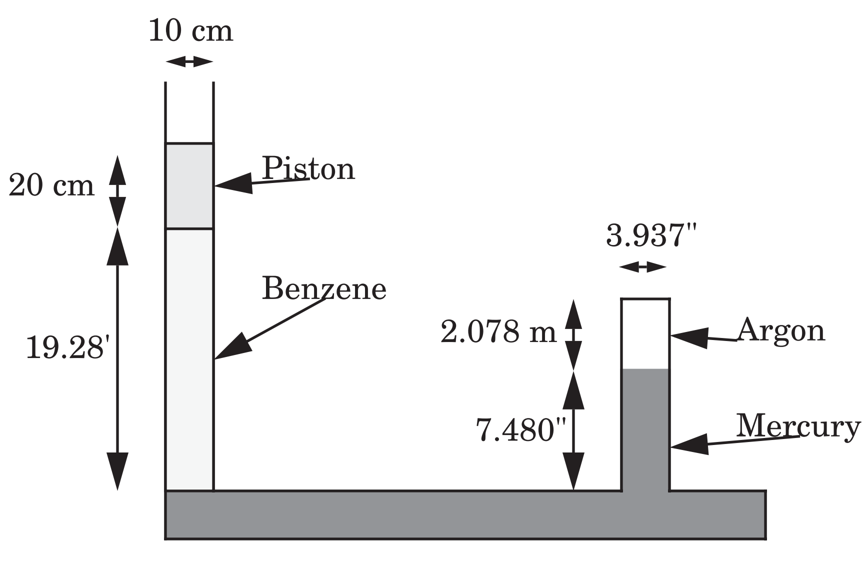
Drawing not to scale

To test the apparatus 1.25 g-mol of ideal gas A and 0.75 g-mol of ideal gas B are mixed together and placed inside the sealed cylinder. A and B react according to the equation $A + B = 2C$ where A, B, and C are all ideal gases. For the experimental conditions the equilibrium constant, $K = 2$. The gases then react to equilibrium. At the end of the experiment mercury rises to a height of 32.84 inches inside the sealed cylinder and a 21.48 foot-high column of ethyl alcohol sits atop a 27.13 meter-high column of liquid gallium ($\rho = 6095$ kg/m^3) inside the open cylinder.

(a) Calculate the extent of the reaction.

(b) Calculate h, the height of the column of the ideal gas mixture.

8. A cylindrical piston of an unknown solid rides atop a column of benzene inside a cylinder whose top end is open to the atmosphere and whose bottom end opens into a reservoir of mercury. Attached to another part of this mercury reservoir is a cylinder whose top is sealed and whose bottom opens into the mercury reservoir. Above the mercury in the second cylinder is 1 g-mol of argon at a pressure of 1.519 bar absolute. The dimensions of the cylinders and columns are given in the drawing. The entire system is at 77°F. What is the density of the unknown solid used to make the piston?



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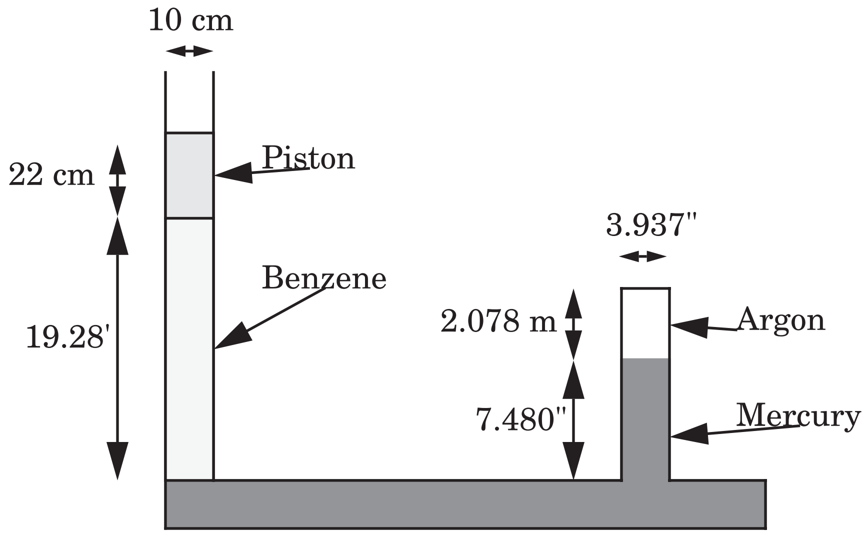
9. A cylindrical piston ($\rho = 12.9$ g/cm^3) rides atop a column of benzene inside a cylinder whose top end is open to the atmosphere and whose bottom end opens into a reservoir of mercury. Attached to another part of this mercury reservoir is a cylinder whose top is sealed and whose bottom opens into the mercury reservoir.

Above the mercury in the second cylinder is 1 g-mol of argon. The dimensions of the cylinders and columns are given in the drawing. What is the temperature of the system?



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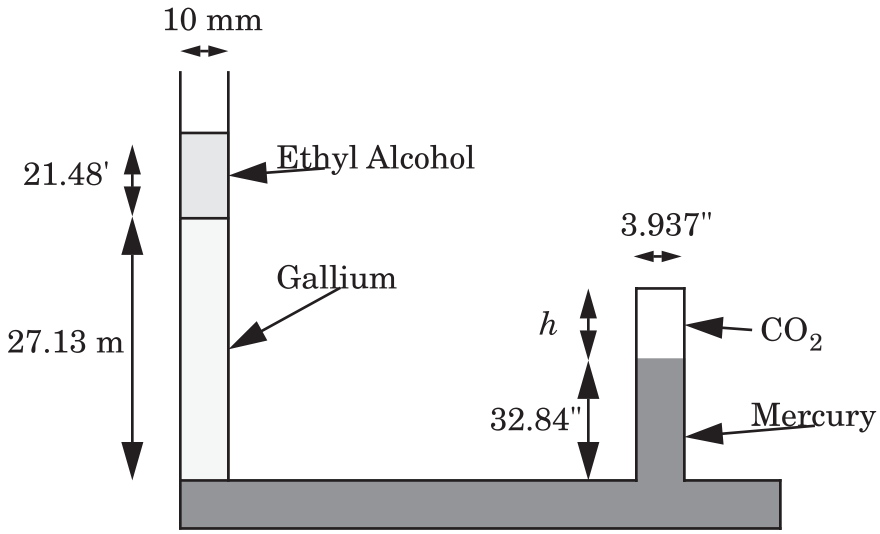
10. A stream of gaseous dilithium warfate (T_c = 277.92°R, P_c = 49.7 atm, MW = 31.41593) enters a compressor at 77°F and 33.9 ft H_2O at a rate of 3072 ft^3/h. The outlet conditions are 184.73°F and 1013.25 bar. What is the flow rate at the outlet?

11. A flow of 100 ft^3/min of propane at 500°F and 14.7 psig enters a chilled compressor. The propane leaves the compressor at 406°F and 85.1 bar absolute. What is the flow rate at the exit?

12. A flow of 1 ft^3/min of ethane at 255°F and 9768 kPa absolute enters a throttling valve. The ethane leaves the throttle at 392°F and 10.0 psig. What is the flow rate at the exit?

13. A column of ethyl alcohol sits atop a column of liquid gallium (ρ = 6095 kg/m^3), inside a cylinder whose top end is open to the atmosphere and whose bottom end opens into a reservoir of mercury. Attached to another part of this mercury reservoir is a cylinder whose top is sealed and whose bottom opens into the mercury reservoir. Above the mercury in the second cylinder

is 1 g-mol of carbon dioxide. The dimensions of the cylinders and columns are given in the drawing. The entire system is at 31.05°C.



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(a) Calculate the pressure at the mercury-carbon dioxide interface.

(b) Calculate h, the height of the column of carbon dioxide.

14. Assuming Raoult's law to be valid for the system benzene(species 1)/ethylbenzene(species 2) prepare a Pxy diagram for a temperature of 100°C.

15. They system benzene(species 1)/toluene(species 2)/ethylbenzene(species 3) conforms closely to Raoult's law. At a temperature of 100°C and an overall composition of $z_1 = 0.41$, $z_2 = 0.34$, and $z_3 = 0.25$, determine:
    (a) The bubble-point pressure P_b and the bubble composition.
    (b) The dew-point pressure P_d and the dew composition.
    (c) L, V, $\{x_i\}$, and $\{y_i\}$ for a pressure equal to $\frac{1}{2}(P_b + P_d)$.

16. Assuming Raoult's law to be valid for the system n-hexane(1)/n-heptane(2) prepare a Txy diagram for a pressure of 100 kPa.

17. They system n-pentane(1)/n-hexane(2)/n-heptane(3) conforms closely to Raoult's law. At a temperature of 105°C and an overall composition of $z_1 = 0.25$, $z_2 = 0.45$, and $z_3 = 0.30$, determine:
    (a) The bubble-point pressure P_b and the bubble composition.

(b) The dew-point pressure P_d and the dew composition.
(c) L, V, $\{x_i\}$, and $\{y_i\}$ for a pressure equal to $\frac{1}{2}(P_b + P_d)$.

18. Assuming Raoult's law to be valid for the system n-hexane(1)/n-heptane(2) prepare aPxy diagram for a temperature of 100°C.

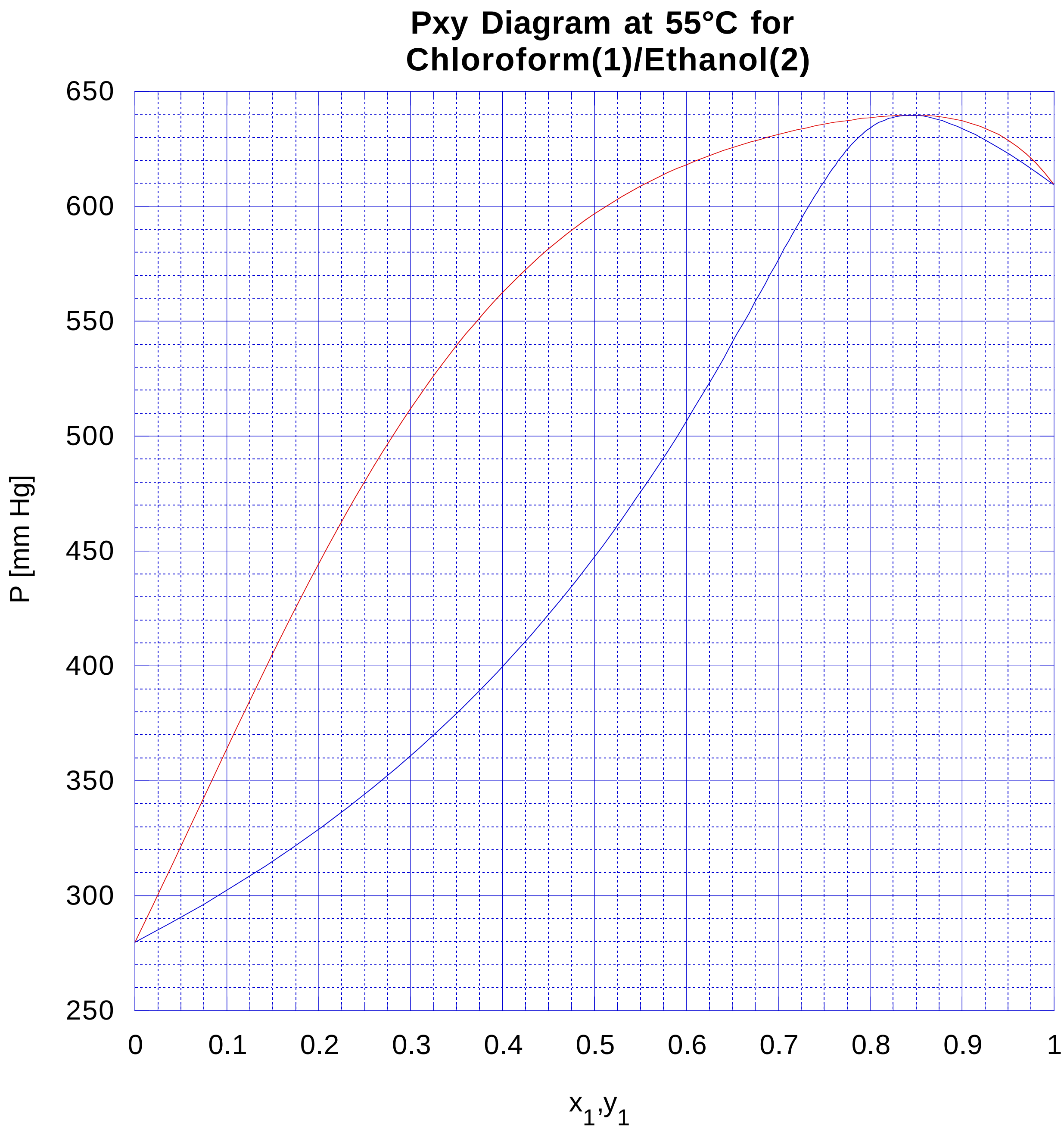
19. They system n-pentane(1)/n-hexane(2)/n-heptane(3) conforms closely to Raoult's law. At a temperature of 105°C and an overall composition of $z_1 = 0.25$, $z_2 = 0.45$, and $z_3 = 0.30$, determine:
(a) The bubble-point pressure P_b and the bubble composition.
(b) The dew-point pressure P_d and the dew composition.
(c) L, V, $\{x_i\}$, and $\{y_i\}$ for a pressure equal to $\frac{1}{2}(P_b + P_d)$.

20. Assuming Raoult's law to be valid for the system benzene(species 1)/ethylbenzene(species 2) prepare a Pxy diagram for a temperature of 100°C.

21. They system benzene(species 1)/toluene(species 2)/ethylbenzene(species 3) conforms closely to Raoult's law. At a temperature of 100°C and an overall composition of $z_1 = 0.41$, $z_2 = 0.34$, and $z_3 = 0.25$, determine:
(a) The bubble-point pressure P_b and the bubble composition.
(b) The dew-point pressure P_d and the dew composition.
(c) L, V, $\{x_i\}$, and $\{y_i\}$ for a pressure equal to $\frac{1}{2}(P_b + P_d)$.

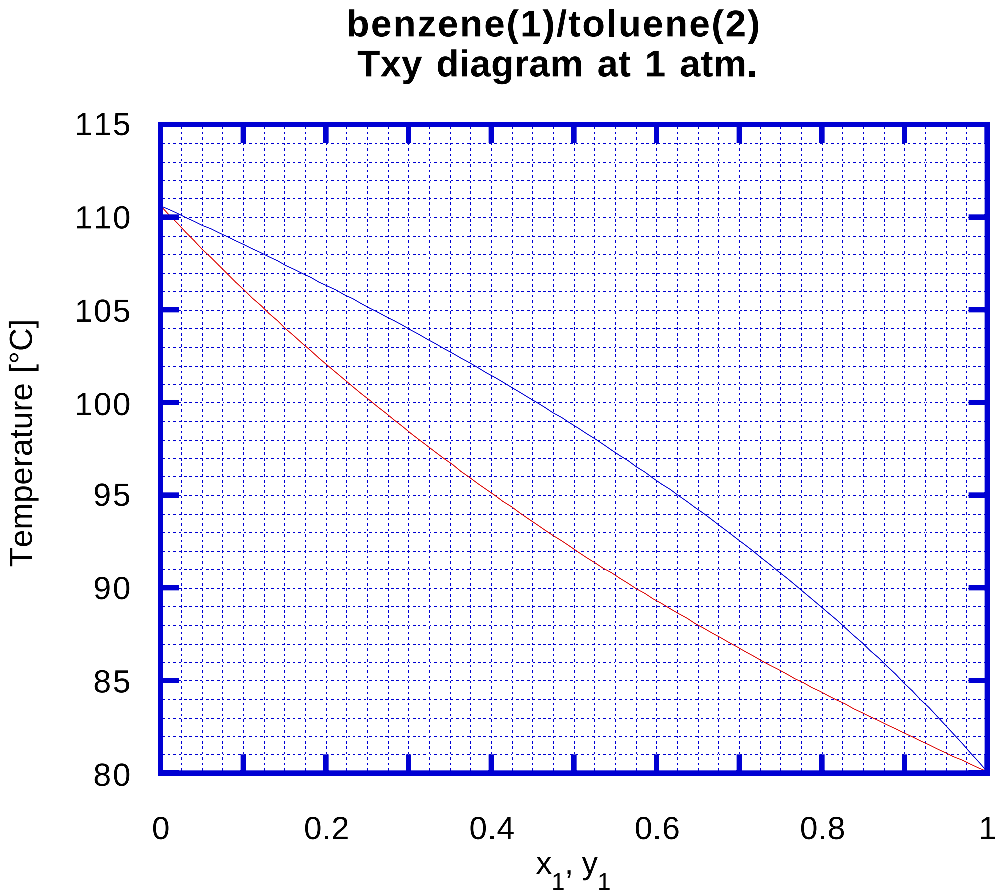
22. Consider a single stage of a distillation column operating at 55°C in which chloroform and ethanol are being separated. A vapor stream containing 55 mol% chloroform and 45 mol% ethanol *enters* the first stage at a rate of 200 mol/h, and liquid containing 35 mol% chloroform and 65 mol% ethanol *exits* this stage at a rate of 150 mol/hr. You may assume (1) the stages are ideal; (2) the streams leaving each stage are in equilibrium; (3) the vapor and liquid flow rates *do not* change by a significant amount from one stage to the next. Estimate the pres-

sure at which this stage is operating and the compositions of the vapor stream *exiting* and the liquid stream *entering* this stage.



23. 70 moles of benzene and 30 moles of toluene are mixed together and then flashed to a state of 90°C and 1 atm.
    (a) How many moles of liquid are present?
    (b) How many moles of vapor are present?
    (c) What is the composition of the liquid?

(d) What is the composition of the vapor?



24. An evacuated vessel is initially filled with argon. Then, liquid benzene and liquid toluene are added. The vessel is then sealed and allowed to equilibrate at 50°C. The liquid phase is 70 mol-percent toluene, and the pressure in the vessel is 1 atm absolute. What is the composition of the gas phase? State any assumptions.

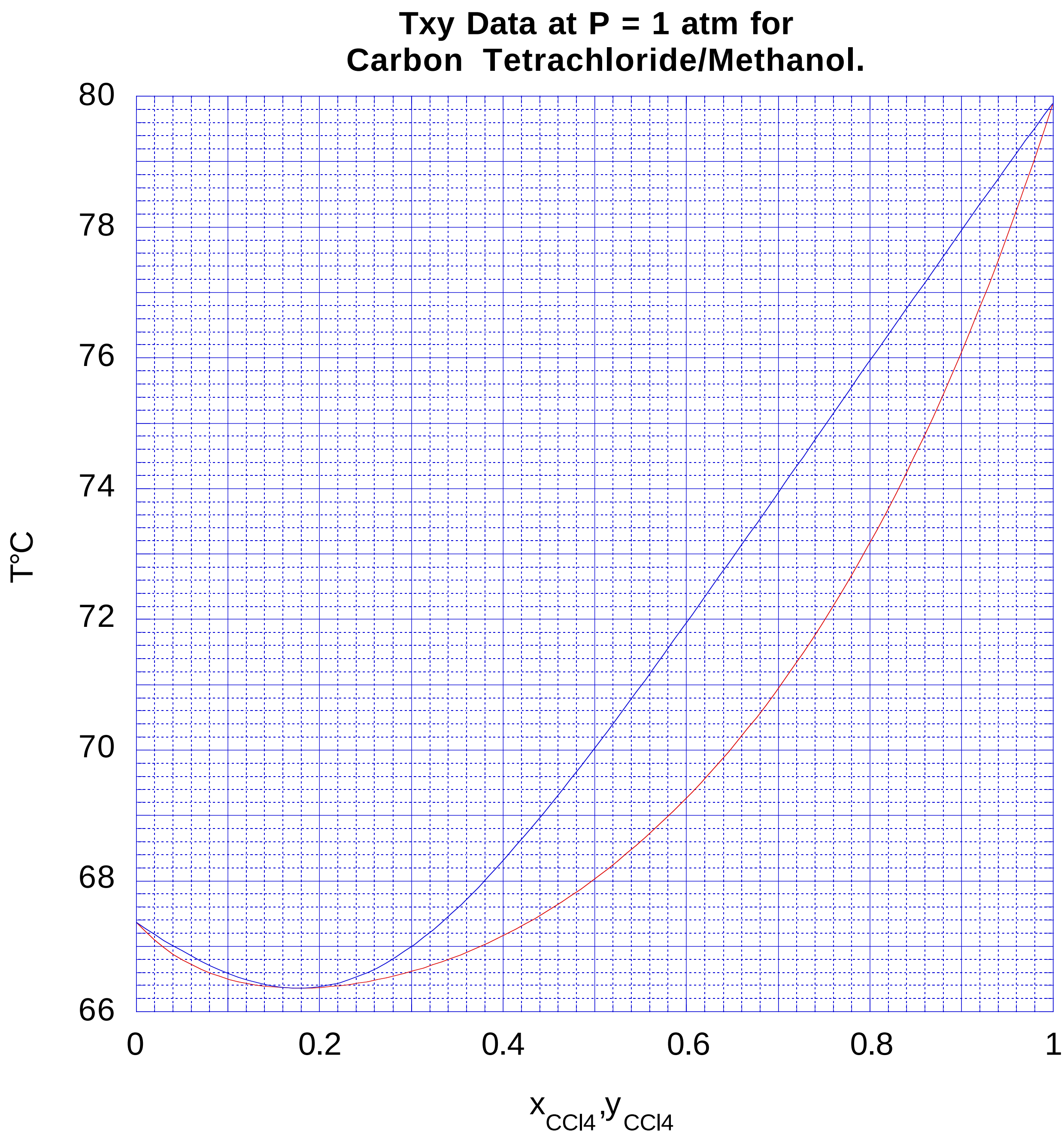
    Data:

    p^*_{benzene} @ 50°C = 271 mm Hg

    p^*_{toluene} @ 50°C = 92 mm Hg

25. A sealed vessel at equilibrium contains only oxygen, (O_2), and water at 30°C and 2 atm total pressure. Give the number of phases present and their compositions in mole fraction.

26. 100 kmol/h of 99% pure carbon tetrachloride (CCl_4) is needed as the feed to a chemical process. A 200 kmol/h waste stream from another process containing 60% CCl_4 and 40% methanol (CH_3OH) is available. A process engineer suggests refining the waste stream to the required purity using a single-stage flash unit operating at 1 atm.

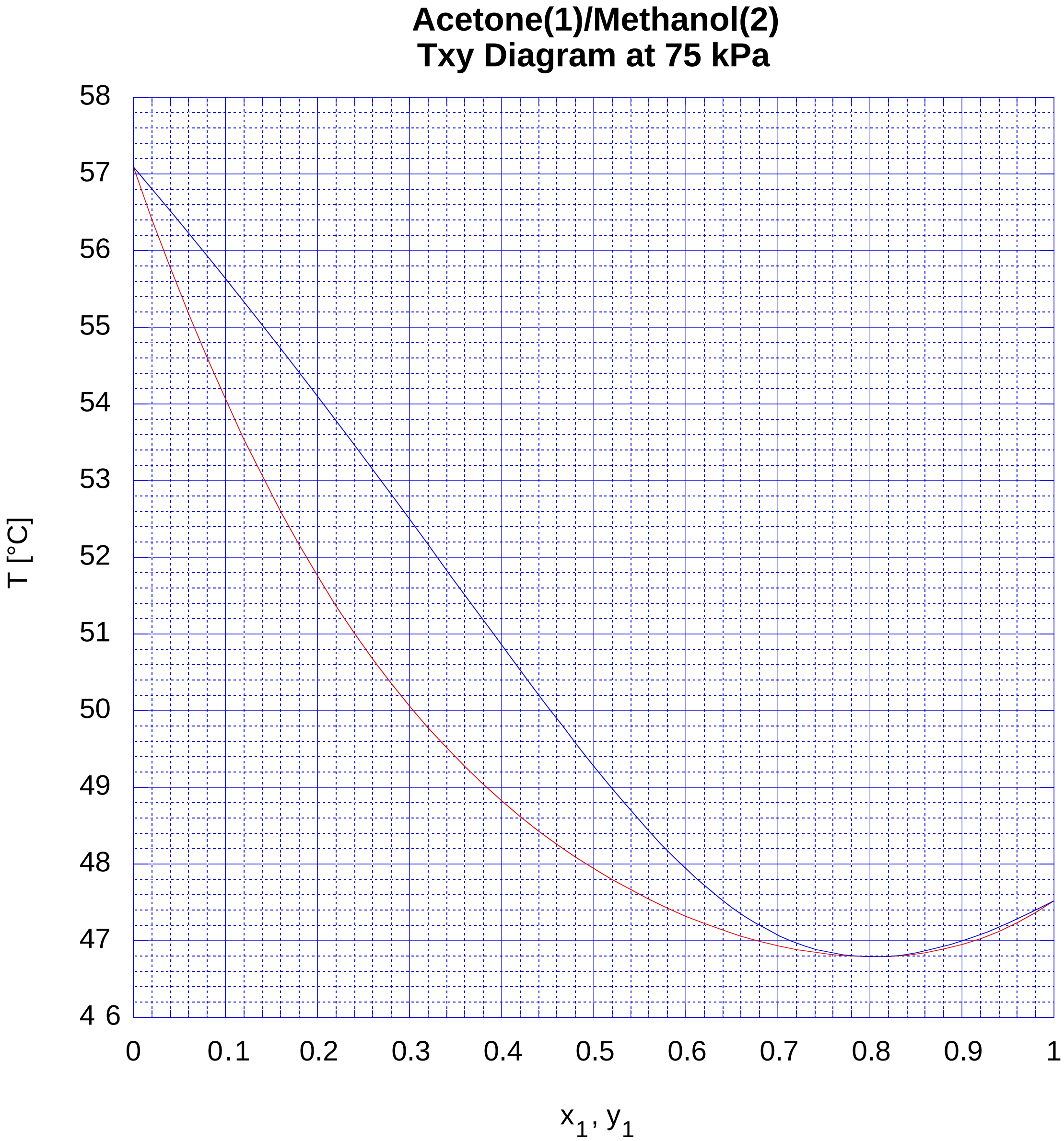


(a) What is the maximum product purity you can get from a single-stage flash with the waste stream as feed? At what temperature should the flash operate? What is the product flow rate at that purity?

(b) At more reasonable conditions of 1°C away from the temperature in part (a), what is the product purity? What are the flow rates in the vapor and liquid streams? Which stream is the product stream?

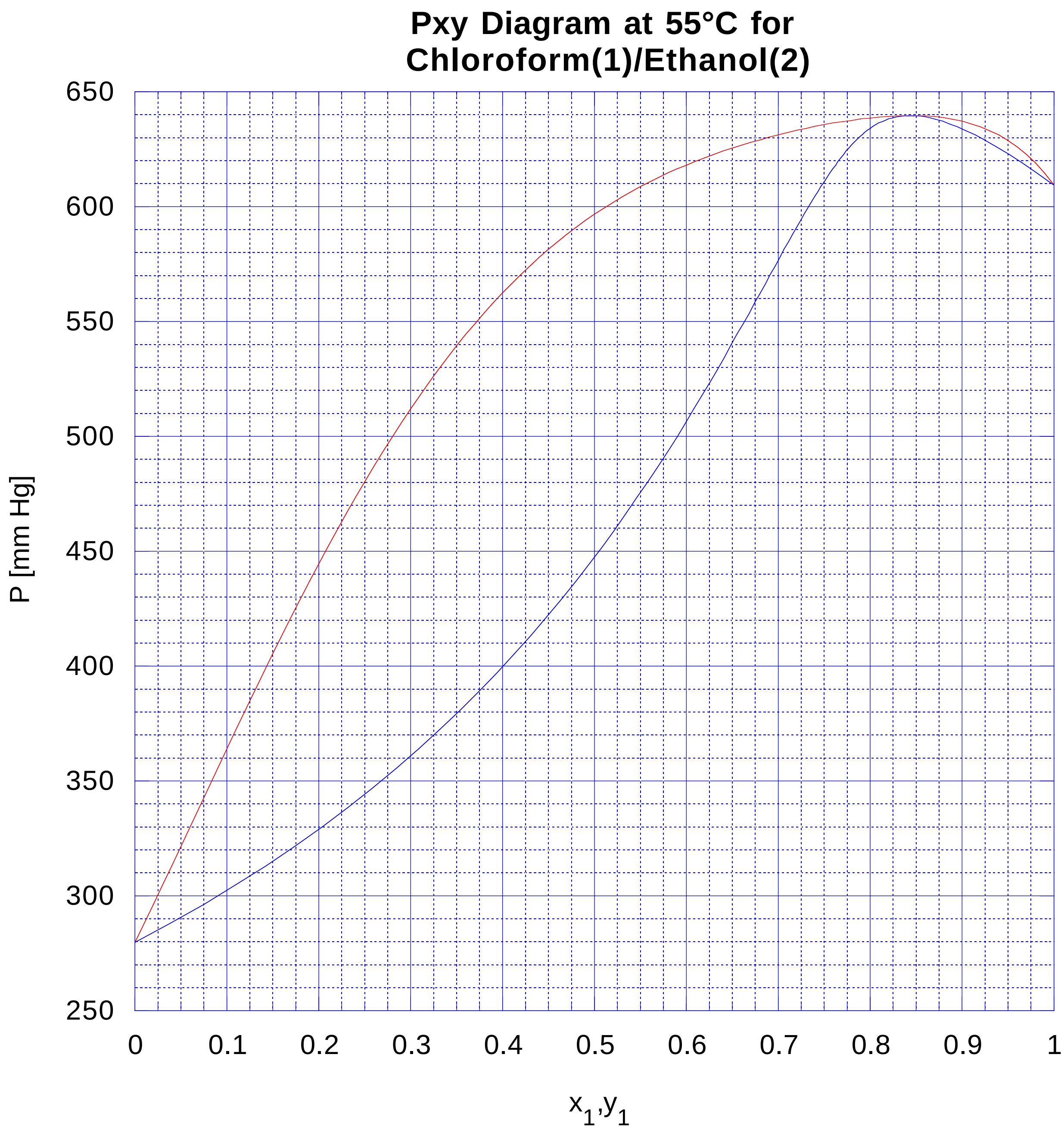
(c) What is your assessment of the feasibility of the process engineer's proposed solution?

27. Consider a distillation column operating at 75 kPa in which acetone and methanol are being separated. A vapor stream containing 30 mol% acetone and 70



mol% methanol enters the first stage at a rate of 200 mol/h, and liquid containing 24 mol% acetone and 76 mol% methanol leaves this stage at a rate of 150 mol/hr. You may assume (1) the stages are ideal; (2) the streams leaving each stage are in equilibrium; (3) the vapor and liquid flow rates do not change by a significant amount from one stage to the next. Estimate the temperature at the first stage and the compositions of the vapor stream leaving this stage and the liquid stream entering it.

28. Consider a distillation column operating at 540 mm Hg in which chloroform and ethanol are being separated. A vapor stream containing 55 mol% chloroform



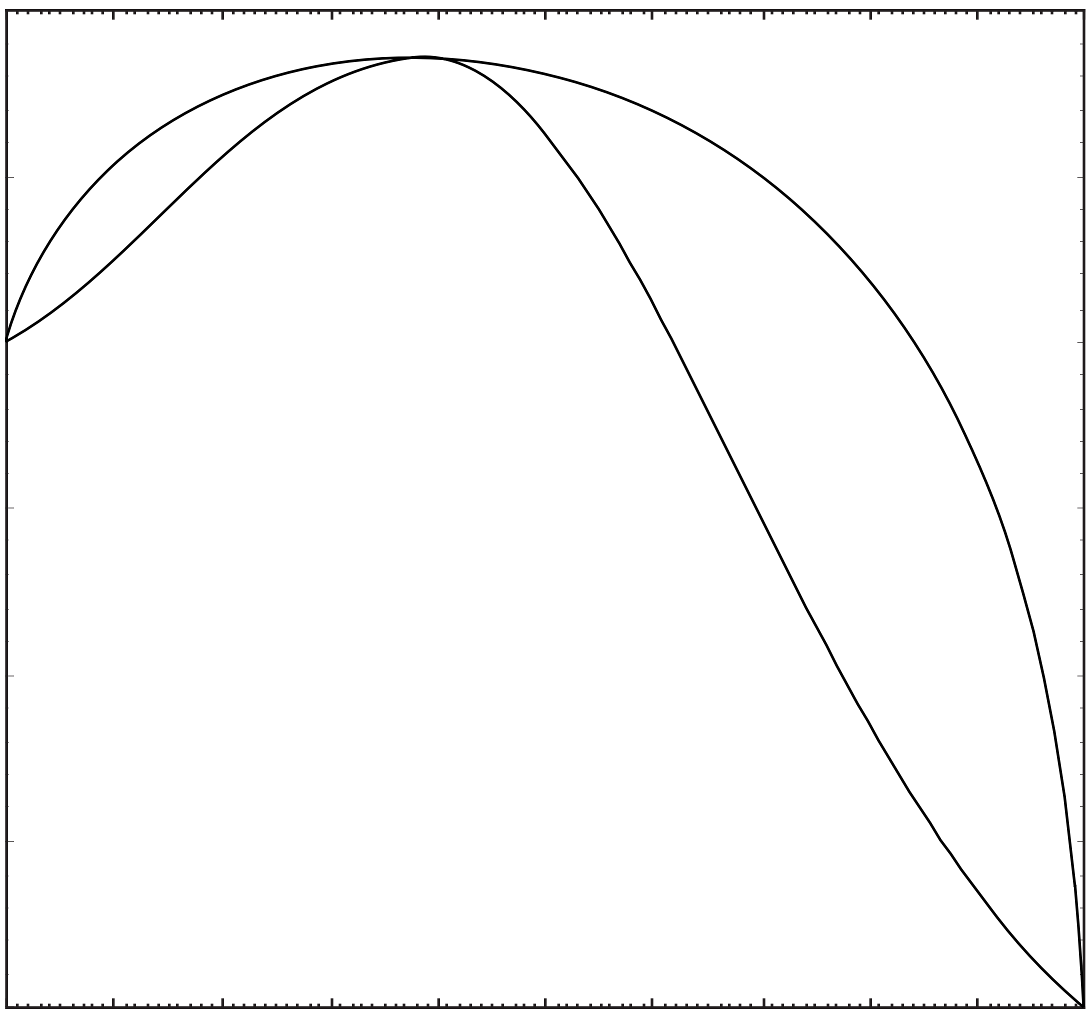
and 45 mol% ethanol enters the first stage at a rate of 200 mol/h, and liquid containing 48 mol% chloroform and 52 mol% ethanol enters this stage at a rate of 150 mol/hr. You may assume (1) the stages are ideal; (2) the streams leaving each stage are in equilibrium; (3) this stage is operating at a temperature of 55°C. *Special Note*: The vapor and liquid flow rates *may* change by a significant amount from one stage to the next. Estimate the compositions and the flow rates of the vapor stream and the liquid stream leaving this stage.

29. The two-component system absurdonitrile/nitromoron exhibits sub-regular solution behavior. The vapor pressures of absurdonitrile(1) and nitromoron(2) are described reasonably well by the Antoine equations.

$$T_1[°\text{C}] = \frac{2796}{14.4 - \ln p^*[\text{kPa}]} - 235.4567\,,\; T_1[°\text{C}] = \frac{3644}{16.6 - \ln p^*[\text{kPa}]} - 233.7976\,.$$

The excess Gibbs energy for absurdonitrile/nitromoron solutions is given by $G^E/(RT) = -2.30x_1x_2$.

The Txy phase diagram of absurdonitrile/nitromoron at 100 kPa is given below.



(a) Label everything you know, can estimate, or can reasonably calculate (within the allotted time) on the phase diagram.

(b) Is the azeotrope high or low boiling.

(c) Does the system exhibit positive or negative deviations from ideality?

(d) What is the dew temperature and dew composition of a 30% nitromoron mixture at 100 kPa (two-figure accuracy is sufficient)?

(e) If a 20% nitromoron mixture at 140 kPa is suddenly flashed to 65°C and 100 kPa, what is the fraction of the mixture that is liquid, what fraction is vapor, and what are the compositions of those two phases (two-figure accuracy is sufficient)?

30. Ethyl alcohol at 68°F ($\rho = 50.0\ \mathrm{lb}_m/\mathrm{ft}^3$, $\mu = 2.5\times10^{-5}\ \mathrm{lb}_f\ \mathrm{s/ft}^2$) flows through a straight commercial steel pipe at a rate of 50 gallons/minute. The inside diameter of the pipe is 1.049 inches. If the pipe is 3000 ft. long, calculate the mechanical energy loss due to friction. Calculate the minimum power requirements (in horsepower) necessary to overcome this loss if the alcohol is driven by a pump (73% efficient) which is in turn driven by an electric motor (92% efficient). If 220 VAC is used to drive the motor determine the minimum current necessary.

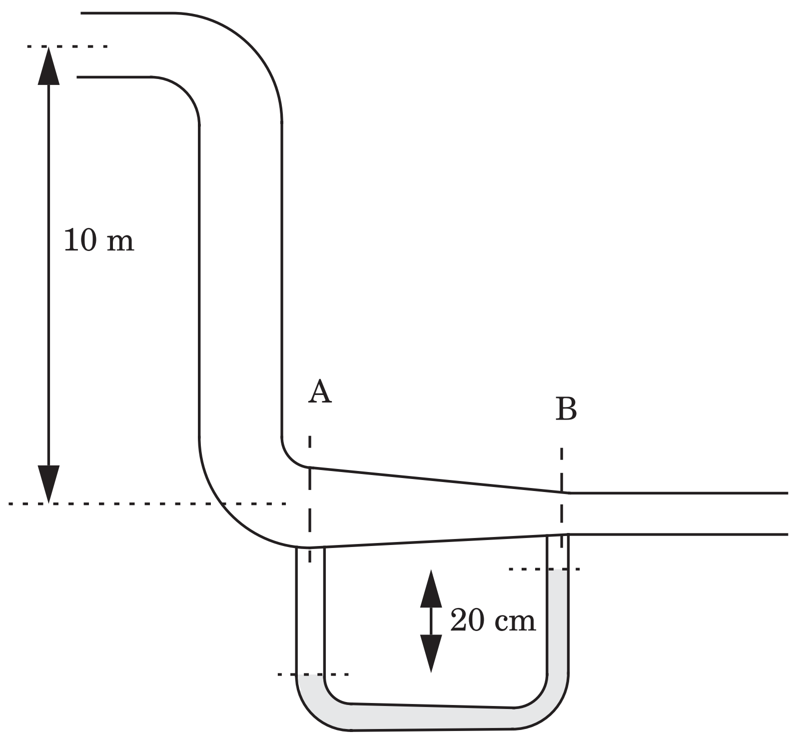
31. A liquid flows through a straight steel pipe at a velocity of 15 ft/s. The inside diameter of the pipe is 2.067 inches. The density of the liquid is $40\ \mathrm{lb_m/ft^3}$ and its viscosity is $0.003\ \mathrm{lb_m/ft\ s}$. If the pipe is 2500 ft long, calculate the mechanical energy loss due to friction. Calculate the minimum power requirements (in horsepower) necessary to overcome this loss if the fluid is driven by a pump (75% efficient) which is in turn driven by an electric motor (90% efficient). If 220 VAC is used to drive the motor determine the minimum current necessary.

32. Water is pumped up a hillside into a reservoir. The pump discharges water at a velocity of 60 ft/s and a pressure of 150 psig. What is the maximum elevation of the reservoir in feet?

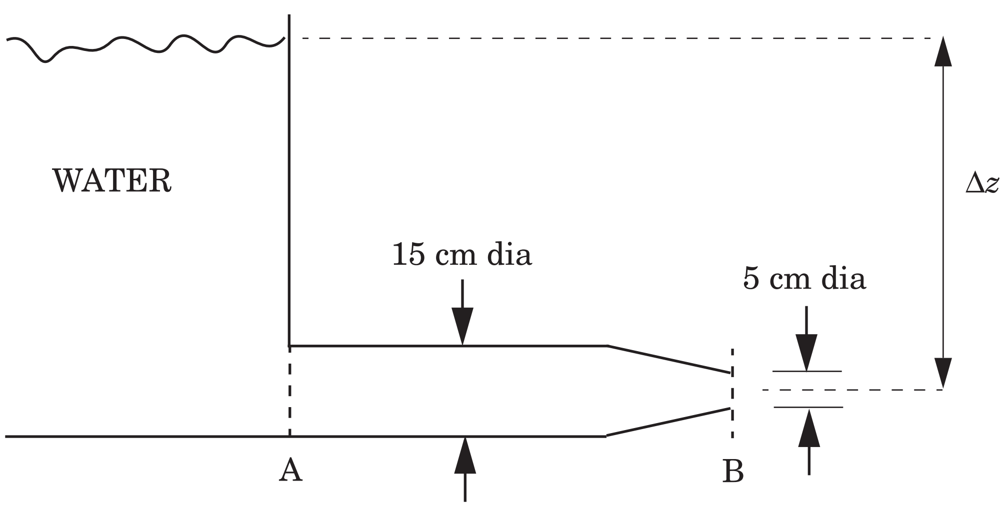
33. Water is flowing through a 2 inch (inside) diameter tube. What is the critical velocity in ft/s?

34. Inviscid water (identical to water except $\mu = 0$) at 4°C is flowing through a frictionless pipe. The ratio of the cross-sectional area at A to the cross-sectional

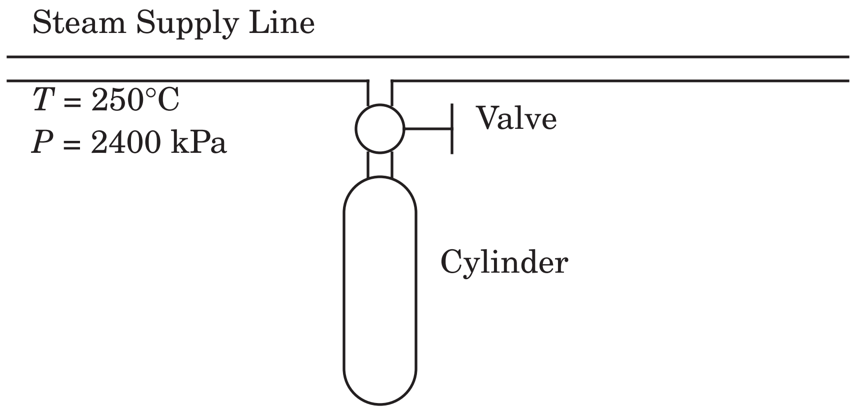
area at B is 3.00. A differential mercury manometer connected between A and B indicates 20.0 cm as shown. What is the maximum possible velocity of water at B?



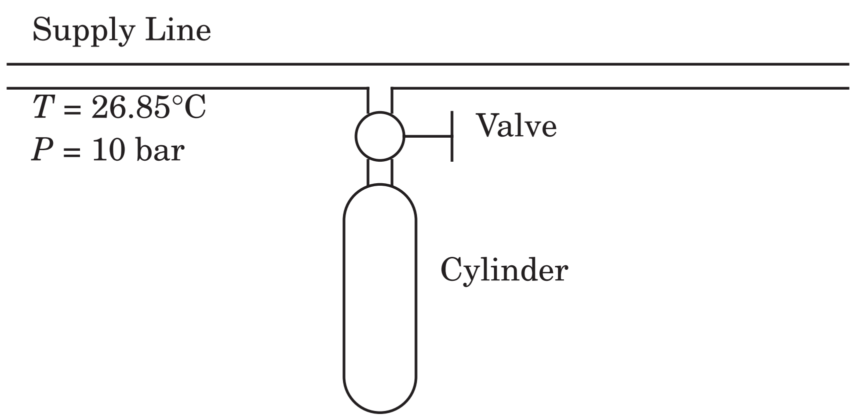
35. What Δz is required to produce a jet velocity, (v_B), of 30 m/s if the frictional losses are $F = \dfrac{15 v_A^2}{2 g_c}$?



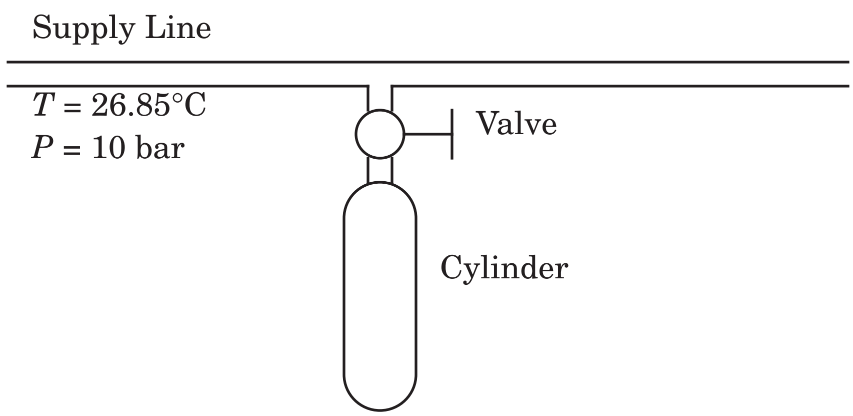
36. An evacuated insulated cylinder is connected to a steam supply line through an insulated valve. The supply line is capable of supplying any required amount of steam at 2400 kPa and 250 °C. At time=0 the valve is opened and the cylinder begins filling. As soon as the pressure in the cylinder equals the line pressure the valve is closed. Assuming the system to be the volume inside the cylinder, write down the First Law, cross out all unneeded terms, and determine the final temperature of the steam in the cylinder.



37. An evacuated insulated gas cylinder is connected to a gas supply line through an insulated valve. The supply line is capable of supplying any required amount of a nondescript diatomic ideal gas ($C_p = (7/2)R$) at 26.85°C and 10 bars pressure. At time=0 the valve is opened and the cylinder begins filling. As soon as the pressure in the cylinder equals the line pressure the valve is closed. Calculate the final temperature of the gas in the cylinder.

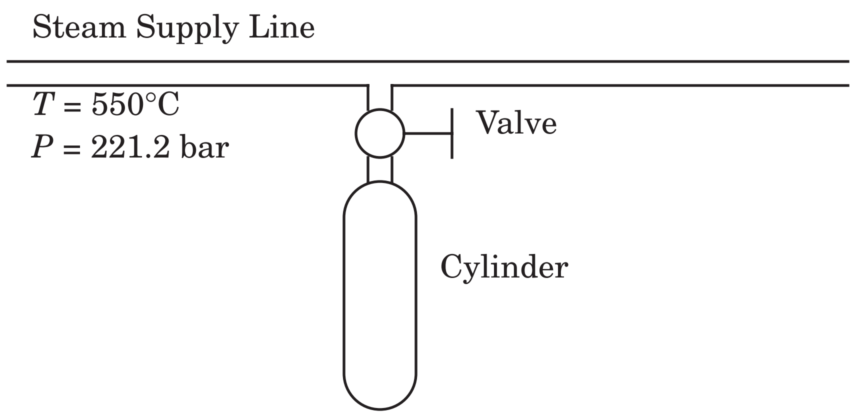


38. An evacuated insulated gas cylinder is connected to a gas supply line through an insulated valve. The supply line is capable of supplying any required amount of a nondescript diatomic ideal gas at 26.85°C and 10 bars pressure. At time=0 the valve is opened and the cylinder begins filling. As soon as the pressure in the cylinder equals the line pressure the valve is closed. Assuming the system to be the volume inside the cylinder, write down the 1st Law and cross out all unneeded terms.



39. An evacuated insulated cylinder is connected to a steam supply line through an insulated valve. The supply line is capable of supplying any required amount of superheated steam at 550°C and 221.2 bars pressure. At time=0 the valve is opened and the cylinder begins filling. As soon as the pressure in the cylinder equals the line pressure the valve is closed. Calculate the final temperature of

the steam in the cylinder. A calculated temperature within 2°C of the correct temperature is sufficiently accurate.



40. An infinite reservoir of compressed air at 1470 psia and 100°F is used to fill a small insulated storage bottle with a volume of 1 ft^3. The bottle is connected to the reservoir through a valve. The bottle initially contains air at 14.7 psia and 70°F. The valve is opened and the bottle begins to fill. When the pressure in the bottle reaches 735 psia the valve is closed. What is the final temperature of the air in °F? Assume air is an ideal diatomic gas.

41. A 1 ft^3 rigid container is filled with air at 20 psia and 100°F. What is the final pressure in the container in psia if 2 BTU's of heat are added?

42. 1 m^3/s of air at 26°C and 10% relative humidity passes through an adiabatic humidifier which saturates the air. The air then passes through a heater which heats it back to 26°C.
    (a) What is the relative humidity of the air exiting the heater?
    (b) How many watts must the heater supply to the air?

43. One mole of a real gas which is described reasonably well by the two-term virial equation is isothermally compressed from P_1 to P_2.
    (a) Calculate W.
    (b) Estimate Q and state any needed assumptions.

44. A mixture of 25 mole% methane, 40 mole% ethane, and 35 mole% propane is burned completely with 25% excess dry air in a continuous reactor. The feed gases enter the reactor at 25°C and 1 atm, and the combustion products emerge 200 °C below the adiabatic flame temperature and at a pressure of 1 atm. The fuel mixture (methane, ethane, and propane without the air) is fed at a rate of 2000 liters/h. Calculate the heat duty of the reactor (in watts) and the volumetric flow rate and the dew point of the combustion products emerging from the reactor.

For this problem may use the heat-capacity correlations in Appendix B.2 of *Felder* even beyond their stated temperature range.

45. 30 mol/h A(g), 15 mol/h E(g) and stoichiometric amounts of B(g) are fed to a reactor at 25°C and a pressure of 1atm. The fractional conversions of A and E are both 100% in the reactor. The reactor products are at a temperature of 200°C and a pressure of 1atm, and are gaseous. All gas-phase species can be treated as ideal gases.

For the above reactor calculate Q_{reactor} in kW.

$A(g) + 5B(g) \rightarrow 3C(g) + 4D(l) \qquad \Delta\hat{H}_r^{25°C} = -1400$ kJ/mol @ P=1 atm

$E(g) + 3B(g) \rightarrow 2F(g) + 2D(l) \qquad \Delta\hat{H}_r^{25°C} = -2000$ kJ/mol @ P=1 atm

Table 1: Data for Problem #44

Species	$C_{p(g)}$ [J/mol°C]	$\Delta\hat{H}_v^{25°C}$ [kJ/mol]
A	68	19
B	30	7
C	36	10
D	72	41
E	40	41
F	35	11

46. An equimolar mixture of methane, ethane, and propane is burned completely with 25% excess dry air in a continuous adiabatic reactor. The feed gases enter the reactor at 25°C and 1 atm, and the combustion products emerge at a pressure of 1 atm. The fuel mixture (methane, ethane, and propane without the air)

is fed at a rate of 2000 liters/h. Calculate the volumetric flow rate and the dew point of the combustion products emerging from the reactor.

47. B is to be produced from A by the reaction:

$$2A \rightarrow B + 2C\,,\ \Delta H_r^\circ = 100\ \text{kJ/mol @ } 25°\text{C}\,.$$

There is a competing side reaction:

$$A + C \rightarrow 3D\,,\ \Delta H_r^\circ = -150\ \text{kJ/mol @ } 25°\text{C}\,.$$

A feed of 100 mol/s of pure A is fed to the processing plant at 25°C. The feed is mixed with recycled A from a distillation column later in the process. The mixture is fed to a chemical reactor where B, C, and D are produced. The products exit the reactor at 75°C and are fed into the distillation column mentioned earlier. The distillate is 22.22%B, 36.11%C, and 25.00%D with the remainder A. It exits at a flow rate of 144 mol/s and a temperature of 50°C. The bottoms is pure A which exits at a flow rate of 275 mol/s and a temperature of 100°C. The bottoms are returned as the recycle stream.

(a) Draw a process flow diagram (PFD) for the process.
(b) Calculate the flow of A, B, C, and D into and out of the reactor. Also calculate the fractional conversion of A in the reactor.
(c) Calculate the heat duty of the reactor.

$$C_p(\text{A}) = 50\ \text{J/mol °C}\,,\ C_p(\text{B}) = 100\ \text{J/mol °C}\,,\ C_p(\text{C}) = 50\ \text{J/mol °C}\,,$$

$$C_p(\text{D}) = 30\ \text{J/mol °C}$$

48. A particular power plant operates with a heat-source reservoir at 300°C and a heat-sink reservoir at 25°C. It has a thermal efficiency equal to 60 percent of the Carnot-engine thermal efficiency for the same temperatures.

(a) What is the thermal efficiency of the plant?
(b) To what temperature must the heat-source temperature be raised to increase the thermal efficiency of the plant to 40 percent? Again η is 60 percent of the Carnot-engine value.

49. If 10 mol/s of ethylene are heated from 200°C to1,000°C in a steady-flow process at approximately atmospheric pressure, what is its entropy change?

50. Consider the heating of a house by a furnace, which serves as a heat-source reservoir at a high temperature T_F. The house acts as a heat-sink reservoir at temperature T, and heat $|Q|$ must be added to the house during a particular time interval to maintain this temperature. Heat $|Q|$ can of course be transferred directly from the furnace to the house, as is the usual practice. However, a third heat reservoir is readily available, namely, the surroundings at temperature T_0, which can serve as another heat source, thus reducing the amount of heat required from the furnace. Given that $T_F = 810$ K, $T = 295$ K, $T_0 = 265$ K, and $Q = 1000$ kJ, determine the minimum amount of heat $|Q_F|$ which must be extracted from the heat-source reservoir (furnace) at T_F. No other sources of energy are available.

51. Consider the air conditioning of a house through use of solar energy. At a particular location experiment has shown that solar radiation allows a large tank of water to be maintained at 205°C. During a particular time interval, heat in the amount of 1,000 kJ must be extracted from the house to maintain its temperature at 20°C when the surroundings temperature is 32°C. Treating the tank of water, the house, and the surroundings as heat reservoirs, determine the minimum amount of heat that must be extracted from the tank of water by any device built to accomplish the required cooling of the house. No other sources of energy are available.

52. Consider the air conditioning of a house through use of solar energy. At a particular location experiment has shown that solar radiation allows a large tank of water to be maintained at 205°C. During a particular time interval, heat in the amount of 1,000 kJ must be extracted from the house to maintain its temperature at 20°C when the surroundings temperature is 32°C. Treating the tank of water, the house, and the surroundings as heat reservoirs, determine the minimum amount of heat that must be extracted from the tank of water by any device built to accomplish the required cooling of the house. No other sources of energy are available.

53. An inventor has devised a complicated non-flow process in which 1 mol of air is the working fluid. The net effects of the process are claimed to be: (1) A change in state of the air from 500 K and 2 bar to 350 K and 1 bar, (2) The production of 2,000 J of work, (3) The transfer of an undisclosed amount of heat to a heat reservoir at 300 K. Determine whether the claimed performance of the process is consistent with the second law. Assume air is an ideal gas for which $C_p = (7/2)R$.

54. An inventor claims to have devised a steady-flow compressor which requires no shaft power input. It is claimed that methane at 200 psia and 120 °F can be compressed to 300 psia where it will emerge at 20 °F, simply by transfer of energy as heat from this device. The patent application states that the device will handle 1 lb_m CH_4 per second and is driven by a “cold source” at –140 °F. Energy is transferred as heat from this device to the cold source at the rate of 60 BTU/s. He further states that the CH_4 enters and exits this device at very low velocity, and that no significant elevation changes are involved. Can these claims be valid? Data for methane are on p. 186 or p. 571.

55. An inventor claims to have designed a machine which can cool a stream of liquid n-hexane from 100°C to 50°C and supply 100 watts of electricity while rejecting an undisclosed amount of heat to the environment at 25°C. If the machine could work, what is the minimum possible flow rate of liquid n-hexane?

56. A device with no moving parts is claimed to provide a steady stream of chilled air at –30°C and 1 bar. The feed to the device is compressed air at 25°C and 5 bar. In addition to the stream of chilled air, a second stream of air flows at an equal mass rate from the device at 70°C and 1 bar. Are these claims in violation of the second law? Assume air is an ideal gas for which $C_p = (7/2)R$.

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59. A device with no moving parts is claimed to provide a steady stream of chilled air at –20°C and 1 bar. The feed to the device is compressed air at 25°C and 4 bar. In addition to the stream of chilled air, a second stream of air flows at an equal mass rate from the device at 70°C and 1 bar. Are these claims in violation of the second law? Assume air is an ideal gas for which $C_p = (7/2)R$.

60. A turbine which runs adiabatically but not reversibly is said to have a turbine efficiency defined as:

$$\eta_{\text{turb}} \equiv \frac{W_{\text{actual}}}{W_{\text{isentropic}}},$$

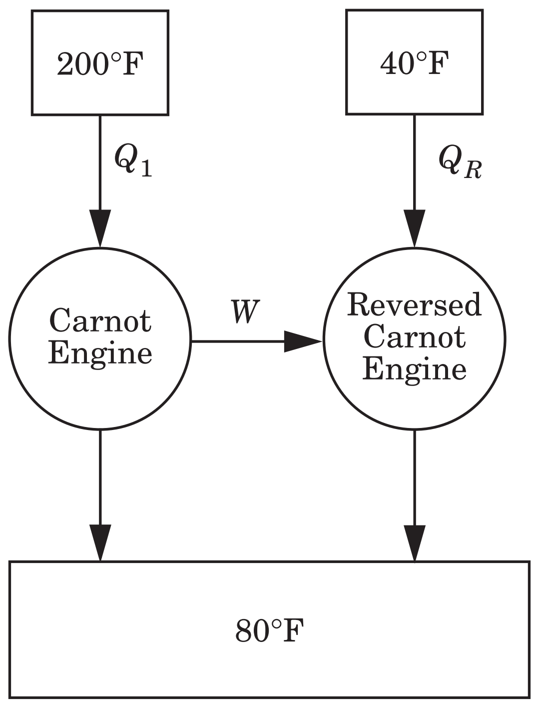
where $W_{\text{isentropic}}$ is the work calculated assuming that the working fluid enters an isentropic turbine at the same temperature and pressure as in the actual turbine, and the working fluid exits from the isentropic turbine at the same pressure as the actual turbine. What is the turbine efficiency of a turbine with a feed of steam at 525°C and 8200 kPa and exit conditions of 7.375 kPa and a quality of 95.0%?

61. A turbine which runs adiabatically but not reversibly is said to have a turbine efficiency defined as:

$$\eta_{\text{turb}} \equiv \frac{W_{\text{actual}}}{W_{\text{isentropic}}},$$

where $W_{\text{isentropic}}$ is the work calculated assuming that the working fluid enters an isentropic turbine at the same temperature and pressure as in the actual turbine, and the working fluid exits from the isentropic turbine at the same pressure as the actual turbine. If the feed to an isentropic turbine is steam at 525°C and 8200 kPa which exits the turbine at 7.375 kPa and a quality of 80.9%, what is the quality of steam exiting from an actual turbine operating between the same conditions with an efficiency of $\eta_{\text{turb}} = 0.747$?

62. A Carnot engine operating between 200°F and 80°F provides work for a reversed Carnot engine (a Carnot refrigerator) operating between 40°F and 80°F. The reversed Carnot engine extracts 1000 BTU from the cold reservoir. Calculate Q_1.



63. In an ideal Rankine cycle steam leaves the boiler and enters the turbine at 4 MPa, 400°C. The condenser pressure is 19.92 kPa. Determine the cycle efficiency. What is the mass flow rate of the water if the net power output is 220 MW?

64. An air-standard Diesel cycle consists of an isentropic compression, an isobaric expansion, an isentropic expansion and an isochoric cooling.
   (a) Sketch an air-standard Diesel cycle on a $P\hat{V}$ diagram.
   (b) Calculate the thermal efficiency of an air-standard Diesel cycle which begins the compression step at a temperature of 20°C and a pressure of 1 bar, the pressure at the end of the compression step is 5 bar, and Q_{hot} = 1500 J/mol. Assume air is an ideal gas for which $C_p = (7/2)R$.

65. An air-standard Diesel cycle consists of an isentropic compression, an isobaric expansion, an isentropic expansion and an isochoric cooling.
   (a) Sketch an air-standard Diesel cycle on a $P\hat{V}$ diagram.
   (b) Calculate the thermal efficiency of an air-standard Diesel cycle which begins the compression step at a temperature of 15°C and a pressure of 1 bar, the specific volume at the end of the compression step is 1/18 of the volume at the beginning of the compression step, and Q_{hot} = 1800 kJ/kg. Assume air is an ideal gas for which $C_p = (7/2)R$.

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67. An air-standard Diesel cycle consists of an isentropic compression, an isobaric expansion, an isentropic expansion and an isochoric cooling.
   (a) Sketch an air-standard Diesel cycle on a $P\hat{V}$ diagram.
   (b) Calculate the thermal efficiency of a air-standard Diesel cycle which begins the compression step at a temperature of 15°C and a pressure of 1 bar, the specific volume at the end of the compression step is 1/18 of the volume at the beginning of the compression step, and Q_{hot} = 1800 kJ/kg. Assume air is an ideal gas for which $C_p = (7/2)R$.

68. The following heat engines produce 80,000 kW of power. Determine in each case the rates at which heat is absorbed from the hot reservoir and discarded to the cold reservoir
   (a) A Carnot engine operating between heat reservoirs at 600 K and 300 K.
   (b) A practical engine operating between the same heat reservoirs but with a thermal efficiency $\eta = 0.3$.

69. In an ideal Rankine cycle steam leaves the boiler and enters the turbine at 4 MPa, 400°C. The condenser pressure is 10.09 KPa. Determine the cycle effi-

ciency. What is the mass flow rate of the water if the net power output is 100 kW?

70. In an ideal Rankine cycle steam leaves the boiler and enters the turbine at 4 MPa, 400°C. The condenser pressure is 19.92 kPa. Determine the cycle efficiency. What is the mass flow rate of the water if the net power output is 220 MW?

71. In an ideal Rankine cycle steam leaves the boiler and enters the turbine at 4 MPa, 400°C. The condenser pressure is 10 KPa. Determine the cycle efficiency. What is the mass flow rate of the water if the net power output is 100 kW?

72. Steam enters a nozzle at 3400 kPa and 400°C at negligible velocity and discharges at a pressure of 2400 kPa. Assuming isentropic expansion of the steam in the nozzle, what is the exit velocity and what is the cross-sectional area at the nozzle throat at this pressure for a flow rate of 0.5 kg/s?

73. Superheated steam at 500°C and 80 bar enters an insulated nozzle at a velocity of 1 m/s. It exits at 450°C and 1 bar. What is the ratio of the inlet diameter of the nozzle to the outlet diameter?

74. A high velocity jet of saturated steam at 30 psia with a mass flow rate of $10\ lb_m/min$ is generated by a nozzle. The inlet pressure to the nozzle is 40 psia. Determine the maximum possible velocity for the exiting jet in ft/s.

75. Steam enters a turbine at 75 psia and 600°F and exits at 1 psia. The turbine is adiabatic but not reversible. It generates 75% of the power that an adiabatic and reversible turbine would operating between the same entering conditions and exiting pressure. What is the quality of the steam exiting the irreversible turbine?

76. What is the minimum power required in kW for a pump to increase the pressure from 2kPa abs. to 6MPa abs. for a water flow rate of 10 kg/s?

77. An heat engine with a 35% thermal efficiency operates between a cold reservoir at 540°R and a hot reservoir at 1080°R, and generates 300 hp. What is the net entropy generation rate for this engine in BTU/hr °R?

78. S In some parts of the Western United States, geothermal energy, i.e., underground hot water, may be an economical source of power. Suppose that the hot water is available at 200 °F and the surroundings temperature for dissipation of heat is 85 °F. A special Rankine cycle is designed to operate between these limits using Freon 12 as the working fluid with a maximum boiler pressure of 250 psia. The stated turbine efficiency is 85%. Assuming that the hot water temperature drops to 140 °F as it is giving up heat to the Freon in the boiler, calculate the water flow rate required for a power output of 25 MW. Assume no superheat of Freon. Data for Freon are on pp. 280–282. Do not interpolate in tables.

79. A reversible cyclic process is performed on n moles of an ideal gas with constant heat capacity C_v.
Step 1–The gas at T_1, P_1, V_1 is isothermally compressed to P_2.
Step 2–The gas is adiabatically compressed to T_3.
Step 3–The gas is isothermally expanded to P_4.
Step 4–The gas is adiabatically expanded to T_1.
(a) Sketch the cycle on a P–V diagram.
(b) Calculate the total work for 1 cycle.

80. An inventor wants to use an air-standard carnot engine as a heat engine to run his electric generator on Monday, Wednesday and Friday, and as a heat pump (refrigerator) to cool his beer on Tuesday, Thursday and Saturday. The specifications on the engine when run as an engine are that the pressure and specific volume at the end of the compression steps are 10 bar and 0.1083 m^3/kg, and at the end of the expansion steps are 0.1 bar and 7.939 m^3/kg. A maximum of 10,000 W of heat can flow into or out of the hot side of the engine.
(a) On Monday, Wednesday and Friday, how much power does the inventor have available to run his generator?
(b) On Tuesday, Thursday and Saturday, how cold can the inventor keep his beer?
(c) What is the coefficient of performance (COP) on Tuesday, Thursday and Saturday?