

SOLUTIONS MANUAL

Basic Principles and Calculations in Chemical Engineering

Eighth Edition

David M. Himmelblau
James B. Riggs



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*We want to thank Christine Bailor for preparing this Solutions Manual,
and for the many students and graders who have contributed to
the solutions it contains.*

David M. Himmelblau
James B. Riggs

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To the Instructor

This *Solutions Manual* accompanies the book *Basic Principles and Calculations in Chemical Engineering, Eighth Edition*, published by Prentice Hall. In addition to the detailed, worked-out solutions for all the problems that follow each chapter in the textbook and answers to the thought problems, you will find in what follows a number of useful components of a syllabus for students, information that usually are handed out during the first day of class:

1. Class grading policies, homework and reading assignments, and examination information.
2. Class objectives.
3. Schedule of topics covered.
4. Suggestions for taking examinations.
5. Format standards for submitting homework.

Suggested Content for the Introductory Course in Chemical Engineering

The introductory course in chemical engineering is usually taught over an interval of one or two semesters, or one or three quarters. The textbook contains more material than can be successfully presented in one quarter and probably in one semester (depending on the background and previous coursework of students). Although an instructor would like to assume that a student has learned all of the material covered in earlier courses in chemistry and physics, it takes just one time in teaching the introductory course to abandon that expectation. The textbook is organized into four parts comprised of 11 chapters plus 6 additional chapters on the accompanying CD that treat material usually not included in a one semester course. The following list suggests the chapters to include in courses of various duration:

One quarter	1–6, 8, 9–10
One semester	1–11
Two quarters	1–7 followed by 8 and 11
Two semesters	1–11 followed by 12–17

Example Course Syllabus
Information for ChE 317
Introduction to Chemical Engineering

Instructor: D.M. Himmelblau
Office hours: M-F 10-11 a.m.

Office: CPE 5.410

1. GENERAL

- a. The prerequisites for ChE 317 are Ch 302 and Math 808. If you have not completed these two courses, you will have to drop ChE 317 and should do so at once.
- b. Class conduct is informal. Feel free to raise your hand at any time to ask a question or for an explanation.

2. EXAMINATIONS

- a. Five two-hour examinations plus a final exam will be held at specified announced dates as shown on the assignment sheets. The last examination will be scheduled during the final exam period (refer to the course schedule for details). The lowest exam of the first 5 (excluding the final exam) will be omitted in calculating your final grade. You must take the final. If you will miss an exam, notify me prior to the exam, not afterwards, to arrange for a makeup exam.

3. GRADING

- a. The grading is based on scores on the examinations, each of which is weighted equally (90%), plus class discussion and homework (10%). The grades are assigned on an **absolute basis**, not a curve:

A	> 82
B	71-82
C	61-70
D	51-60
F	< 51

hence there is no penalty for working together and helping each other.

- b. You will have a grader assigned to this course whose name is _____, office number is Room _____, and office hours are _____.
- c. The recitation session assistant is _____, office number is Room _____, and office hours are _____.
- d. If you disagree with the grader's method of grading and with the total points he has given you on a particular problem, discuss it with the grader first, but if you cannot reach a decision, I will be the referee. Bring exam grade questions to me.
- e. Prepare a grade sheet on which you can keep account of your homework and exam grades so that you will be able to compute your status at any time you wish.

- f. A grade of at least a C is required in this course for subsequent courses in chemical engineering.
4. HOMEWORK PROBLEMS
- a. CHEMICAL ENGINEERING STANDARDS WILL BE REQUIRED AND ENFORCED. (Capital letters intended.)
 - b. Problems are due at the beginning of each class according to the assignment. No late problems can be accepted.
 - c. Turn in as much of a problem as you can get. It is better to get a low grade than a "miss."
 - d. Working together is an important part of professional practice. After the second week of class, students will be assigned to work on homework (not exams!) in pairs. During the first two weeks of class look for a possible compatible partner. You will receive a list of all of the class members with their phone numbers to help in the selection. Exceptions can be made for individuals who insist on working alone.
 - e. After each scheduled homework assignment has been turned in, the solution(s) will be placed in a file located in the ChE stockroom that may be checked out for 2 hours at a time.
5. If you have difficulty in the early part of the course, confer with me **before you get into trouble.**

Course Objectives

The objectives for Chemical Engineering 317 are as follows:

1. To introduce you to the principles and calculation techniques used in the field of chemical engineering.
2. To acquaint you with the fundamentals of material and energy balances as applied to chemical engineering.
3. To acquaint you with efficient methods of problem solving so that you can effectively solve problems you will encounter after leaving school.
4. To offer practice in defining problems, collecting data, analyzing the data, and breaking it down into basic patterns, and selection of pertinent information for application.
5. To review certain principles of applied physical chemistry.
6. To help you decide you have chosen the right field.

Contributions to Program Outcomes

By graduation a chemical engineering student should have achieved certain knowledge, skills, and abilities known as Program Outcomes. ChE 317 contributes to five significant outcomes, namely an ability to:

1. Apply knowledge of mathematics, chemistry, physics computing, safety, ethical practice, and technology to solve engineering problems.
2. Apply and integrate elements of chemical engineering to solve problems in design, operation, and control of processes.
3. Participate in team activity effectively and demonstrate leadership.
4. Communicate effectively via oral, written, and graphic means.
5. Appreciate the societal and economic impact of engineering decisions locally and globally.

Fall Semester Exam Schedule

The first 5 exams are evening exams on Thursday, open book, of 2 hours duration, specific times to be arranged (such as 5-7, 6-8, 7-9, etc.):

Exam 1	September 14
Exam 2	October 1
Exam 3	October 16
Exam 4	November 1
Exam 5	November 15

The final exam is listed in the University final exam schedule (that will appear about December 1).

Fall Semester Schedule for the Recitation Section

The recitation section will meet on Thursday, 2–3:30 p.m. in CPE 2.220. The objective of the recitation section is to let you ask questions and provide assistance in problem solving for old or new ChE 317 homework and exam problems on a one-to-one basis.

Attendance is not required, *but* you will miss the unique opportunity to get personal attention if you want it. You will also miss questions asked by other students that you have not considered. You will also have the chance to meet other students in the class, and discuss anything (!) with them.

No assignments are made, no grades given, no lectures presented, and no formal structure exists for the recitation section. It's up to you to make use of it.

Suggestions for Taking Exams

1. Bring what you want to the exams—they are open book. Be sure to have adequate pencils, batteries, etc.
2. Read the entire examination through quickly before starting to work any one problem. Then work first on those problems which seem the simplest or about which you are most confident in solving.
3. Be sure to allot your working times to the questions roughly according to the grade value of each. If a problem is not completed in the time allotted, it is usually better to discontinue work on it and spend time on the other problems. Be sure to spend at least some time on each problem. Partial solutions to all problems usually result in a higher overall grade than complete solutions to only a small portion of the problems (provided you do enough work on a problem to indicate that the correct method of attack is being used).
4. When starting work on a problem read it through carefully and be certain you understand it. Spend a short time thinking about the method of solution instead of writing down what first comes to mind.
5. When writing down the solution, organize your work in a neat and logical manner in spite of the time constraints. This step not only impresses the grader but also permits him or her to follow the work closely enough so that if a mistake is made he or she can still evaluate the succeeding work. Neatness and organization also permit you to check your work more easily and to find quickly information needed later in the problem.
6. In answering a question write enough so that the grader does not have to guess what you had in mind. For example, when using equations, write down the equation first and then substitute numbers. A group of numbers alone may confer little information to the grader, especially if they are the wrong numbers. When using data obtained from tables or charts, state the source—and in some cases the method of using the source. Draw pictures, and separate subproblems from each other.
7. If it is obvious that you are not going to finish a problem, carefully outline the remainder of the solution by numbered steps, and include sufficient details, such as pertinent equations and methods of solving them, sources for remaining necessary data, etc.
8. If you start to get rattled, slow down a bit— perhaps even think of something besides the examination for a minute or two. Remember that this one examination is not going to make or break you whatever success you have on it. View the problem bothering you as you would a bridge hand, crossword puzzle, or other game that involves solving a problem based on a given set of facts with available information.
9. Sample old exams are located in the ChE Stockroom, and can be taken out and copied. Practice solving old exams two or three days in advance of each exam to isolate your weaknesses in subject material and exam taking skills.

***What you should know about this course at the beginning
that will be clear by final exam time***

1. You no longer are a freshman so that the material covered proceeds at a rapid pace.
2. Your notions of teaching and learning will require substantial adjustment. Our goal is not for you to reproduce what was told to you in the classroom or you read in the text. Your study habits probably must change.
3. Lecture time is at a premium and must be used efficiently. Listening is not learning any more than lecturing is teaching. You are responsible for learning the material, a phase that will occur primarily outside the classroom. The instructor cannot “teach” all the skills you need in the short time of a class. It will take you two or three hours on the average per hour of class time to become proficient.
4. The instructor’s job is to provide a framework of the topic along with demonstrations to guide you in your learning of concepts, methods, and efficient problem solving skills. It is not to imprint you with isolated facts and problem types.
5. If you read the material in the assigned section for the next period before coming to class, the lecture will make more sense, and you can ask questions to clarify any uncertain issues.

Standards for Chemical Engineering Homework Assignments

1. Engineering paper must be used (paper ruled on the back with a grid).
2. Use the unruled side of the sheet for the calculations, and the back side for drawings (rarely required).
3. Use the sheet with the holes to the left.
4. Turn in your work with the paper folded vertically.
5. Write neatly. Make the text in your calculations in letters 0.20 inches high—these match the horizontal grid spacing on the back of the paper. Leave 0.20 inches (one grid interval) between lines. The idea is to be professional in presenting your work.
6. Use engineering/scientific notation for numbers such as 0.341 and 1.453×10^5 . Use judgment as to how many zeros you put after the decimal point or before the first significant figure. Note: always put a zero before the decimal point for a number less than unity.
7. Indicate multiplication and division using units as seen below. (Note: Use vertical and horizontal rules as necessary.)

$$\frac{3.45 \text{ lb NaCl}}{1 \text{ ft}^3 \text{ soln}} \left| \frac{4 \text{ gal soln}}{\right. \left. \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \right| =$$

As you gain experience, you can suppress the units for simple problems and show multiplication and division thus (use parenthesis rather than centered dots as the dots get confused with periods, dust specks, etc.)

$$(3.45)(4)\left(\frac{1}{7.48}\right) =$$

8. Use a solid line across the page between the vertical rules on the engineering paper to demarcate the end of a part of a problem with multiple parts. Denote the end of the entire problem by a line across the page from the left hand rule to the far right edge of the paper.
9. Always show the units of your answer, underline the numbers and units, and draw an arrow from the right edge of the paper to the answer so that the answer is easy to pick out on the page thus

$$\frac{8.5 \text{ lbH}_2}{\text{lb F}} \left| \frac{1 \text{ lb mol H}_2}{2.02 \text{ lb H}} \right| \frac{1 \text{ lb mol Zn}}{1 \text{ lb mol H}_2} = \frac{4.21 \text{ lb mol Zn}}{\text{lb F}} \quad \longleftrightarrow \text{ part (a) of the problem}$$

10. Indicate a new problem by placing the problem number in the left hand margin.
11. Always show the basis of your calculations thus

Basis: 100 lb feed

12. On each submission place your class number, the date, the assignment number, your name, and the page numbering at the top of each and every page, even if you staple the pages together, thus

317	Sept. 10, 2003	Assignment No. 5	Jones, Robert	2/3
↑	↑	↑	↑	↑
Class	Date	Assignment Identification	Your name	Page 2 of 3 pages submitted

TYPICAL ASSIGNMENTS FOR ONE SEMESTER

	Topic and Problem Assignments Due	All assignments are in the 8th edition. Study:
1.	First Class meeting. No assignments due	
2.	UNITS, DIMENSIONS, UNIT CONVERSION 2.1.1, 2.2.2, 2.2.6	Chapter 2
3.	DIMENSIONAL CONSISTENCY, SIGNIFICANT FIGURES, VALIDATION, MOLES 2.3.1, 2.3.3, 2.3.8	Chapter 2
4.	METHODS OF ANALYSIS AND MEASUREMENT 2.6.1a, 2.6.4a, 2.9.1	Chapter 2
5.	BASIS, TEMPERATURE, PRESSURE 2.7.1a,b,c; 2.11.2, 2.11.5	Chapter 2
6.	PRESSURE MEASUREMENT 2.11.9	Chapter 2
7.	INTRODUCTION TO MATERIAL BALANCES 3.1.11, 3.1.19, 3.1.16, 3.1.7, 3.1.8	Chapter 3
8.	STRATEGY FOR SOLVING MATERIAL BALANCES 3.2.2, 3.2.4, 3.2.5, 3.2.9, 3.2.14	Chapter 3
9.	No class meeting. Exam No. 1 in the evening.	
10.	MATERIAL BALANCES WITHOUT REACTION— SINGLE UNITS 4.1.7, 4.1.8, 4.1.10, 4.1.12	Chapter 4
11.	MATERIAL BALANCES (CONTINUED) 4.1.18, 4.1.20, 4.1.23, 4.1.25	Chapter 4
12.	STOICHIOMETRY 5.1.2a,e; 5.1.5; 5.2.14; 5.2.15	Chapter 5
13.	MATERIAL BALANCES WITH REACTION— SINGLE UNITS 5.3.1, 5.3.2, 5.3.6, 5.3.7	Chapter 5
14.	MATERIAL BALANCES WITH REACTION— SINGLE UNITS (CONTINUED) 5.5.5, 5.5.7, 5.5.10, 5.5.13	Chapter 5

	Topic and Problem Assignments Due	All assignments are in the 8th edition. Study:
15.	Review for Exam No. 2.	Chapters 4–5
16.	No class meeting. Exam No. 2 in the evening.	
17.	MATERIAL BALANCE PROBLEMS WITH MULTIPLE UNITS 6.1.2, 6.1.5, 6.2.1, 6.2.7	Chapter 6
18.	MATERIAL BALANCE PROBLEMS WITH RECYCLE (NO REACTION) 6.3.1b,d; 6.3.2; 6.3.16, 6.3.17	Chapter 6
19.	MATERIAL BALANCE PROBLEMS WITH RECYCLE (WITH REACTION) 6.3.8, 6.3.13, 6.3.21	Chapter 6
20.	IDEAL GAS AND PARTIAL PRESSURE 7.1.1, 7.1.5, 7.1.12c, 7.1.22, 7.1.31	Chapter 7
21.	MATERIAL BALANCES WITH IDEAL GASES 7.1.52, 7.1.44, 7.1.55	Chapter 7
22.	REAL GASES—COMPRESSIBILITY 7.3.1, 7.3.3, 7.3.13	Chapter 7
23.	REAL GASES—EQUATIONS OF STATE 7.2.8, 7.2.5, 7.2.17, 7.2.13	Chapter 7
24.	Review for Exam No. 3.	Chapters 6–7
25.	No class meeting. Exam No. 3 in the evening.	
26.	SINGLE COMPONENT-TWO PHASE SYSTEMS (VAPOR PRESSURE) 8.2.1, 8.2.9, 8.3.2 a to e, 8.3.4, 8.3.5b, 8.3.19, 8.3.20	Chapter 8
27.	TWO PHASE GAS-LIQUID SYSTEMS 8.3.17, 8.3.22a, 8.4.2, 8.4.4, 8.4.7	Chapter 8
28.	TWO PHASE GAS-LIQUID SYSTEMS (CONTINUED) 8.4.14, 8.4.16, 8.4.18, 8.4.27	Chapter 8

	Topic and Problem Assignments Due	All assignments are in the 8th edition. Study:
29.	VAPOR-LIQUID EQUILIBRIA AND THE PHASE RULE 8.2.4, 8.2.5, 8.5.3, 8.5.6, 8.5.14, 8.5.18	Chapter 8
30.	Review for Exam No. 4	Chapter 8
31.	No class meeting. Exam No. 3 in the evening.	
32.	ENERGY: TERMINOLOGY, CONCEPTS, AND UNITS 9.1.1, 9.1.5, 9.1.7, 9.1.11, 9.2.4, 9.2.21, 9.2.22	Chapter 9
33.	ENERGY BALANCES—CLOSED SYSTEMS 9.3.31a,b; 9.3.9; 9.3.25; 9.3.45	Chapter 9
34.	ENERGY BALANCES—OPEN SYSTEM 9.3.31, 9.3.32, 9.3.17a, 9.3.33	Chapter 9
35.	CALCULATING ENTHALPY CHANGES 9.2.26, 9.2.37, 9.2.46	Chapter 9
36.	APPLICATIONS OF ENERGY BALANCES WITHOUT REACTION-CLOSED SYSTEMS 9.3.19, 9.3.39, 9.3.40	Chapter 9
37.	APPLICATIONS OF ENERGY BALANCES WITHOUT REACTION-OPEN SYSTEMS 9.3.21, 9.3.41	Chapter 9
38.	Review for Exam No. 5	Chapter 9
39.	No class meeting. Exam No. 5 in the evening.	
40.	ENERGY BALANCES WITH REACTION 10.1.6; 10.1.8a,b; 10.2.1a; 10.2.3; 10.2.4	Chapter 10
41.	CONTINUED 10.2.17, 10.2.6, 10.2.10, 10.4.6	Chapter 10
42.	PARTIAL SATURATION AND HUMIDITY 11.1.1	Chapter 11
43.	HUMIDITY CHARTS 11.2.1, 11.3.1, 11.3.7	Chapter 11
44.	Exam No. 6 is the final exam held on the scheduled final exam period (3 hours).	

TYPICAL EXAMS FOR A ONE SEMESTER COURSE
(scheduled in the evening to avoid time constraints on students)

Exam No. 1
(Open Book, 1 1/2 hours)

PROBLEM 1 (5%)

Hydrogen can be separated from natural gas by diffusion through a round tube. The rate of separation is given by

$$N = 2\pi D\rho R$$

where

N = rate of transport of H₂ from the tube, g moles/(sec)(cm of length of tube)

D = diffusion coefficient

ρ = molar density of H₂, g moles/cm³

R = log mean radius of tube, $r_2 - r_1 / \ln \left(\frac{r_2}{r_1} \right)$, with r in cm.

What are the units of D?

PROBLEM 2 (10%)

A pallet of boxes weighing 10 tons is dropped from a lift truck from a height of 10 feet. The maximum velocity the pallet attains before hitting the ground is 6 ft/sec. How much kinetic energy does the pallet have in (ft)(lb_f) at this velocity?

PROBLEM 3 (5%)

The specific gravity of a fuel oil is 0.82. What is the density of the oil in lb/ft³? Show all units.

PROBLEM 4 (10%)

Sulfur trioxide (SO₃) can be absorbed in sulfuric acid solution to form more concentrated sulfuric acid. If the gas to be absorbed contains 55% SO₃, 41% N₂, 3% SO₂, and 1% O₂, how many parts per million of O₂ are there in the gas? (b) What is the composition of the gas on a N₂ free basis?

PROBLEM 5 (15%)

You have 100 kilograms of gas of the following composition:

CH ₄	30%
H ₂	10%
N ₂	60%

What is the average molecular weight of this gas?

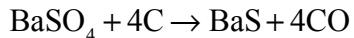
PROBLEM 6 (15%)

If the heat capacity of a substance is 5.32 J/(g)(°C) and its molecular weight is 37.4, what is its heat capacity in

- (a) J/(g)(°F)
- (b) J/(lb)(°R)
- (c) J/(gmol)(K)

PROBLEM 7 (20%)

A rock containing 100% BaSO₄ is burned with coke (94%C, 6% ash) and the composition of the product is BaSO₄ (11.1%) BaS (72.9%), C (13.9%, ash (2.2%). The reaction is



Calculate the percent excess reactant, and the degree of completion of the reaction.

PROBLEM 8 (20%)

A gas cylinder to which is attached a Bourden gauge appears to be at a pressure of 27.38 in. Hg at 70°F. the barometer needs 101.8 kPa. A student claims that the pressure in the tank is 1.3 psia, but another student points out that this is impossible—the pressure is really 28.2 psia. Can 1.3 psia be correct? Explain and show calculations to back up your explanation.

EXAM NO. 2
(Open Book, 2 hours)

PROBLEM 1 (25%)

A chemist attempts to prepare some very pure crystals of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ by dissolving 200 g of Na_2SO_4 (MolWt=142.05) in 400 g of boiling water. He then carefully cools the solution slowly until some $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ crystallizes out. Calculate the g of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ recovered in the crystals per 100 g of initial solution, if the residual solution after the crystals are removed contains 28% Na_2SO_4 .

	Right answer but: -10 if answer is in g of Na_2SO_4 and not g of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$		-10 if answer not per 100 g of initial soln
--	---	--	---

PROBLEM 2 (25%)

Water pollution in the Hudson River has claimed considerable recent attention, especially pollution from sewage outlets and industrial wastes. To determine accurately how much effluent enters the river is quite difficult because to catch and weigh the material is impossible, weirs are hard to construct, etc. One suggestion which had been offered is to add a trace Br^- ion to a given sewage stream, let it mix well, and sample the sewage stream after it mixes well.

On one test of the proposal you add ten pounds of NaBr per hour for 24 hours to a sewage stream with essentially no Br^- in it. Somewhat downstream of the introduction point a sampling of the sewage stream shows 0.012% NaBr . The sewage density is 60.3 lb/ft³ and river water density is 62.4 lb/ft³.

What is the flow rate of the sewage in lb/min?

	-10 if answer based on 0.012 fractin and not 0.00012.		-15 if 24 hr basis was used and then not converted back to per hour basis.
--	---	--	---

PROBLEM 3 (25%)

In preparing 5.00 moles of a mixture of three gases (SO_2 , H_2S , and CS_2), gases from three tanks are combined into a fourth tank. The tanks have the following compositions (mole fractions):

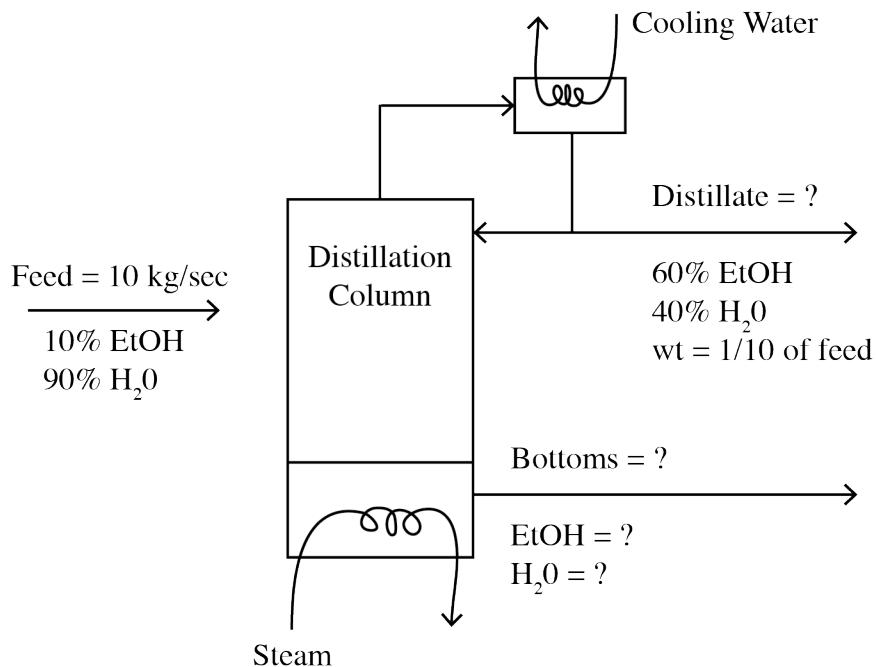
	Gas	Tank 1	Tank 2	Tank 3	Tank 4
	SO_2	0.10	0.20	0.25	0.20
	H_2S	0.40	0.20	0.25	0.26
	CS_2	0.50	0.60	0.50	0.54

How much of Tanks 1, 2, and 3 must be mixed to give a product with composition of Tank4?

	-10 for correct answer but wrong basis		-15 A lot of people said no soln. They used wrong basis, etc. No soln but correct mat'l balance
--	---	--	---

PROBLEM 4 (25%)

- 10% a) For the given distillation process, calculate the composition of the bottoms stream.
- 15% b) If steam leaked into the column at 1000 mole/sec and all else was constant, what would the new bottoms composition be? -5 (should be g-mole), if assumed to k-mole and not stated.



Exam No. 3
(Open Book Exam, 2 hours)

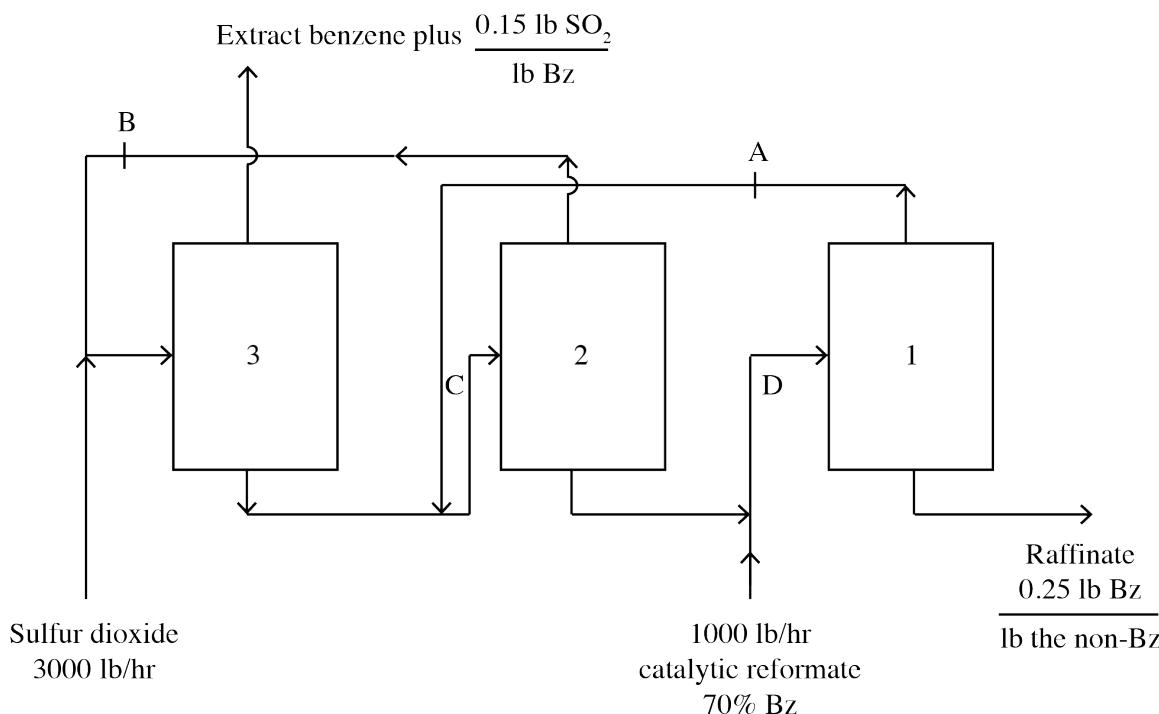
PROBLEM 1 (35%)

A company burns an intermediate product gas having the composition 4.3% CO₂, 27% CO, 10% H₂, 1.0% CH₄, and the residual N₂ together with a waste oil having the composition 87% C, 13% H₂. Analysis of the stack gas gives an Orsat analysis of 14.6% CO₂, 0.76% CO, and 7.65 O₂ and the rest N₂. Calculate the fraction of the total carbon burned that comes from the product gas.

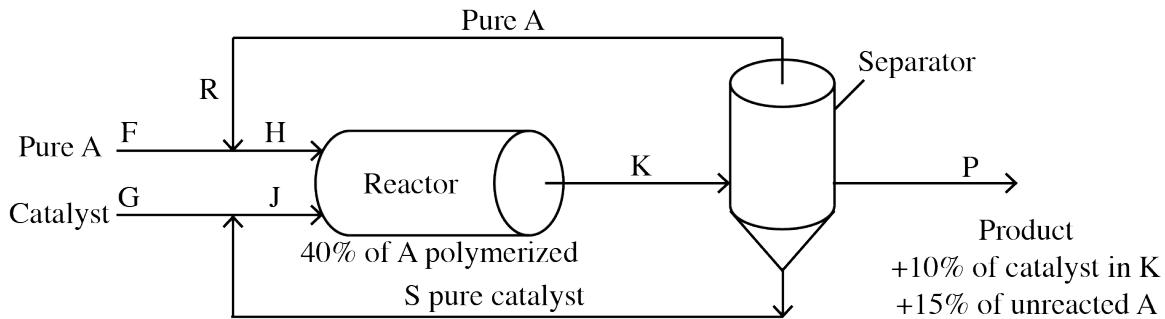
PROBLEM 2 (35%)

Benzene, toluene and other aromatic compounds can be recovered by solvent extraction with sulfur dioxide. As an example, a catalytic reformate stream containing 70% by weight benzene and 30% non-benzene material is passed through the counter-current extractive recovery scheme shown in the diagram below. One thousand pounds of the reformate stream and 3000 pounds of sulfur dioxide are fed to the system per hour. The benzene product stream (the extract) contains 0.15 pound of sulfur dioxide per pound of benzene. The raffinate stream contains all the initially charged non-benzene material as well as 0.25 pound of benzene per pound of the non-benzene material. The remaining component in the raffinate stream is the sulfur dioxide.

- (a) How many pounds of benzene are extracted per hour, i.e. are in the extract?
- (b) If 800 pounds of benzene containing in addition 0.25 pound of the non-benzene material per pound of benzene are flowing per hour at point A and 700 pounds of benzene containing 0.07 pound of the non-benzene material per pound of benzene are flowing at point B, how many pounds (exclusive of the sulfur dioxide) are flowing at points C and D?



PROBLEM 3 (30%)



Reactant A is polymerized as shown in the figure. It is mixed with fresh catalyst and recycled catalyst. Conversion of A is 40% on one pass through the reactor. Fresh catalyst (G) enters at the rate of 0.40 lb G per lb of A in stream H. The separator removes 90% of the catalyst and recycles it as well as recycling unreacted A. Nevertheless, the product stream P constraints 15% of the unreacted A and 10% of the catalyst exiting in stream K as well as the polymer product. Determine the ratio of stream R to G.

Note: catalyst does not react in the process!

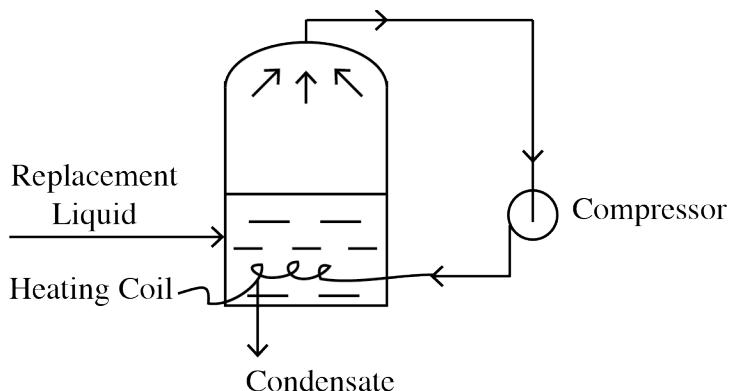
Exam No. 4
(Open Book, 2 hours)

PROBLEM 1 (25%)

In the vapor-recompression evaporator (not insulated) shown in the figure below, the vapors produced on evaporation are compressed to a higher pressure and passed through the heating coil to provide the energy for evaporation. The steam entering the compressor is 98% quality at 10 psia, the steam leaving the compressor is at 50 psia and 400°F, and 6 Btu of heat are lost from the compressor per pound of steam throughput. The condensate leaving the heating coil is at 50 psia, 200°F. The replacement liquid is at the temperature of the liquid inside the evaporator.

Computer:

- the work in Btu needed for compression per pound of H₂O going through the compressor.
- the Btu of heat transferred from the heating coil to the liquid in the evaporator per pound of H₂O through the coil.
- Bonus of 5 points for correct answer to the question: What is the total heat gained or lost by the entire system?



PROBLEM 2 (25%)

An insulated, sealed tank that is 2 ft³ in volume holds 8 lb of water at 100°F. A 1/4 hp stirrer mixes the water for 1 hour. What is the fraction vapor at the end of the hour? Assume all the energy from the motor enters the tank.

For this problem you do not have to get a numerical solution. Instead list the following in this order:

- State what the system you select is.
- Specify open or closed.
- Draw a picture.
- Put all the known or calculated data on the picture in the proper place.
- Write down the energy balance (use the symbols in the text) and simplify it as much as possible. List each assumption in so doing.
- Calculate W.

7. Lists the equations with data introduced that you would use to solve the problem.
 8. Explain step by step how to solve the problem (but do not do so).

PROBLEM 3 (15%)

What is the enthalpy change in Btu when 1 pound mole of air is cooled from 600°F to 100°F at atmospheric pressure.

Compute your answer by two ways:

- 1) Use the tables of the combustion gases.
- 2) Use the heat capacity equation for air.

PROBLEM 4 (10%)

Answer the following questions by placing T for true and F for false on your answer page. Grading: +2 if correct, 0 if blank, -1 if wrong.

- (a) Heat and thermal energy are synonymous terms used to express one type of energy.
- (b) You can find the enthalpy change at constant pressure of a substance such as CO₂ from the solid to the gaseous state by integrating

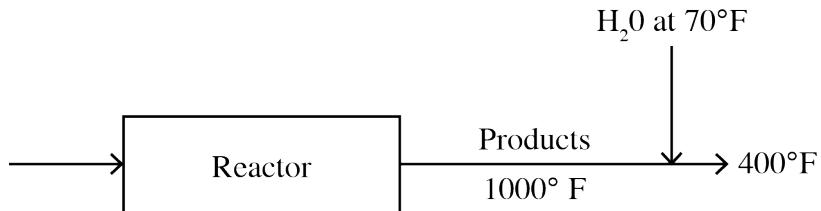
	$\int_{T_1}^{T_2} C_p dT$	from T ₁ (solid temperature) to T ₂ (gas temperature) for a constant pressure path.
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- (c) The enthalpy change of a substance can never be negative.
- (d) Heat and work are the only methods of energy transfer in a non-flow process.
- (e) Both Q and ΔH can be classed as state functions (variables)

PROBLEM 5 (25%)

Hot reaction products (assume they have the same properties as air) at 1000°F leave a reactor. In order to prevent further reaction, the process is designed to reduce the temperature of the products to 400°F by immediately spraying liquid water into the gas stream.

How many lb of water at 70°F are required per 100 lb of products leaving at 400°F?



For this problem you do not have to get a numerical solution. Instead list the following in this order.

1. State what the system you select is.
2. Specify open or closed.
3. Draw a picture.
4. Put all the known or calculated data on the picture in the proper places.
5. Write down the material and energy balances (use the symbols in the text) and simplify them as much as possible, list each assumption in so doing.
6. Insert the known data into the simplified equation(s) you would use to solve the problem.

Exam No. 5
(Open Book, 2 hours)

PROBLEM 1 (10%)

Answer the following questions briefly (no more than 3 sentences);

- a. Does the addition of an inert dilutent to the reactants entering an exothermic process increase, decrease, or make no change in the heat transfer to or from the process?
- b. If the reaction in a process is incomplete, what is the effect on the value of the standard heat of reaction? Does it go up, down, or remain the same?
- c. How many properties are needed to fix the state of a gas so that all of the other properties can be determined?
- d. Consider the reaction $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$.

Is the heat of reaction with the reactants entering and the products leaving at 500K higher, lower, or the same as the standard heat of reaction?

PROBLEM 2 (10%)

Explain how you would calculate the adiabatic reaction temperature for Problem 5 below if the outlet temperature is not specified. List each step. (You can cite some of the steps listed in Problem 5 if you list them by number in Problem 5.)

PROBLEM 3 (20%)

A flue gas at 750°F and 1 atm of composition 14.0% CO₂, 1.0% CO, 6.4% O₂, and the balance N₂ is the product of combustion with excess air at 750°F and 1 atm that is used to burn coke (C).

- a. What is the volume in ft³ of the flue gas leaving the furnace per pound of carbon burned?
- b. What is the volume of air in ft³ entering the furnace per pound of C burned?

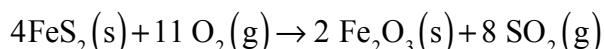
PROBLEM 4 (20%)

Seven pounds of N₂ are stored in a cylinder 0.75 ft³ volume at 120°F. Calculate the pressure in the cylinder in atmospheres:

- a. Assuming N₂ to be an ideal gas.
- b. Assuming N₂ is a real gas and using compressibility factors.

PROBLEM 5 (40% — one half each for the material and energy balances)

Pyrites (FeS₂) is converted to sulfur dioxide (SO₂) gas according to the reaction



The air, which is 35% excess (based on the above reaction) for combustion, enters at 27°C, the ore at 18°C, and the products leave at 900K. Because of equipment degradation, unburned FeS₂ exits from the process. In one hour 8000 kg of pyrites are fed to the process, and 2000 kg of Fe₂O₃ are produced. What is the heat added or removed from the process?

Data: For FeS₂, $C_p = 44.77 + 5.590 \times 10^{-2} T$ where T is in Kelvin and C_p is in J/(g mol)(K).

For F₂O₃, $C_p = 103.4 + 6.71 \times 10^{-2} T$ with the same units.

Exam No. 6
(Open Book, 2 hours)

PROBLEM 1 (20%)

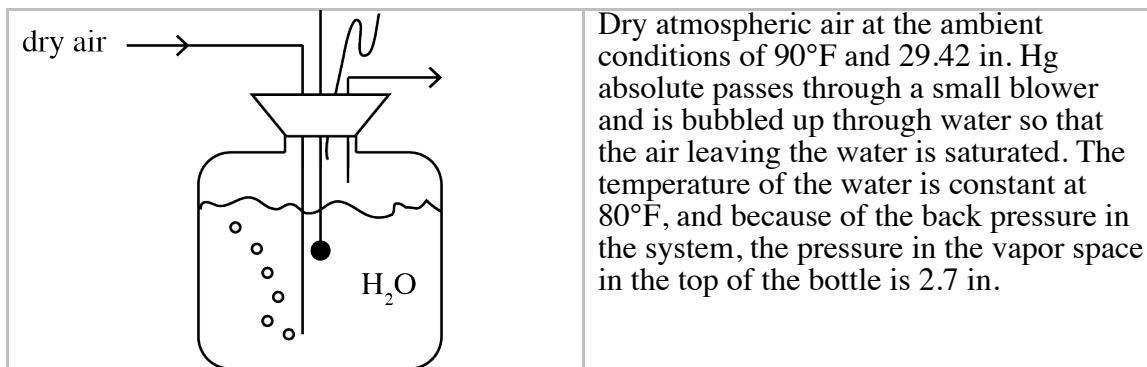
A high pressure line carries natural gas (all methane) at 10,000 kPa and 40°C. How would you calculate the volume of the gas under these conditions that is equivalent to 0.03 m³ of CH₄ at standard conditions using an equation of state? Select one equation other than van der Waal's equation, and list it on your solution page. Give a list of steps to complete the calculations. Include all the proper equations, and include a list of data involved, but you do not have to obtain a solution for the volume.

PROBLEM 2 (20%)

From the following data estimate the vapor pressure of sulfur dioxide at 100°C.

	Temperature (°C)	-10	6.3	32.1	55.5
	Vapor pressure (atm)	1	2	5	10

PROBLEM 3 (20%)



H₂O greater than atmospheric pressure. The bottle is weighted after the air is blown for 2 hours, 13 minutes, 47 seconds, and the decrease in weight was found to be 8.73 lb. What was the hourly rate of flow of air at ambient conditions in ft³?

PROBLEM 4 (20%)

A vessel with a volume of 2.83 m³ contains a mixture of nitrogen and acetone at 44.0°C and 100.0 kPa. The dew point of the mixture is 20.0°C and the relative saturation of the acetone in the mixture is 58.39%. The vapor pressure of acetone at 44.0°C is 65.35 kPa and it is 24.62 kPa at 20.0°C.

- What is the partial pressure of acetone vapor in the original mixture, in kPa?
- How many kg moles of acetone does the original mixture contain?
- If the nitrogen-acetone mixture is cooled with the volume remaining at 2.83 m³ constant so that 27.0 percent of the acetone condenses, what is the final temperature of the mixture in °C?

PROBLEM 5 (20%)

A wet sludge contains 50 percent water by weight. This sludge is first centrifuged, and 0.1 kilograms of water are removed per kilogram of wet sludge feed. The sludge is dried further using air so that the final product contains 10 percent by weight water. The air for drying is heated, passed into an oven drier, and vented back into the atmosphere. On a day when atmospheric pressure is 760mm Hg, the temperature is 70°F and the relative humidity is 50%, calculate the cubic meters of wet air required to dry one kilogram of sludge fed to the process. The air vented from the oven drier is at 100°F and 780mm Hg. It has a dew point of 94°F.

Solutions Chapter 2

2.1.1

- | | |
|-----|-------------------------------|
| (a) | N/mm or nm (nanometer) |
| (b) | $^{\circ}\text{C}/\text{M/s}$ |
| (c) | 100 kPa |
| (d) | 273.15 K |
| (e) | 1.50m, 45 kg |
| (f) | 250 $^{\circ}\text{C}$ |
| (g) | J/s |
| (h) | 250 N |

2.2.1

- a. Basis: 1 mi³

$$\frac{1 \text{ mi}^3}{1 \text{ mi}} \left| \begin{array}{l} (5280 \text{ ft}) \\ \hline 1 \text{ mi} \end{array} \right|^3 \left| \begin{array}{l} (12 \text{ in}) \\ \hline 1 \text{ ft} \end{array} \right|^3 \left| \begin{array}{l} (2.54 \text{ cm}) \\ \hline 1 \text{ in} \end{array} \right|^3 \left| \begin{array}{l} (1 \text{ m}) \\ \hline 100 \text{ cm} \end{array} \right|^3 = [4.17 \times 10^9 \text{ m}^3]$$

- b. Basis: 1 ft³/s

$$\frac{1 \text{ ft}^3}{1 \text{ s}} \left| \begin{array}{l} 60 \text{ s} \\ \hline 1 \text{ min} \end{array} \right| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} = [449 \text{ gal / min}]$$

2.2.2

a.

$$\frac{0.04 \text{ g}}{(\text{min})(\text{m}^3)} \left| \begin{array}{l} 60 \text{ min} \\ \hline 1 \text{ hr} \end{array} \right| \left| \begin{array}{l} (12 \text{ in})^3 \\ \hline 1 \text{ ft}^3 \end{array} \right| \frac{1 \text{ lb}_m}{454 \text{ g}} = [9.14 \frac{\text{lb}_m}{(\text{hr})(\text{ft}^3)}]$$

b.

$$\frac{2 \text{ L}}{\text{s}} \left| \begin{array}{l} 3600 \text{ s} \\ \hline 1 \text{ hr} \end{array} \right| \left| \begin{array}{l} 24 \text{ hr} \\ \hline 1 \text{ day} \end{array} \right| \frac{1 \text{ ft}^3}{28.32 \text{ L}} = [6.1 \times 10^3 \frac{\text{ft}^3}{\text{day}}]$$

c.

$$\frac{6 \text{ (in.)(cm}^2\text{)}}{(\text{yr})(\text{s})(\text{lb}_m)(\text{ft}^2)} \left| \begin{array}{l} 1 \text{ ft}^2 \\ \hline (12 \text{ in})^2 \end{array} \right| \frac{(1 \text{ in})^2}{(2.54 \text{ cm})^2} \left| \begin{array}{l} 1 \text{ yr} \\ \hline 365 \text{ days} \end{array} \right| \left| \begin{array}{l} 1 \text{ day} \\ \hline 24 \text{ hr} \end{array} \right| \left| \begin{array}{l} 1 \text{ hr} \\ \hline 3600 \text{ s} \end{array} \right| \frac{2.2 \text{ lb}_m}{1 \text{ kg}}$$

$$\frac{1 \text{ ft}}{12 \text{ in}} \left| \begin{array}{l} 0.3048 \text{ m} \\ \hline 1 \text{ ft} \end{array} \right| = [1.14 \times 10^{-11} \frac{\text{m}}{(\text{kg})(\text{s}^2)}]$$

Solutions Chapter 2

2.2.3 a. Basis: 60.0 mile/hr

$$\frac{60.0 \text{ mile}}{\text{hr}} \left| \begin{array}{c} 5280 \text{ ft} \\ 1 \text{ mile} \end{array} \right| \frac{1 \text{ hr}}{3600 \text{ sec}} = \boxed{88 \frac{\text{ft}}{\text{sec}}}$$

b. Basis: $50.0 \text{ lb}_m/(\text{in})^2$

$$\frac{50.0/\text{lb}_m}{(\text{in})^2} \left| \begin{array}{c} 454 \text{ g} \\ 1 \text{ lb} \end{array} \right| \frac{1 \text{ kg}}{1000 \text{ g}} \left| \begin{array}{c} 1(\text{in})^2 \\ (2.54 \text{ cm})^2 \end{array} \right| \frac{(100 \text{ cm})^2}{(1 \text{ m})^2} = \boxed{3.52 \times 10^4 \frac{\text{kg}}{\text{m}^2}}$$

c. Basis: $6.20 \text{ cm}/(\text{hr})^2$

$$\frac{6.20 \text{ cm}}{(\text{hr})^2} \left| \begin{array}{c} 1 \text{ m} \\ 100 \text{ cm} \end{array} \right| \frac{10^9 \text{ nm}}{1 \text{ m}} \left| \begin{array}{c} 1(\text{hr})^2 \\ (3600 \text{ sec})^2 \end{array} \right| = \boxed{4.79 \frac{\text{nm}}{\text{sec}^2}}$$

2.2.4

$$\frac{20 \text{ hp}}{1 \text{ hp}} \left| \begin{array}{c} 0.7457 \text{ kW} \end{array} \right| = 14.91 \text{ kW}$$

No, not enough power even at 100% efficiency; $68 \text{ kW} = 91.2 \text{ hp}$.

2.2.5

$$\frac{1 \text{ hr}}{525 \text{ mile}} \left| \begin{array}{c} 2200 \text{ gal} \\ 1 \text{ hr} \end{array} \right| \frac{1000 \text{ mile}}{} = \boxed{4190.5 \text{ gal}}$$

$$\frac{1 \text{ hr}}{475 \text{ mile}} \left| \begin{array}{c} 2000 \text{ gal} \\ 1 \text{ hr} \end{array} \right| \frac{1000 \text{ mile}}{} = \boxed{\frac{4210 \text{ gal}}{(20 \text{ gal})}}$$

None: 20 gal more are needed.

2.2.6

Let t_A be the time for A to paint one house; t_B for B
 A does a house in 5 hours, or 1 house/5 hr. B does one house
 in 3 hours, or 1 house/3 hr.

$$\frac{1 \text{ house}}{5 \text{ hr}} \left| \begin{array}{c} t_A \text{ hr} \\ 1 \text{ house} \end{array} \right| + \frac{1 \text{ house}}{3 \text{ hr}} \left| \begin{array}{c} t_B \text{ hr} \end{array} \right| = 1 \text{ house}$$

Also $t_A = t_B$ so that $\frac{3}{15} t_A + \frac{5}{15} t_A = 1$ or $\frac{8}{15} t_A = 1$

$$t_A = \frac{15}{8} \text{ hr} = t_B = 1.875 \text{ hr} \text{ or } \boxed{112.5 \text{ min}}$$

Solutions Chapter 2

- 2.2.7** (a) mass, because masses are balanced
 (b) weight, because the force exerted on the mass pushes a spring

2.2.8

$$\frac{20.0g}{(m)(s)} \left| \frac{1 \text{ lb}_m}{453.6 \text{ g}} \right| \left| \frac{0.3048\text{m}}{1 \text{ ft}} \right| \left| \frac{3600\text{s}}{1 \text{ hr}} \right| \left| \frac{1 (\text{lb}_f)(\text{s}^2)}{32.174(\text{lb}_m)(\text{ft})} \right| \left| \frac{1(\text{hr})^2}{(3600)^2\text{s}^2} \right|$$

$$= \boxed{1.16 \times 10^{-7} \frac{(\text{lb}_f)(\text{hr})}{\text{ft}^2}}$$

2.2.9

$$\frac{1.0 \text{ Btu}}{(\text{hr})(\text{ft}^2) \left(\frac{\text{°F}}{\text{ft}} \right)} \left| \frac{24 \text{ hrs}}{1 \text{ day}} \right| \left| \frac{1 \text{ ft}^2}{(12 \text{ in})^2} \right| \left| \frac{1 \text{ in}^2}{(2.54 \text{ cm}^2)} \right| \left| \frac{(100 \text{ cm})^2}{1 \text{ m}^2} \right| \left| \frac{1.8 \text{ °F}}{1 \text{ °C}} \right| \left| \frac{2.54 \text{ cm}}{\text{in}} \right|$$

$$\frac{252 \text{ cal}}{1 \text{ Btu}} \left| \frac{12 \text{ in}}{1 \text{ ft}} \right| \left| \frac{4.184 \text{ J}}{1 \text{ cal}} \right| \left| \frac{1 \text{ kJ}}{1000 \text{ J}} \right| = 1.49 \times 10^4 \frac{\text{kJ}}{(\text{day})(\text{m}^2)(\text{°C}/\text{cm})}$$

- 2.2.10** Basis: 1 lb H₂O

a. $\text{KE} = \frac{1}{2} \text{mv}^2 = \frac{1}{2} \left| \frac{1 \text{ lb}_m}{2} \right| \left| \left(\frac{3 \text{ ft}}{\text{s}} \right)^3 \right| \left| \frac{(\text{s}^2)(\text{lb}_f)}{32.174(\text{ft})(\text{lb}_m)} \right| = 0.14(\text{ft})(\text{lb}_f)$

b. Let A = area of the pipe and v = water velocity. The flow rate is

$$q = Av = \left(\frac{\pi D^2}{4} \right) (v)$$

$$\frac{\pi}{4} \left| \frac{(2 \text{ in})^2}{(12 \text{ in})^2} \right| \left| \frac{(1 \text{ ft})^2}{\text{S}} \right| \left| \frac{3 \text{ ft}}{1 \text{ min}} \right| \left| \frac{60 \text{ s}}{1 \text{ min}} \right| \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| = \boxed{29.37 \text{ gal/min}}$$

2.2.11

$$\text{PE} = \frac{75 \text{ gal}}{\text{min}} \left| \frac{8.33 \text{ lb}_m}{\text{gal}} \right| \left| \frac{32.2 \text{ ft}}{\text{sec}^2} \right| \left| \frac{100}{\text{ft}} \right| \left| \frac{60 \text{ s}}{\text{hr}} \right| \left| \frac{\text{s}^2 \cdot \text{lb}_f}{32.2 \text{ lb}_m \cdot \text{ft}} \right| \left| \frac{\text{Btu}}{778 \text{ ft-lb}_f} \right| = 4818 \text{ Btu/hr}$$

$$\text{Pump Work} = \frac{2 \text{ hp}}{\text{hp-hr}} \left| \frac{2545 \text{ Btu}}{\text{hp-hr}} \right| = 5090 \text{ Btu/hr}$$

Rate of energy input for heating = PW - PE = 5090 - 4818 = 272 Btu/hr

Solutions Chapter 2

2.2.12 The object has a mass of 21.3 kg (within a precision of $\pm .1$ kg). The weight is the force used to support the mass.

2.2.13 In American Engineering System

$$\text{Power} = FV$$

$$= \frac{800 \text{ lb}_f}{1} \left| \frac{300 \text{ ft}}{\text{min}} \right| = \boxed{2.4 \times 10^5 \frac{(\text{lb}_f)(\text{ft})}{\text{min}}} \text{ or } 7.27 \text{ hp}$$

In SI

$$\begin{aligned} \text{Power} &= \frac{4000 \text{ N}}{1} \left| \frac{1.5 \text{ m}}{\text{s}} \right| \left| \frac{1 \text{ (watt)(s)}}{1(\text{N})(\text{m})} \right| \\ &= \boxed{6000 \text{ watts}} \end{aligned}$$

2.2.14

$$\begin{aligned} \text{KE} &= \frac{1}{2} m v^2 \\ &= \end{aligned}$$

$$\frac{1}{2} \left| \frac{2300 \text{ kg}}{0.454 \text{ kg}} \right| \left| \frac{1 \text{ lb}_m}{\text{kg}} \right| \left| \left(\frac{10.0 \text{ ft}}{\text{s}} \right)^2 \right| \left| \frac{1}{32.2 \text{ lb}_m} \right| \left| \frac{1}{\text{ft}} \right| \left| \frac{1 \text{ Btu}}{778.2(\text{ft})(\text{lb}_f)} \right| \left| \frac{1}{\text{sec}^2} \right|$$

$$= \boxed{10.11 \text{ Btu}}$$

2.2.15 Basis: 10 tons at 6 ft/s

$$\text{KE} = \frac{1}{2} m v^2 = \frac{1}{2} \left| \frac{20,000 \text{ lb}_m}{2} \right| \left| \left(\frac{6 \text{ ft}}{\text{s}} \right)^2 \right| \left| \frac{1(\text{s}^2)(\text{lb}_f)}{32.2(\text{ft})(\text{lb}_m)} \right| = \boxed{11,200(\text{ft})(\text{lb}_f)}$$

2.2.16 Basis: 1 mRNA

$$\frac{1 \text{ nRNA}}{\text{nRNA}} \left| \frac{3x \text{ ribonucleotides}}{264 \text{ ribonucleotides}} \right| \frac{1 \text{ active ribosome}}{264 \text{ ribonucleotides}} \left| \frac{1200 \text{ amino acids}}{\text{min-active ribosome}} \right| \frac{\text{protein}}{x \text{ amino acids}} =$$

13.6 protein molecules formed per min per nRNA

Solutions Chapter 2

2.3.1

- a₁. A is in g/cm³
 a₂. B is in g/(cm³)(°C)
 a₃. Since the exponent of e must be dimensionless
 C is in atm⁻¹

$$b_1 \quad A = \frac{1.096 \text{ g}}{\text{cm}^3} \left| \frac{(30.48)^3 \text{ cm}^3}{\text{ft}^3} \right| \frac{1 \text{ lb}_m}{454 \text{ g}} = \boxed{68.4 \frac{\text{lb}_m}{\text{ft}^3}}$$

$$b_2 \quad B = \frac{0.00086 \text{ g}}{(\text{cm}^3)(^\circ\text{C})} \left| \frac{(30.48)^3 \text{ cm}^3}{\text{ft}^3} \right| \frac{1 \text{ lbm}}{454 \text{ g}} \left| \frac{1^\circ\text{C}}{1.8^\circ\text{R}} \right| = \boxed{0.0298 \frac{\text{lb}_m}{(\text{ft}^3)(^\circ\text{R})}}$$

$$b_3 \quad C = \frac{0.000953}{\text{atm}} \left| \frac{1 \text{ atm}}{14.7 \text{ lb}_f/\text{in}^2} \right| = \boxed{0.0000648 \frac{1}{\text{lb}_f/\text{in}^2}}$$

2.3.2

Introduce the units. The net units are the same on both sides of the equation.

$$(\text{ft})(\text{ft})^{1.5} \left(\frac{\text{ft}}{\text{s}^2} \right)^{1/2} = \frac{\text{ft}^3}{\text{s}}$$

2.3.3

$$\text{No. } q = 0.6(2\text{m}^2) \left[\frac{(2)}{\text{s}^2} \left| \frac{9.8\text{m}}{\text{s}^2} \right| \frac{10^3 \text{ m}}{\text{kg}} \left| \frac{50 \times 10^3 (\text{kg})(\text{m})}{(\text{s}^2)(\text{m}^2)} \right| \frac{1}{1 - \left(\frac{2}{5} \right)^2} \right]^{1/2}$$

The net units on the right hand side of the equation are

$$\text{m}^2 \left[\frac{\text{m}^3}{\text{s}^4} \right]^{1/2} \neq \frac{\text{m}^3}{\text{s}}$$

Consequently, the formula will not yield 80.8 m³/s, presumably in the formula the g should be g_c for use in the AE system.

Solutions Chapter 2

2.3.4

$$Q = 0.61S \sqrt{(2\Delta p)/\rho} \quad \text{assume hole is open to atmosphere}$$

$$\Delta p = \frac{144 \text{ in}^2}{1 \text{ ft}^2} \left[\frac{23 \text{ lb}_f}{\text{in}^2} + \frac{73 \text{ in gas.}}{0.703 \text{ H}_2\text{O}} \right] \left[\frac{0.703 \text{ H}_2\text{O}}{1 \text{ gas}} \right] \left[\frac{1 \text{ ft}}{12 \text{ in}} \right] \left[\frac{14.7 \frac{\text{lb}_f}{\text{in}^2}}{33.91 \text{ ft H}_2\text{O}} \right]$$

$$= 3,579 \text{ lb}_f/\text{ft}^2$$

$$\rho = \frac{0.703 \frac{\text{lb}}{\text{ft}^3}}{1 \text{ lb}/\text{ft}^3 \text{H}_2\text{O}} \left[\frac{62.4 \frac{\text{lbH}_2\text{O}}{\text{ft}^3 \text{H}_2\text{O}}}{= 43.87 \frac{\text{lb}_m}{\text{ft}^3}} \right]$$

$$S = \pi \left(\frac{1}{(4)12} \right)^2 = 3.41 \times 10^{-4} \text{ ft}^2$$

$$Q = (3600)(0.61)(3.41 \times 10^{-4}) \sqrt{(2)(3579)g_c / 43.87} = \boxed{54 \frac{\text{ft}^3}{\text{hr}}}$$

Solutions Chapter 2

2.3.5 a. $Z = 1 + \rho B + \rho^2 C + \rho^3 D$

	Units
B	$\text{cm}^3 / \text{g mol}$
C	$(\text{cm}^3 / \text{g mol})^2$
D	$(\text{cm}^3 / \text{g mol})^3$

b. $Z = 1 + \rho^* B^* + (\rho^*)^2 C^* + (\rho^*)^3 D^*$

	Units
B^*	$\text{ft}^3 / \text{lb}_m$
C^*	$(\text{ft}^3 / \text{lb}_m)^2$
D^*	$(\text{ft}^3 / \text{lb}_m)^3$

If B is the original coefficient, B^* is obtained by multiplying B by conversion factors.
Let MW is the molecular weight of the compound.

$$B^* \frac{\text{ft}^3}{\text{lb}_m} = \frac{B \text{ cm}^3}{\text{g mol}} \left| \left(\frac{1 \text{ ft}}{30.48 \text{ cm}} \right)^3 \right| \left| \frac{1 \text{ g mol}}{\text{MW g}} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}_m} \right| = \boxed{B \frac{0.016}{\text{MW}}}$$

$$C^* \left(\frac{\text{ft}^3}{\text{lb}_m} \right)^2 = C \left(\frac{\text{cm}^3}{\text{g mol}} \right)^2 \left| \left(\frac{1 \text{ ft}}{30.48 \text{ cm}} \right)^6 \right| \left| \left(\frac{1 \text{ g mol}}{\text{MW g}} \right)^2 \right| \left| \left(\frac{454 \text{ g}}{1 \text{ lb}_m} \right)^2 \right| = \boxed{C \frac{2.57 \times 10^{-4}}{\text{MW}^2}}$$

$$D^* \left(\frac{\text{ft}^3}{\text{lb}_m} \right)^3 = \boxed{D \frac{4.096 \times 10^{-6}}{\text{MW}^3}}$$

Solutions Chapter 2

2.3.6

$$u \left[\frac{m}{s} \right] = k[1] \left[\left(\frac{\tau}{\rho} \right)^{1/2} \left(\frac{N}{m^2} \right)^{1/2} \left(\frac{m^3}{kg} \right)^{1/2} \right]$$

To get u in ft/s, substitute for τ and for ρ , and multiply both sides of the equation by 3.281 ft/1 m (k is dimensionless).

$$\tau \frac{N}{m^2} = \frac{\tau' lb_f}{ft^2} \left| \left(\frac{3.281 \text{ ft}}{1 \text{ m}} \right)^2 \right| \frac{1 \text{ N}}{0.2248 \text{ lb}_f}$$

$$\rho \frac{kg}{m^3} = \frac{\rho' lb_m}{ft^3} \left| \left(\frac{3.281 \text{ ft}}{1 \text{ m}} \right)^3 \right| \frac{1 \text{ kg}}{0.454 \text{ lb}_m}$$

$$u' = 2.57 k \left(\frac{\tau'}{\rho'} \right)$$

2.3.7

Place units for the symbols in the given equation, and equate the units on the left and right hand sides of the equation by assigning appropriate units to the coefficient 0.943.

LHS RHS

$$\frac{Btu}{(hr)(ft^2)(\Delta^\circ F)}^2 \left[\left(\frac{Btu}{(hr)(ft)(\Delta^\circ F)} \right)^3 \left(\frac{lb_m}{ft^3} \right)^2 \left| \frac{ft}{(hr)^2} \right| \frac{Btu}{lb_m} \left| \frac{(hr)(ft)}{lb_m} \right| \frac{1}{\Delta^\circ F} \right]^4$$

The units are the same on the right and left so that 0.943 has no units associated with it.

2.3.8

$$\eta = \frac{\text{numerator}}{\text{denominator}}$$

$$\text{Numerator} = Y_{x/s}^c \gamma_b \Delta H_{b/e^-}^c$$

$$= \left(\frac{\text{mol cell C}}{\text{mole substrate C}} \right) \left(\frac{e^- \text{ equiv.}}{\text{mol cell C}} \right) \left(\frac{\text{energy}}{\text{mol } e^- \text{ equiv.}} \right)$$

$$= \frac{\text{energy}}{\text{mol substrate C}} \quad (1)$$

Solutions Chapter 2

$$\text{Denominator} = \Delta H_{\text{cat}}^c$$

$$= \frac{\text{energy}}{\text{mol substrate C}} \quad (2)$$

$$\eta = \frac{(1)}{(2)} = \frac{\text{energy}}{\text{energy}}$$

There is no missing conversion factor
What the author claimed about the units is correct.

2.3.9

For dimensional consistency:
B – absolute temperature in either °R or K
C – absolute temperature in either °R or K
A – dimensionless

In most cases the argument of a logarithm function should be dimensionless, but in this case it will not be. Therefore, the numerical values of A, B, and C will depend upon the units used for temperature and the units used for p^* .

2.3.10

The equation is

$$\Delta p = 4fp \left[\left(v^2 / 2g \right) (L/D) \right]$$

The units on the right hand side (with f dimensionless) in SI are

$$\frac{\rho \frac{\text{kg}}{\text{m}^3}}{} \left| \begin{array}{c} \frac{\text{m}^2}{\text{s}^2} \\ \frac{(\text{kg})(\text{m})}{\text{s}^2} \end{array} \right| \frac{\text{m}}{\text{m}} \rightarrow \frac{1}{\text{m}^2}$$

hence the equation is not dimensionally consistent because Δp has the units of N/m². If g is replaced with g, the units would be correct.

2.4.1

Two because any numbers added to the right hand side of the decimal point in 10 are irrelevant.

2.4.2

The sum is 1287.1430. Because 1234 has only 4 significant figures to the left of an implied decimal point, the answer should be 1287 (no decimal point).

Solutions Chapter 2

2.4.3 The number of significant figures to the right of the decimal point is 1 (from 210.0m), hence the sum of 215.110 m should be rounded to 215.1 m.

2.4.4 A calculator gives 569.8269 000, but you should truncate to 4 significant figures, or 569.8 cm².

2.4.5 Two significant figures (based on 6.3). Use 4.8×10^3 .

2.4.6 Step 1: The product 1.3824 is rounded off to 1.4

Step 2: Calculate errors.

For absolute error, the product 1.4 means 1.4 ± 0.05

Thus $\frac{0.05}{1.4} \times 100\% = 3.6\% \text{ error}$

Similarly 3.84 has $\frac{0.005}{3.84} \times 100\% = 0.13\% \text{ error}$

and 0.36 has $\frac{0.005}{0.36} \times 100\% = 1.4\% \text{ error}$

Total 2.7% error

2.6.1 a) $\frac{4 \text{ g mol mg Cl}_2}{\text{gmol MgCl}_2} \left| \frac{(95.23)\text{g MgCl}_2}{\text{gmol MgCl}_2} \right. = 380.9 \text{ g}$

b) $\frac{2 \text{ lb mol C}_3\text{H}_8}{\text{lb mol C}_3\text{H}_8} \left| \frac{(44.09)\text{lb C}_3\text{H}_8}{\text{lb mol C}_3\text{H}_8} \right. \left| \frac{454\text{g C}_3\text{H}_8}{1 \text{ lb C}_3\text{H}_8} \right. = 4 \times 10^4 \text{ g C}_3\text{H}_8$

c) $\frac{16 \text{ g N}_2}{(28.02)\text{g N}_2} \left| \frac{\text{gmol N}_2}{\text{gmol N}_2} \right. \left| \frac{1 \text{ lb mol N}_2}{454 \text{ gmol N}_2} \right. = [1.26 \times 10^{-3} \text{ lb mol N}_2]$

(d) $\frac{3 \text{ lb C}_2\text{H}_6\text{O}}{(46.07) \text{ lb C}_2\text{H}_6\text{O}} \left| \frac{1 \text{ lb mol C}_2\text{H}_6\text{O}}{1 \text{ lb mol C}_2\text{H}_6\text{O}} \right. \left| \frac{454 \text{ g mol}}{1 \text{ lb mol}} \right. = [29.56 \text{ g mol C}_2\text{H}_6\text{O}]$

Solutions Chapter 2

2.6.2

$$(a) \frac{16.1 \text{ lb mol HCl}}{1 \text{ lb mol HCl}} \left| \frac{36.5 \text{ lb HCl}}{1 \text{ lb mol HCl}} \right| = \boxed{588 \text{ lb HCl}}$$

$$(b) \frac{19.4 \text{ lb mol KCl}}{1 \text{ lb mol KCl}} \left| \frac{74.55 \text{ lb KCl}}{1 \text{ lb mol KCl}} \right| = \boxed{1466 \text{ lb KCl}}$$

$$(c) \frac{11.9 \text{ g mol NaNO}_3}{1 \text{ g mol NaNO}_3} \left| \frac{85 \text{ g NaNO}_3}{1 \text{ g mol NaNO}_3} \right| \left| \frac{2.20 \times 10^{-3} \text{ lb}}{1 \text{ g}} \right| = \boxed{2.23 \text{ lb NaNO}_3}$$

$$(d) \frac{164 \text{ g mol SiO}_2}{1 \text{ g mol SiO}_2} \left| \frac{60.1 \text{ g SiO}_2}{1 \text{ g mol SiO}_2} \right| \left| \frac{2.20 \times 10^{-3} \text{ lb}}{1 \text{ g}} \right| = \boxed{21.7 \text{ lb SiO}_2}$$

2.6.3

Basis: 100 g of the compound

<u>comp.</u>	<u>g</u>	<u>MW</u>	<u>g/mol</u>	<u>Ratio of Atoms</u>
C	42.11	12	3.51	1.09
O	51.46	16	3.22	1
H	6.43	1.008	6.38 13.11	2

Multiply by 11 to convert the ratios into integers

The formula becomes $\text{C}_{12}\text{O}_{11}\text{H}_{22}$

Checking MW: $12(12) + 11(16) + 22(1.008) = 342$ (close enough)

Solutions Chapter 2

2.6.4 Vitamin A, C₂₀O H₃₀, Mol Wt.: 286 Vitamin C, C₆H₈O₆, mol. wt: 176

Vitamin A:

$$\text{a. } \text{Vitamin A} = \frac{2.00 \text{ g mol}}{1 \text{ g mol}} \left| \frac{286 \text{ g}}{454 \text{ g}} \right| \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| = [1.26 \text{ lb}]$$

$$\frac{16 \text{ g}}{454 \text{ g}} \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| = 0.0352 \text{ lb}$$

$$\text{Vitamin C} = \frac{2.00 \text{ g mol}}{\text{g mol}} \left| \frac{176 \text{ g}}{454 \text{ g}} \right| \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| = [0.775 \text{ lb}]$$

$$\frac{16 \text{ g}}{454 \text{ g}} \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| = [0.0352 \text{ lb}]$$

$$\text{b. } \text{Vitamin A} = \frac{1.00 \text{ lb mol}}{1 \text{ lb mol}} \left| \frac{286 \text{ lb}}{454 \text{ g}} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| = [130,000 \text{ g}]$$

$$\text{Vitamin C} = \frac{1.00 \text{ lb mol}}{1 \text{ lb mol}} \left| \frac{176 \text{ lb}}{454 \text{ g}} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| = [79,900 \text{ g}]$$

$$\text{For both } \frac{12 \text{ lb}}{1 \text{ lb}} \left| \frac{454 \text{ g}}{454 \text{ g}} \right| = [5450 \text{ g}]$$

2.6.5 $\frac{1 \text{ kg}}{5.2 \text{ m}^3} \left| \frac{1160 \text{ m}^3}{\text{kg mol}} \right| = 223.1 \text{ kg/kg mol}$

2.6.6 Mass fraction to mole fraction:

$$x_1 = \frac{\frac{\omega_1}{\text{MW}_1}}{\frac{\omega_1}{\text{MW}_1} + \frac{(1-\omega_1)}{\text{MW}_2}}$$

Mole fraction to mass fraction

$$\omega_1 = \frac{x_1 \text{MW}_1}{(x_1)(\text{MW}_1) + (1-x_1)(\text{MW}_2)}$$

Solutions Chapter 2

2.6.7 Basis: 100 kg mol gas

Comp.	Mol % = mol	MW	kg
CH ₄	30	16	480
H ₂	10	2	20
N ₂	60	28	1680
Total	100		2180

$$\boxed{\frac{21.8 \text{ kg}}{\text{kg mol}}}$$

2.6.8 Basis: 100 g mol gas

Comp.	mol = %	MW	g
CO ₂	19.3	44	849.2
N ₂	72.1	28	2018.8
O ₂	6.5	32	208.0
H ₂ O	2.1	18	37.8
	100.0		3113.8

$$\text{Avg. mol. wt} = \frac{3113.8}{100.0} = \boxed{31.138}$$

2.6.9 Basis: 100 lb mol

Comp.	% = mol	MW	lb
CO ₂	16	44	2640
CO	10	28	280
N ₂	30	28	840
			3760

$$\text{Avg. MW} = 37.6 \text{ lb/lb mol}$$

- 2.7.1**
- (a) A gas requires a convenient basis of 1 or 100 g moles or kg moles (if use SI units).
 - (b) A gas requires a convenient basis of 1 or 100 lb moles (if use AE units).
 - (c) Use 1 or 100 kg of coal, or 1 or 100 lb of coal because the coal is a solid and mass is a convenient basis.
 - (d) Use 1 or 100 moles (SI or AE) as a convenient basis as you have a gas.
 - (e) Same answer as (e).

Solutions Chapter 2

2.7.2 Since the mixture is a gas, use 1 or 100 moles (SI or AE) as the basis.

2.7.3 Pick one day as a basis that is equivalent to what is given—two numbers:

(a) 134.2 lb C1 (b) 10.7×10^6 gal water.

2.8.1 Basis: 1000 lb oil

$$\frac{0.926 \frac{\text{lb oil}}{\text{ft}^3}}{1.00 \frac{\text{lb H}_2\text{O}}{\text{ft}^3}} \left| \frac{62.4 \frac{\text{lb H}_2\text{O}}{\text{ft}^3}}{} \right| = 57.78 \frac{\text{lb oil}}{\text{ft}^3 \text{ oil}}$$

$$\frac{1000 \text{ lb oil}}{57.78 \text{ lb oil}} \left| \frac{1 \text{ ft}^3 \text{ oil}}{} \right| \left| \frac{7.48 \text{ gal}}{1 \text{ ft}^3} \right| = 129.5 \text{ gal}$$

2.8.2 Basis: 10,010 lb

$$\frac{10,010 \text{ lb}}{8.80 \text{ lb}} \left| \frac{1 \text{ gal}}{} \right| \left| \frac{0.134 \text{ ft}^3}{\text{gal}} \right| = 152 \text{ ft}^3$$

2.8.3 Basis: 1 g mol each compound

	<u>g mol</u>	<u>mw</u>	<u>g</u>	<u>ρ (g/cm³)</u>	<u>V (cm³)</u>
Pb	1	207.21	207.21	11.33	18.3
Zn	1	65.38	65.38	7.14	9.16
C	1	12.01	12.01	2.26	5.31

$$\hat{V} = \frac{\text{mass (g)}}{\text{density (g/cm}^3)}$$

Set 2 is the correct one

2.9.1	<u>Component</u>	<u>g mol</u>	<u>mol fraction</u>	<u>MW</u>	<u>g</u>	<u>mass fraction</u>
	Na	1	0.20	23	23	0.22
	C1	1	0.20	35.45	35.45	0.33
	O	3	0.60	16	48	0.45
		5			106.45	1.00

Solutions Chapter 2

2.9.2 Basis: 1 gal of solution.

Mass of solution:

$$\frac{1.0824 \text{ lb soln}}{\frac{\text{ft}^3 \text{ H}_2\text{O}}{1.00 \frac{\text{lb H}_2\text{O}}{\text{ft}^3 \text{H}_2\text{O}}}} \left| \begin{array}{c} 62.4 \frac{\text{lb H}_2\text{O}}{\text{ft}^3 \text{H}_2\text{O}} \\ \hline \end{array} \right| \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \left| \begin{array}{c} 1 \text{ gal} \\ \hline \end{array} \right| = 9.03 \text{ lb soln.}$$

$$\text{Mass fraction KOH} = \frac{0.813 \text{ lb}}{9.03 \text{ lb}} = 0.09$$

$$\text{Mass fraction H}_2\text{O} = 1 - 0.09 = \frac{0.91}{1.00 \text{ Total}}$$

2.9.3

Basis: 30 lb gas

Comp.	lb	MW	lb mol	mol fr.
CO ₂	20	44	0.455	0.56
N ₂	10	28	0.357	0.44
	30		0.812	1.00

2.9.4

a)

b)

c) Yes, because for solids and liquids the ratio in ppb is mass, whereas for gases the ratio is in moles.

Solutions Chapter 2

2.9.5 On a paper free basis the total ppm are:

Brand A: 6060 ppm Brand B: 405 ppm

The respective mass fractions are:

The other entries are similar

	Fe	Cu	Pb
Brand A:	$\frac{1310}{6060} = 0.216$	$\frac{2000}{6060} = 0.330$	
	$\frac{2750}{6060} = 0.454$		
Brand B:	$\frac{350}{405} = 0.864$	$\frac{50}{405} = 0.123$	
	$\frac{5}{405} = 0.0123$		

$$V_s = \frac{5 \text{ m}}{|30.2 \text{ m}|} \left| \frac{200 \text{ mm}}{|1000 \text{ mm}|} \right| \frac{1 \text{ m}}{|1000 \text{ mm}|} |2 \text{ sides}| = 60.4 \text{ m}^3$$

Ends

$$V_e = \frac{5 \text{ m}}{|27.2 \text{ m}|} \left| \frac{200 \text{ mm}}{|1000 \text{ mm}|} \right| \frac{1 \text{ m}}{|1000 \text{ mm}|} |2 \text{ ends}| = 54.4 \text{ m}^3$$

Solutions Chapter 2

Floor

$$V_f = \frac{27.4 \text{ m}}{|} \frac{30.4 \text{ m}}{|} \frac{200 \text{ mm}}{|} \frac{1 \text{ m}}{1000 \text{ mm}} = 166.592 \text{ m}^3$$

$$\text{Total volume} = 281.392 \text{ m}^3$$

$$\text{Mass of concrete} = \frac{281.392 \text{ m}^3}{|} \frac{2080 \text{ kg}}{\text{m}^3} = 585,295$$

Volume of displaced water required to float:

$$\frac{586,543.36 \text{ kg}}{|} \frac{1 \text{ m}^3 \text{ H}_2\text{O}}{1000 \text{ kg H}_2\text{O}} = 586.543 \text{ m}^3$$

$$V = LWh \rightarrow h = \frac{V}{LW}$$

$$h = \frac{586.54 \text{ m}^3}{|} \frac{|}{27.4 \text{ m}} \frac{|}{30.4 \text{ m}} = \boxed{0.703 \text{ m}}$$

2.9.6

Basis: 190,000 ppm

$$\frac{190,000 \text{ g PCB}}{10^6} \times 100 = 19\%$$

Solutions Chapter 2

2.9.7

Basis: 100 g of the sample

The biomass sample is

$$\underline{g = \% \text{ dry weight of cells}}$$

C	50.2
O	20.1
N	14.0
H	8.2
P	<u>3.0</u>
	95.5
other	<u>4.5</u>
Total	100.0

$$\frac{10.5 \text{ g cells}}{\text{g mol ATP}} \left| \frac{50.2 \text{ g C}}{100 \text{ g cells}} \right| \frac{1 \text{ g mol C}}{12 \text{ g C}} = 0.439 \text{ g mol C/g mol ATP}$$

2.9.8



a. $\frac{2 \times 10^7 \text{ disintegrations}}{\text{min}} \left| \frac{1 \text{ min}}{60} \right| \frac{1 \text{ curie}}{3 \times 10^{10} \text{ disintegrations/s}} \left| \frac{10^6 \mu \text{ curie}}{1 \text{ curie}} \right| = 11 \mu \text{ curie}$

b. $\frac{2 \times 10^7 \text{ disintegrations}}{\text{min}} \left| \frac{0.80}{\text{min}} \right| = \boxed{1.6 \times 10^7 \text{ cpm}}$

2.9.9

The relation to use is

$$t_{1/2} = \ln(2) / (k)(\text{OH}^-)$$

with $(\text{OH}^-) = 1.5 \times 10^6$

	<u>k</u>	<u>$t_{1/2} (\text{seconds})$</u>
Methanol	0.15×10^{-12}	30.8×10^5
Ethanol	1×10^{-12}	4.6×10^5
MTBE	0.60×10^{-12}	7.7×10^5

The order is in increasing persistence ethanol, MTBE, and methanol.

Solutions Chapter 2

2.9.10 Yes. Bases are first entries.

$$\frac{4800 \text{ g mol CC1}_4}{10^9 \text{ g mol air}} \left| \frac{10^3 \text{ g mol air}}{\text{kg mol air}} \right| \left| \frac{\text{kg mol air}}{22.8 \text{ m}^3} \right| \left| \frac{154 \text{ g CC1}_4}{\text{g mol CC1}_4} \right| \left| \frac{103 \text{ mg CC1}_4}{\text{g CC1}_4} \right| = \\ 32.4 \text{ mg CC1}_4/\text{m}^3 \text{ which exceeds the NIOSH standards}$$

2.9.11

a. $\frac{25,600 \text{ ton P}}{\text{yr}} \left| \frac{2.6 \text{ yr}}{1.2 \times 10^{14} \text{ gal}} \right| \left| \frac{1 \text{ gal}}{3.785 \text{ L}} \right| \left| \frac{2000 \text{ lb}}{1 \text{ ton}} \right| \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| \left| \frac{10^6 \mu \text{ g}}{1 \text{ g}} \right| = \\ 133.1 \mu \text{ g/L}$

b. $\frac{19,090 \text{ lb(P)municipal}}{30,100 \text{ lb(P)total}} = 63.4\%$

c. $\frac{19,090 \text{ lb(P)municipal}}{30,100 \text{ lb(P)total}} \left| \frac{0.70 \text{ lb(P)det.}}{1 \text{ lb(P)municipal}} \right| \left| \frac{100 \text{ lb(P)total}}{30,100 \text{ lb(P)total}} \right| = 44.4\%$

For d. and e. assume that (P)outflow remains unchanged.

d. P retained/yr = $2,240 + 6,740 + 0.7 \times 19,090 - 4,500 = 17,843 \text{ ton/yr}$.

P conc. in ppb =

$$\frac{17,843 \text{ ton}}{\text{yr}} \left| \frac{2.6 \text{ yr}}{1.2 \times 10^{14} \text{ gal}} \right| \left| \frac{2000 \text{ lb}}{\text{ton}} \right| \left| \frac{1 \text{ g / cm}^3}{8.345 \text{ lb/gal}} \right| \left| \frac{10^9 \text{ g}}{1 \text{ billion g}} \right| = 92.6 \text{ ppb}$$

This is greater than 10 ppb. Eutrophication will not be reduced.

e. P retained/yr = $2,240 + 6,740 + 0.3 \times 19,090 - 4,500 = 10,207 \frac{\text{ton}}{\text{yr}}$

P conc. in ppb =

$$\frac{10,207 \text{ ton}}{\text{yr}} \left| \frac{2.6 \text{ yr}}{1.2 \times 10^{14} \text{ gal}} \right| \left| \frac{2000 \text{ lb}}{\text{ton}} \right| \left| \frac{1 \text{ g / cc}}{8.345 \text{ lb/gal}} \right| \left| \frac{10^9 \text{ g}}{1 \text{ billion g}} \right| = 53.2 \text{ ppb}$$

This will not help.

Solutions Chapter 2

2.9.12

Basis: 10^6 g mol gas

$$\frac{350 \text{ g mol H}_2\text{S}}{10^6 \text{ g mol gas}} \left| \frac{1 \text{ g mol gas}}{1 \text{ g mol CO}_2} \right| \frac{34 \text{ g H}_2\text{S}}{1 \text{ g mol H}_2\text{O}} \left| \frac{1 \text{ g mol CO}_2}{44 \text{ g CO}_2} \right.$$

$$= \frac{270}{10^6} \frac{\text{g H}_2\text{S}}{\text{g CO}_2} = \frac{270}{10^6} \frac{\text{g H}_2\text{S}}{\text{g total liquid}}$$

mass fraction H₂S = 2.70×10^{-4}

2.9.13

(a) $\frac{1 \text{ mol O}_2}{100 \text{ mol gas}} \Rightarrow \frac{10^4 \text{ mol O}_2}{10^6 \text{ mol gas}}$ or 10^4 ppm

(b) Basis: 100 mol gas

answer

Comp.	% = mol	mol fr.	or mol %
SO ₃	55	0.932	93.2
SO ₂	3	0.051	5.1
O ₂	1	0.017	1.7
Total	59	1.000	100.0

2.9.14

MW	CaCO ₃ :	100.06
	Ca	40.05
	Mg	24.3
	C	12.01
	O	16.00

$$\frac{100.06 \text{ g CaCO}_3}{\text{g mol CaCO}_3} \left| \frac{1 \text{ g mol CaCO}_3}{1 \text{ g mol Ca}} \right| \frac{1 \text{ g mol Ca}}{40.05 \text{ g Ca}} = 2.50 \frac{\text{g CaCO}_3}{\text{g Ca}}$$

Similarly $\frac{\text{g CaCO}_3}{\text{g Mg}} = 4.118 \frac{\text{g CaCO}_3}{\text{g Mg}}$

Total alkalinity = $2.50 (56.4) + 4.118 (8.8) =$ $177 \frac{\text{mg CaCO}_3}{\text{L}}$

Solutions Chapter 2

2.9.15 No. 1 molecule in 10^{23} or more is not 13-20 ppb

2.9.16 On a mol basis, the carbon dioxide concentration in air is about 350 parts per million (ppm), while that of oxygen is about 209,500 ppm. If the atmospheric concentration of carbon dioxide is increasing at about 1% per year (i.e., from 350 ppm this year to 353.5 ppm next year), and not to 1%, the 3.5-ppm change in dioxide concentration causes the oxygen concentration to fall from 209,500 to about 209,497 ppm, which is less than a 0.002% decrease. So, there is no need to worry about an oxygen deficit at present.

2.10.1 $T_K = -10 + 273 = 263K$

$$T^{\circ}F = -10(1.8) + 32 = 14^{\circ}F$$

$$T^{\circ}R = 14 + 460 = 474^{\circ}R$$

2.10.2 Yes, if the temperature scale is a linear relative one ($^{\circ}C$, $^{\circ}F$), or a logarithmic scale ($\ln 1^{\circ}$ is zero). No, if the scale is absolute, but read J. Wisniak, *J. Chem. Educ.*, **77**, 518-522 (2000) for a different conclusion.

2.10.3 $C_p = 8.41 + \underbrace{2.4346 \times 10^{-5} T_K}_{\left(2.4346 \times 10^{-5} \frac{J}{(gmol)(K)^2} \right) (T_K)}$

Substitute $1.8 TK = T^{\circ}R$

$$\begin{aligned} C_p &= 8.41 + 2.4346 \times 10^{-5} \frac{J}{(gmol)(K)^2} \left(\frac{T^{\circ}R}{1.8} \right) \\ &= \boxed{8.41 + 1.353 \times 10^{-5} T^{\circ}R} \end{aligned}$$

Solutions Chapter 2

2.10.4

a) $\frac{10^\circ\text{C}}{1.0^\circ\text{C}} \left| \frac{1.8^\circ\text{F}}{1.8^\circ\text{C}} \right| + 32 = 50^\circ\text{F}$

b) $\frac{10^\circ\text{C}}{1.0^\circ\text{C}} \left| \frac{1.8^\circ\text{F}}{1.8^\circ\text{C}} \right| + 32 + 460^\circ\text{R} = 510^\circ\text{R}$

c) $\frac{-25^\circ\text{F} - 32^\circ\text{F}}{1.8} \left| \frac{1.0^\circ\text{C}}{1.8^\circ\text{F}} \right| + 273\text{K} = 241.3\text{K}$

d) $\frac{150\text{K}}{1.0\text{K}} \left| \frac{1.8^\circ\text{R}}{1.8^\circ\text{F}} \right| = 270^\circ\text{R}$

2.10.5 First multiply the RHS of the equation so that

Btu (lbmol)(°F)	1054.8J	1 lb mol 454 gmol	1.8°F 1.0°C	1°C 1K
--------------------	---------	----------------------	----------------	-----------

$$= 4.182 \frac{\text{J}}{(\text{gmol})(\text{°K})}$$

and substitute $T^\circ\text{F} = 1.8T^\circ\text{C} + 32$

$$C_p = [8.488 + 0.5757 \times 10^{-2}(1.8T^\circ\text{C} + 32) - 0.2159 \times 10^{-5}(1.8T^\circ\text{C} + 32)^2 + \\ 0.3059 \times 10^{-9}(1.8T^\circ\text{C} + 32)^3] 4.182 \frac{\text{J}}{(\text{gmol})(\text{°K})}$$

Simplifying,

$$C_p = 36.05 + 0.0447T - 0.2874 \times 10^{-4} T^2 + 0.7424 \times 10^{-8} T^3$$

2.10.6 The instrument does not contain mercury, but has to contain a fluid that responds at -76°C and can be calibrated to measure temperature.

Solutions Chapter 2

2.11.1

Basis: 15cm³ water

a. $m = \rho V = \frac{1000 \text{ kg}}{\text{m}^3} \left| \frac{10 \text{ m}}{} \right| \left| \frac{10 \text{ m}}{} \right| \left| \frac{0.15 \text{ m}}{} \right| = [15,000 \text{ kg}]$

b. $\frac{F}{A} = \frac{m g}{A} = \frac{15,000 \text{ kg}}{A} \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{10 \text{ m}}{10 \text{ m}} \right| \left| \frac{1 \text{ N}}{1 \frac{(\text{kg})(\text{m})}{\text{s}^2}} \right| \left| \frac{1 \text{ Pa}}{\frac{\text{N}}{\text{m}^2}} \right| = 1470 \text{ Pa}$
 $= [1.47 \text{ kPa}]$

$$\frac{1.470 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{1 \text{ atm}}{} \right| \left| \frac{14.7 \text{ psi}}{\text{atm}} \right| = [0.21 \text{ psi}]$$

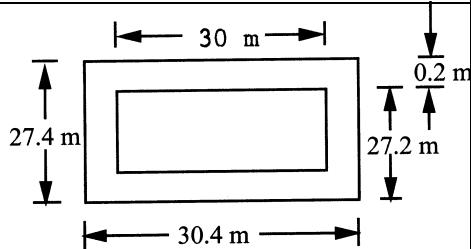
or $\frac{15 \text{ cm H}_2\text{O}}{2.54 \text{ cm}} \left| \frac{1 \text{ in.}}{12 \text{ in.}} \right| \left| \frac{1 \text{ ft}}{33.91 \text{ ft H}_2\text{O}} \right| \left| \frac{14.696 \text{ psi}}{} \right| = 0.21$

2.11.2

$$\rho_{\text{concrete}} = 2080 \text{ kg/m}^3$$

$$\rho_{\text{water}} = 1000 \text{ kg/m}^3$$

Volume of concrete:



Sides

$$V_s = \frac{5 \text{ m}}{} \left| \frac{30.2 \text{ m}}{} \right| \left| \frac{200 \text{ mm}}{} \right| \left| \frac{1 \text{ m}}{1000 \text{ mm}} \right| \left| 2 \text{ sides} \right| = 60.4 \text{ m}^3$$

Ends

$$V_e = \frac{5 \text{ m}}{} \left| \frac{27.2 \text{ m}}{} \right| \left| \frac{200 \text{ mm}}{} \right| \left| \frac{1 \text{ m}}{1000 \text{ mm}} \right| \left| 2 \text{ ends} \right| = 54.4 \text{ m}^3$$

Floor

$$V_f = \frac{27.4 \text{ m}}{} \left| \frac{30.4 \text{ m}}{} \right| \left| \frac{200 \text{ mm}}{} \right| \left| \frac{1 \text{ m}}{1000 \text{ mm}} \right| = 166.592 \text{ m}^3$$

Solutions Chapter 2

Total volume = 281.392 m³

$$\text{Mass of concrete} = \frac{281.392 \text{ m}^3}{\text{m}^3} \left| \frac{2080 \text{ kg}}{\text{m}^3} \right. = 585,295$$

Volume of displaced water required to float:

$$\frac{586,543.36 \text{ kg}}{1000 \text{ kg H}_2\text{O}} \left| \frac{1 \text{ m}^3 \text{ H}_2\text{O}}{\text{m}^3} \right. = 586.543 \text{ m}^3$$

$$V = LW h \rightarrow h = \frac{V}{LW}$$

$$h = \frac{586.54 \text{ m}^3}{27.4 \text{ m}} \left| \frac{}{30.4 \text{ m}} \right. = [0.703 \text{ m}]$$

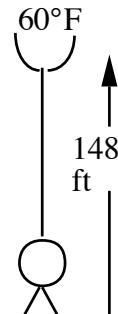
2.11.3 The pressure is a gauge pressure.

Basis: 50.0 psig

a.

$$\frac{50.0 \text{ psig}}{14.7 \text{ psia}} \left| \frac{33.91 \text{ ft H}_2\text{O}}{} \right. = 115 \text{ ft}$$

(difference)



b. No. Insufficient height.

Alternate solutions can be applying $\Delta p = \rho \Delta h g$

2.11.4 $\frac{\text{lb}_f}{\text{in.}^2} \left| \frac{\text{in.}^2}{\text{in.}^2} \right. = \text{lb}_f \rightarrow \text{lb}_m$ in the AE system

so the procedure is ok, although the unit conversion is ignored.

Solutions Chapter 2

2.11.5 Basis: Depth = 1000 m $p = p_0 + \rho gh$

$$p = 1 \text{ atm} +$$

$$\frac{1000 \text{ m}}{\text{cm}^3} \left| \begin{array}{l} 1.024 \text{ g} \\ \hline \end{array} \right| \left| \begin{array}{l} 9.8 \text{ m} \\ \hline 10^3 \text{ g} \end{array} \right| \left| \begin{array}{l} 1 \text{ kg} \\ \hline (\text{kg})(\text{m}) \end{array} \right| \left| \begin{array}{l} (\text{kg})(\text{m})^3 \\ \hline 1 \text{ m} \end{array} \right|^3 \left| \begin{array}{l} 1 \text{ N} \\ \hline (\text{kg})(\text{m})^2 \end{array} \right| \left| \begin{array}{l} 1 \text{ kPa} \\ \hline 1 \text{ N} \end{array} \right| \left| \begin{array}{l} 1 \text{ atm} \\ \hline (\text{kg})(\text{m})^2 \end{array} \right| \frac{1 \text{ atm}}{1.013 \times 10^5 \text{ N/m}^2}$$

$$= \frac{100.1 \text{ atm}}{1 \text{ atm}} \left| \begin{array}{l} 101.3 \text{ kPa} \\ \hline \end{array} \right| = 1.014 \times 10^4 \text{ kPa}$$

Alternative solution:

$$101.3 \text{ kPa} + \frac{1000 \text{ m sea H}_2\text{O}}{1.00 \text{ g sea H}_2\text{O}} \left| \begin{array}{l} 1.024 \text{ g H}_2\text{O} \\ \hline 1 \text{ m} \end{array} \right| \left| \begin{array}{l} 3.28 \text{ ft} \\ \hline 33.91 \text{ ft H}_2\text{O} \end{array} \right| \frac{101.3 \text{ kPa}}{1 \text{ m}} = 1.003 \times 10^4$$

$$+ 0.01 \times 10^4$$

$$= 1.013 \times 10^4$$

2.11.6 (a) $p_{\text{ABS}} = p_{\text{Gauge}} + p_{\text{atm}}$

$$\left(\frac{22.4 \text{ lb}_f}{1 \text{ in.}^2} \left| \begin{array}{l} 144 \text{ in.}^2 \\ \hline 1 \text{ ft}^2 \end{array} \right. \right) + \left(\frac{28.6 \text{ in. Hg}}{1} \left| \begin{array}{l} 14.7 \text{ psia} \\ \hline 29.92 \text{ in. Hg} \end{array} \right. \right) = \boxed{5250 \text{ lb}_f/\text{ft}^2}$$

$$(b) \left(\frac{22.4 \text{ psig}}{14.7 \text{ psia}} \left| \begin{array}{l} 29.92 \text{ in. Hg} \\ \hline \end{array} \right. \right) + 28.6 \text{ in. Hg} = \boxed{74.2 \text{ in. Hg}}$$

$$(c) \left(\frac{22.4 \text{ psig}}{14.7 \text{ psia}} \left| \begin{array}{l} 1.013 \times 10^5 \text{ N/m}^2 \\ \hline \end{array} \right. \right) + \left(\frac{28.6 \text{ in. Hg}}{27.92 \text{ in. Hg}} \left| \begin{array}{l} 1.013 \times 10^5 \text{ N/m}^2 \\ \hline \end{array} \right. \right) = \boxed{2.51 \times 10^5 \text{ N/m}^2}$$

$$(d) \left(\frac{22.4 \text{ psig}}{14.7 \text{ psia}} \left| \begin{array}{l} 33.91 \text{ ft H}_2\text{O} \\ \hline \end{array} \right. \right) + \left(\frac{28.6 \text{ in. Hg}}{29.92 \text{ in. Hg}} \left| \begin{array}{l} 33.91 \text{ ft H}_2\text{O} \\ \hline \end{array} \right. \right) = \boxed{84.1 \text{ ft H}_2\text{O}}$$

2.11.7 Neither John is necessarily right. The pressure at the top of Pikes Peak is continually changing.

Solutions Chapter 2

2.11.8 $\Delta p = \rho gh$

$$\text{a. } = \frac{1 \text{ g}}{\text{cm}^3} \left| \frac{9.8 \text{ m}}{\text{s}^2} \right| \left| \frac{13.1 \text{ m}}{1000 \text{ g}} \right| \left| \frac{1 \text{ kg}}{\text{m}^3} \right| \left| \frac{(100 \text{ cm})^3}{\text{m}^3} \right| \left| \frac{\text{Pa}}{1 \text{ kg}} \right| \left| \frac{1 \text{ kPa}}{1000 \text{ Pa}} \right|$$

$$= 128.4 \text{ kPa}$$

$$\text{b. } \frac{F}{A} = \frac{mg}{A_{\text{Bottom}}} = \frac{\rho Vg}{A_{\text{Bottom}}} = \frac{\rho(\text{S.A.})(t)g}{A_{\text{Bottom}}}$$

$$A_{\text{Bottom}} = \frac{\pi}{4} D^2 = \frac{\pi}{4} \left| \frac{(30.5 \text{ m})^2}{\text{m}^2} \right| = 730.62 \text{ m}^2$$

$$A_{\text{Top}} = 730.62 \text{ m}^2$$

$$A_{\text{side}} = \pi Dh = \pi(30.5 \text{ m})(13.1 \text{ m}) = 1255.2 \text{ m}^2$$

$$\text{S.A.} = A_{\text{Top}} + A_{\text{Bottom}} + A_{\text{Side}}$$

$$= (730.62 + 730.62 + 1255.22) \text{ m}^2 = 2716.46 \text{ m}^2$$

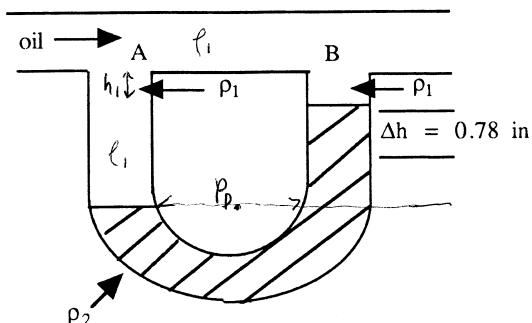
$$\frac{\rho(\text{S.A.})(t)g}{A} =$$

$$\frac{7.86 \text{ g}}{\text{cm}^3} \left| \frac{(100 \text{ cm}^3)}{\text{m}^3} \right| \left| \frac{2,716.46 \text{ m}^2}{\text{m}^2} \right| \left| \frac{9.35 \times 10^{13} \text{ m}}{730.6 \text{ m}^2} \right| \left| \frac{9.8 \text{ m}}{\text{s}^2} \right|$$

$$\frac{1 \text{ kg}}{1000 \text{ g}} \left| \frac{1 \text{ Pa}}{1 \text{ kg} / \text{ms}^2} \right| \left| \frac{1 \text{ kPa}}{1000 \text{ Pa}} \right| = 2.68 \text{ kPa}$$

Solutions Chapter 2

2.11.9



$$p_A + \rho_1 gh_1 + \rho_2 g \Delta h = P_D$$

$$p_B + \rho_1 gh_1 + \rho_2 g \Delta h = P_D$$

$$p_A - p_B = \rho_1 gh_1 + \rho_2 g \Delta h \quad \rho_1 gh_1 - \rho_1 g \Delta h$$

$$= \rho_2 g \Delta h_1 - \rho_1 g \Delta h = g \Delta h (\rho_2 - \rho_1)$$

$$= \frac{9.8 \text{ m}}{\text{s}^2} \left| \frac{0.78 \text{ in}}{3.28 \text{ ft}} \right| \left| \frac{1 \text{ m}}{1 \text{ cm}} \right| \left| \frac{13.546 \times 0.91 \text{ g}}{\text{cm}^2} \right| \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right|$$

$$\begin{aligned} & \frac{1 \text{ ft}}{12 \text{ in}} \left| \left(\frac{100 \text{ cm}}{1 \text{ m}} \right)^3 \right| \left| \frac{\frac{1 \text{ N}}{\text{m}^2}}{\frac{1 \text{ kg}}{(\text{m})(\text{s})^2}} \right| \left| \frac{1 \text{ Pa}}{\frac{1 \text{ N}}{\text{m}^2}} \right| \left| \frac{760 \text{ mm H}_2}{101.3 \times 10^3 \text{ Pa}} \right| \\ & = 18.4 \text{ mm Hg} \end{aligned}$$

The pressure at A is higher than the pressure at B.

Alternate solution:

$$\Delta p = \frac{(0.78 \text{ in.})}{13.546} \left| (13.546 - 0.91) \right| \left| \frac{760 \text{ mm Hg}}{29.92 \text{ in. Hg}} \right| = 18.5 \text{ mm Hg}$$

Solutions Chapter 3

3.1.1

Boundary: Around both pumps and include the soil at the end of the pipes.

It's an open system.

It's at steady-state except at startup (note system boundary limits fluid), or if fluid enters, unsteady state.

3.1.2

Either open (flow) or closed (batch) is acceptable if explanation is given

- (1) flow – material comes in and out continuously over a suitably long period of time
- (2) batch – material is injected into the system, and then in a short period of time, a reaction occurs with the system valves closed.

3.1.3

- (a) open if you have to replace water, and water evaporates; otherwise closed
- (b) open

3.1.4

If the overall flows in and out over a time period for several batches are considered, and the local batches ignore, the process can be treated as continuous.

3.1.5

- a) closed
- b) open
- c) open
- d) closed

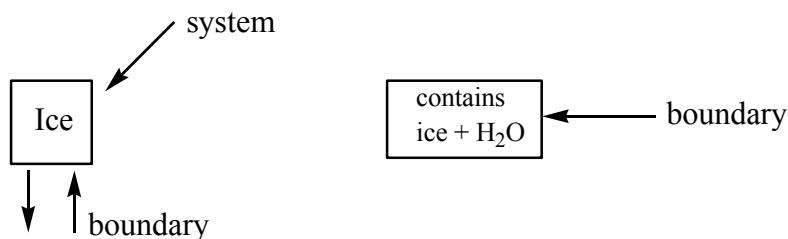
Solutions Chapter 3

3.1.6

The system is the radiator.

	<u>Open System</u>	<u>Closed System</u>	<u>Steady-State</u>	<u>Unsteady State</u>
a)	X			X
b)	X			X
c)	X (Before filling)	X (After filling)	X (After filling)	X (Before Filling)
d)		X	X	

3.1.7

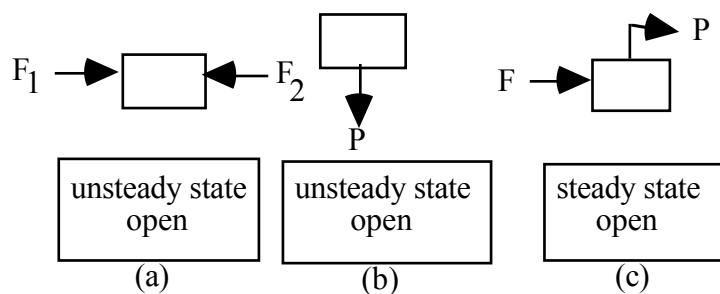


(c) Unsteady state for any assumptions

b} assume water (melted ice) leaves the system
a} open flow

b} assume water stays in system because the ice and water
a} closed batch remain on melting

3.1.8



Solutions Chapter 3

3.1.9

- | | | | | | | | |
|-------|---------------------------------------|-----|-----|-----|-----|-----|-----|
| | (a) | (b) | (c) | (d) | (e) | (f) | (g) |
| 1. | | | x | | x | | |
| 2. | x | | | x | | | |
| <hr/> | | | | | | | |
| 3. | x | | | x | | | |
| 4. | Depends on the time period considered | | | | | | |
| <hr/> | | | | | | | |
| 5. | x | | | x | | | |
| 6. | | x | x | | x | | |
| <hr/> | | | | | | | |
| 7. | x | | | x | | | |

3.1.10

If the overall flows in and out over a time period for several batches are considered, and the local batches ignore, the process can be treated as continuous.

3.1.11

Basis: 1 minute

Accumulation (kg) In (kg) Out (kg)

$$m_{\text{final}} - 0 = 300 + 100 - 380$$

$$n_{\text{final}} = 20 \text{ kg}$$

$$\frac{20 \text{ kg}}{\text{min}} \left| \frac{60 \text{ min}}{1 \text{ hr}} \right. = \boxed{1200 \text{ kg}}$$

3.1.12

Basis: 600 kg solution

Accumulation (kg) In (kg) Out (kg)

$$n_{\text{final}} - 0 = 100 + 500 - 300$$

$n_{\text{final}} = 300 \text{ kg}$ if no water evaporates in which case less than 300 kg would remain

Solutions Chapter 3

3.1.13

(c) 27.0 g

3.1.14

Based on the process measurements, there are 5,000 lb/h more flow for the process leaving the heat exchanger than the feed rate to the heat exchanger; therefore, the material balance for the process fluid does not close. The reason for this discrepancy could be faulty flow sensor readings or possibly a leak of the condensate or steam into the process stream.

3.1.15

Basis: Data shown on flowsheet units are MTA

<u>In</u>	<u>Out</u>
2.5×10^6	404×10^3
	228×10^3
	152×10^3
	101×10^3
	67×10^3
	36×10^3
	100×10^3
	<u>1190×10^3</u>
	<u>$2,278 \times 10^3$</u>

mass in does not equal to mass out

Reasons:

- (1) Some of the material was burned as fuel
- (2) Some of the material formed gases that were exhausted to atmosphere (such as H₂O, CO₂).
- (3) errors in measurement.
- (4) Some process streams are not shown.

Solutions Chapter 3

3.1.16

In = 250,000 ton/yr.

Out = 244,500 ton/yr.

In (ton/yr)

Out (ton/yr)

250,000	Combustibles	3,800
	Combustibles	39,500
	Polyethylene	30,000
	Polystyrene	5,000
	PVC	40,000
	Acrylonitorile	20,000
	DB	8,000
	Phenol	10,000
	Acetone	5,750
	Rubber	10,000
	LPG	24,000
	Aromatics	<u>48,000</u>
	Total	244,050

Balance is not exact but very good for an operating plant.

3.1.17

Basis: 1 week

$$\text{in (tons)} = 920 + 0.6 = 920.6$$

$$\text{out (tons)} = 3.8 + 620 + 0.01 + 0.01 + 0.08 + 1.1 + 275 + 20 = 920$$

Yes

Solutions Chapter 3

3.1.18

The density of the crystalline silicon in the cylinder is 2.4 g/cm^3 .

Basis: 62 kg silicon

The system is the melt, and there is no generation or consumption. Let Δm_t be the accumulation.

$$\begin{array}{rcl} \text{Accumulation} & \text{Input} & \text{Output} \\ \Delta m_t & = & 0 - 0.5(62 \text{ kg}) \end{array}$$

$$\boxed{\Delta m_t = -31 \text{ kg}}$$

Let t be the time in minutes to remove one-half of the silicon

$$\frac{2.4 \text{ g}}{\text{cm}^3} \left| \frac{\pi(17.5\text{cm})^2}{4} \right| \left| \frac{0.3 \text{ cm}}{\text{min}} \right| \left| \frac{t \text{ min}}{2} \right| = \frac{1}{2}(62,000 \text{ g})$$

$$\boxed{t = 179 \text{ min}}$$

3.1.19

Basis: 1 hr

Overall material balance (kg): $13,500 + 26,300 \stackrel{?}{=} 39,800$

Yes. The balance is satisfied

NaCl balance: $0.25(13,500) + 0.05(26,300) \stackrel{?}{=} 0.118(39,800)$
 $4690 \cong 4696$

The balance is closely satisfied but not exactly.

The closure is good for industrial practice.

Solutions Chapter 3

3.1.20

Basis: 1 hour

The overall material balance is

$$\frac{\text{In (lb)}}{106,000} = \frac{\text{Out (lb)}}{74,000 + 34,000} = 108,000$$

The error in the overall material balance is 2000 lb/h or 1.9%; therefore, the overall material balance is within the expected error for industrial flow sensors.

Propylene balance: $0.7 \times 106,000 = (0.997)(74,000) + (0.1)(34,000)$
 $74,200 = 73,778 + 3,400 = 77,178$ (3.8% error)

Propane balance: $0.4 \times 106,000 = (0.003)(74,000) + (0.9)(34,000)$
 $31,800 = 222 + 30,600 = 30,622$ (3.8% error)

Note that the relative error for the component balances are twice as large as the relative error for the overall material balance, indicating that there is additional error in the composition measurements used for the component balances.

3.1.21

Basis: 100 kg wet sludge

The system is the thickener (an open system). No accumulation, generation, or consumption occur. The total mass balance is

$$\frac{\text{In}}{100 \text{ kg}} = \frac{\text{Out}}{70 \text{ kg} + \text{kg of water}}$$

Consequently, the water amounts to 30 kg.

3.2.1 (a) water and air.

- (b) Insulation, air and what is in the atmosphere.
- (c) Yes (cold water in, hot water out)
- (d) Yes

Solutions Chapter 3

3.2.2

Four balances are possible, 3 components plus 1 total.

$$0.10F_1 + 0.50F_2 + 0.20F_3 = 0.35P$$

$$0.20F_1 + 0F_2 + 0.30F_3 = 0.10P$$

$$0.70F_1 + 0.50F_2 + 0.50F_3 = 0.55P$$

$$\text{Total balance } F_1 + F_2 + F_3 = P$$

Only 3 of the equations are independent.

3.2.3

If you specify F, P, W, you can calculate all of the stream variables.

- a) Unknown: three stream values F, P, W (plus two compositions if you take into account all of the variables).
- b) The two known compositions are not given but may be calculated from $\sum x_i = 1$,
- c) Two components exist; hence two independent material balances can be written.
The problem cannot be solved unless one stream value is specified.

3.2.4

- (a) No. The equations have no solution – they are parallel lines.

The rank of the coefficient matrix is only 1 because the

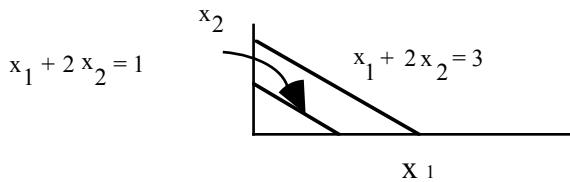
$$\det \begin{bmatrix} 1 & 2 \\ 1 & 2 \end{bmatrix} = 0$$

The rank of the augmented matrix is 2

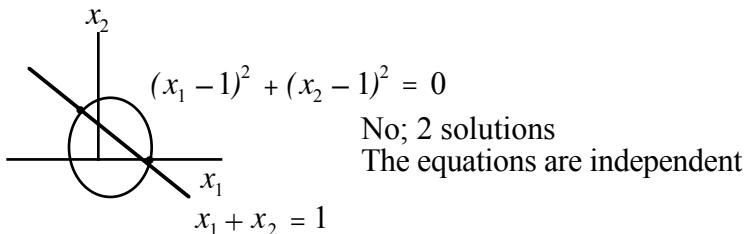
Largest non zero det. of $\begin{bmatrix} 1 & 2 & 1 \\ 1 & 2 & 3 \end{bmatrix}$ is of order 2

Thus, although the 2 equations are independent and the number of variables is 2 (the necessary conditions), the sufficient conditions are not met.

Solutions Chapter 3



(b)



Two solutions exist as can be seen from the plot hence no unique solution exists.

3.2.5

The number of independent equations is just 3. The number of unknown quantities is 3, hence a unique solution is possible.

3.2.6

No for both

$$\begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$$

- a) $\begin{vmatrix} 1 & 2 & 3 \end{vmatrix}$ rank of coefficient matrix is 2.
 $\begin{vmatrix} 3 & 5 & 7 \end{vmatrix}$ rank of augmented matrix is 2.

$$r = 2, n = 3 \quad \text{multiple solutions exist}$$

$$\begin{bmatrix} 1 & 0 & 1 \end{bmatrix}$$

- b) $\begin{vmatrix} 5 & 4 & 9 \end{vmatrix}$ 3rd column is sum of 1st two columns, so rank is 2.
 $\begin{vmatrix} 2 & 4 & 6 \end{vmatrix}$ rank of augmented matrix is 2, also.

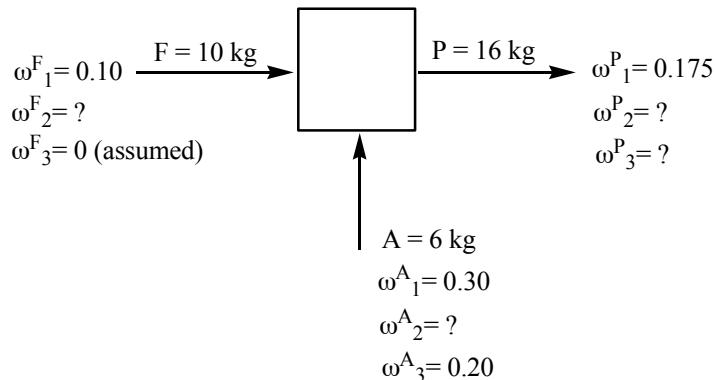
$$r = 2, n = 3 \quad \text{multiple solutions exist}$$

Solutions Chapter 3

3.2.7

(a) F; (b) F; (c) F (the maximum can be more than the number of independent equations).

3.2.8



Unknowns (4): $\omega_2^F, \omega_2^A, \omega_2^P, \omega_3^P$

Equations:

Mass balances:

- (1): $F(0.10) + A(0.30) = P(0.175)$
 or $10(0.10) + 6(0.30) = 16(0.175)$ redundant
- (2): $F(\omega_2^F) + A(\omega_2^A) = P(\omega_2^P)$
 or $10(\omega_2^F) + 6(\omega_2^A) = 16(\omega_2^P)$
- (3): $F(0) + A(0.20) = P(\omega_2^P)$
 or $10(0) + 6(0.20) = 16(\omega_2^P)$

$\omega_2^F, \omega_2^A, \omega_2^P, \omega_3^P$

10	6	-16	0
0	0	-0	16

coeff. matrix

Two independent material balances exist (the rank of the coefficient matrix is 2). In addition three sum of mole fraction equations exist. The total number of equations is 5, hence the degrees of freedom = -1. The problem is overspecified, and will require at least squares solution.

Solutions Chapter 3

3.2.9

Examine the row of C_3H_8 . None of the concentrations are greater than the desired 50% so 50% is not achievable by any combination of A, B, or C. Or look at the CH_4 row.

3.2.10

Basis: $D = 100 \text{ lb}$

	A	B	C	D
	x_1	x_2	x_3	
Coefficient matrix is	5.0	0	0	M 1.4
	90.0	10.0	0	M 31.2
	5.0	85.0	8.0	M 53.4
	0	5.0	80.0	M 12.6
	0	0	12.0	M 14

No unique solution exists with 5 equations and 4 variables. A least squares solution could be determined, or the 4 equations with the most accurate data solved.

The rank of the coefficient matrix is 3

The rank of the augmented matrix is 4

Hence no unique solution exists.

3.2.11

You can see by inspection that no combination of tanks 1,2 and 3 will give a mole fraction of 0.52 for the mixture.

Basis: 2.50 mol of tank 4

Let x_i = be the total moles of tank i

The balances are

$$\begin{aligned}0.23x_1 + 0.20x_2 + 0.54x_3 &= 0.25(2.5) = 0.625 \\0.36x_1 + 0.33x_2 + 0.27x_3 &= 0.23(2.5) = 0.575 \\0.41x_1 + 0.47x_2 + 0.19x_3 &= 0.52(2.5) = 1.300\end{aligned}$$

The coefficient matrix has a rank of 3 as does the augmented matrix so the set of equations has a solution. However, the solution is

$$\boxed{\begin{aligned}x_1 &= -4.00 \\x_2 &= 6.36 \\x_3 &= -0.327\end{aligned}}$$

The values of x_1 and x_3 are not physically realizable!

Solutions Chapter 3

3.2.12

Number of unknowns:

$$F, W, P \text{ and } 9 \text{ compositions:} \quad 12$$

Equations

$$\text{Specifications: } x_{CF}^W = 0 \quad 1$$

$$\text{Sum of mole fractions} = 1 \quad 3$$

$$\text{Material balances (3 species)} \quad \underline{3} \quad \underline{7}$$

$$\text{Degrees of freedom} = \quad 5$$

You can make any set of measurements that results in independent equations (assuming equal accuracy). For example, you cannot use all the flows, or all the compositions in one stream, as the resulting set of material balances will not consist of 5 independent balances, but a lesser number.

3.2.13

The inerts are treated as a compound.

$$\text{Unknowns: } 5 \text{ compounds} \times 5 \text{ streams plus } 5 \text{ streams} = \quad 30$$

Equations: Specifications:

Concentrations not shown in diagram assumed

to be zero 8

Concentrations with % given 7

E = 11 kg 1

Material balances: 5 5

Implicit equations ($\sum \omega_i = 1$) 5 26

a. Degrees of freedom (additional specifications) = 4

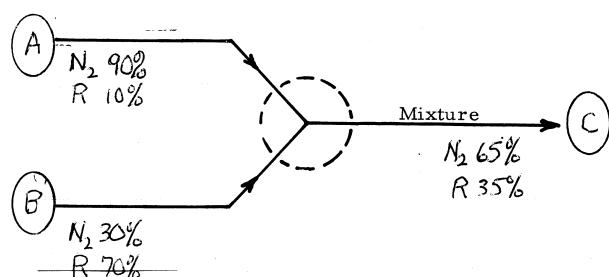
You must make 4 measurements that result in independent equations

b. No.

Solutions Chapter 3

3.2.14a

a.



b. The remaining gas is 100% minus the N₂, and was put on the figure as R.

c. Basis: 100 mol A

d. Unknowns: A, B, C

Equations: N₂ and R material balances

$$\text{Basis} = A = 100 \text{ mol}$$

Note: You could treat the values of R as unknowns in each stream, and then there would be 3 more unknowns and 3 more independent equations ($\sum x_i = 1$ or $\sum m_i = \text{total mass flow}_i$)

e. & f. N₂: $100(0.90) + B(0.30) = C(0.65)$

R: $100(0.10) + B(0.70) = C(0.35)$

Total: $100 + B = C$

Two of the above equations are independent

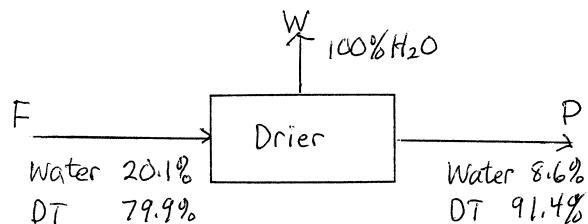
g. Solution: $B = 71.4 \text{ mol}$ $C = 171.4 \text{ mol}$

$$\frac{A}{B} = \frac{100}{71.4} = \boxed{1.40}$$

Solutions Chapter 3

3.2.14b

a.



$DT = \text{dry timber}$

b. The DT is the balance of each stream.

c. Basis: $F = 100 \text{ kg}$

d. Unknowns: F, W, P OR $F, W, P, DT^F, DT^W, DT^P, H_2O^F, H_2O^P, H_2O^W$

Equations:

Basis: $F = 100 \text{ kg}$

Material Balances: Water, DT
(total); 2 independent

Degrees of freedom = 0

Equations:

$F = 100 \text{ kg}$

Material Balances: Water, DT,
(total); 2 independent

Specifications: 3 for water

Implicit equations: 3 of $\sum \omega_i = 1$

Degrees of freedom = 0

e.&f. Introducing the specifications and basis into the material balances:

Water: $(0.201)100 = (1)W + (0.086)P$

DT: $(0.80)100 = 0 + (0.914)P$ a tie element

Total: $100 = W + P$

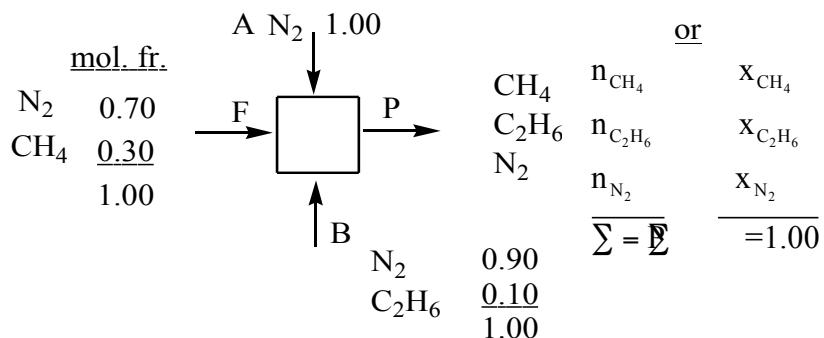
g. $W = 12.5 \text{ kg}$ $P = 87.5 \text{ kg}$

$$\frac{W}{F} = \frac{12.5 \text{ kg}}{100 \text{ kg}} = \boxed{0.125 \text{ kg/kg}}$$

Solutions Chapter 3

3.2.14c

a. & b.



c. Basis: B = 100 mol

d. Unknowns:

Assume all of the variables except those that are specified as zero are included in the analysis.

	<u>stream variable</u>		<u>component variables</u>	
F	1		2	
A	1		1	
P	1		3	
B	<u>1</u> 4	+	<u>2</u> 8	= <u>12</u>

Equations:

Basis: 1

Material balances: N₂, CH₄, C₂H₆ 3

Specified ratio: n_{CH₄}/n_{C₂H₆} = 1.3 1

Specified values of n: 2 + 1 + 0 + 2 = 5

Implicit equations ($\sum x_i = 1$ in P) 1

(Note: the implicit equations of streams

F, A, and B are redundant with the specifications)

Total 11

Degrees of freedom = 1

More information is needed to solve the problem uniquely.

Solutions Chapter 3

3.2.15

Here are some possibilities. Consult the tables at the end of the Chapter for more suggestions.

1. Rephrase the problem to make sure you understand it?
2. Draw a simple diagram of what was happening?
3. Think about what was going into the tank and what was coming out?
4. Imagine yourself inside the tank, and ask what was going on around you?
5. Ask whether there were any physical laws to consider (such as conservation of matter or energy)?
6. Try to imagine the answer as a number, graph, table, or whatever?
7. Try to identify essential variables?
8. Choose a notation?
9. Look for a ready-made formula for the answer?
10. Look for simplifying assumptions?
11. Try to find an easier version of the problem?
12. Look for bounds (simple models that would definitely underestimate or overestimate the answer)?

Solutions Chapter 4

4.1.1

Basis: 100 kg cucumbers
 $P - 100 = \text{evaporated}$

	<u>Initial</u>	<u>Final (P)</u>	<u>Evaporated</u>
Cucumber	1 kg	2%	-
Water	<u>99 kg</u>	<u>98%</u>	<u>100%</u>
	100 kg	100%	100%

Cucumber balance: $0.02P - 0.01(100) = 0$

$$P = \boxed{50 \text{ kg}} \quad \text{Answer is: Yes}$$

4.1.2

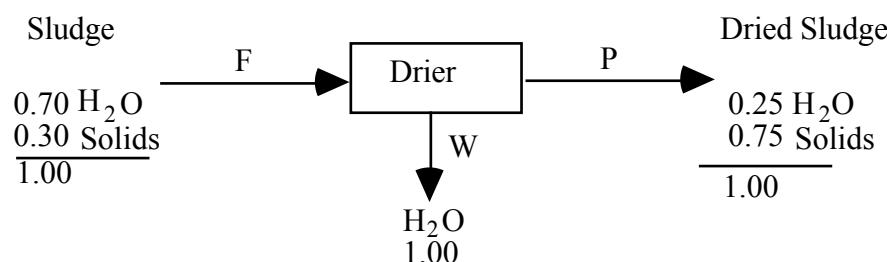
Initial	Final
$\frac{\text{plant } 5 \text{ ppm}}{\text{soil } 6 \text{ ppm}}$	$\frac{\text{Plant } 755 \text{ ppm}}{\text{Soil } 5 \text{ ppm}}$
Final - Initial	Final - Initial
Arsenic balance: $S(5) - S(6) =$	$P(755) - P(5)$

$$750P = S \text{ or } \frac{S}{P} = \boxed{750}$$

4.1.3

Step 5: Basis is 1 ton (2000 lb) sludge

Steps 1, 2, 3, 4:



Solutions Chapter 4

Steps 6 and 7:

Basis: 2000 lb F

Balances: H_2O
Solids

Unknowns: P, W

Steps 8 and 9:

Total: $2000 = P + W$

Solids: $2000 (0.30) = P (0.75)$

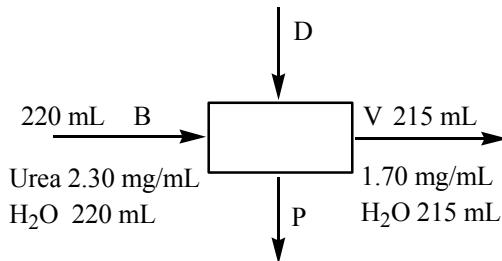
$$P = 800 \text{ lb}$$

$$W = 2000 - 800 = \boxed{1200 \text{ lb}}$$

4.1.4

Step 5: Basis: 1 min

Steps 2, 3, 4:



Steps 6 and 7: Unknowns: m^P_{urea} and $m^P_{H_2O}$ with two equations: urea and H_2O . Degrees of freedom = 0.

Steps 8 and 9:

(a) H_2O balance: $220 \text{ mL} - 215 \text{ mL} = \boxed{5 \text{ mL}}$

$$\text{Urea balance: } \frac{2.30 \text{ mg}}{\text{mL}} \left| \begin{array}{l} 220 \text{ mL} \\ - 215 \text{ mL} \end{array} \right. = \frac{1.70 \text{ mg}}{\text{mL}} \left| \begin{array}{l} 215 \text{ mL} \\ - 215 \text{ mL} \end{array} \right. = \boxed{141 \text{ mg}}$$

(b) Dialysate: $1500 + 5 = 1505 \text{ mL}$

Urea: 141 mg

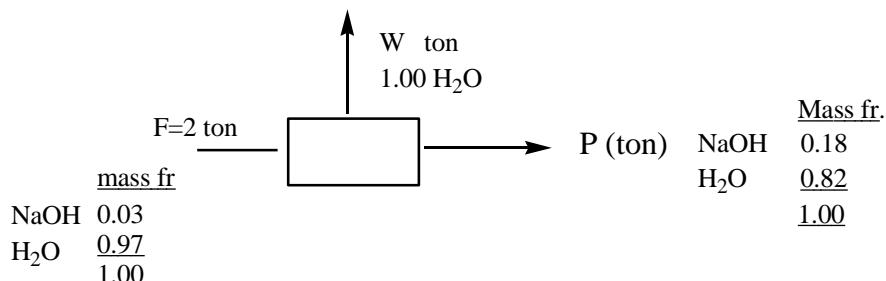
$$\text{Concentration: } 141/1505 = \boxed{0.0934 \text{ mg/mL}}$$

Solutions Chapter 4

4.1.5

Step 5: Basis: 1 day

Steps 2, 3, 4:



Step 6: Unknowns, 2: P, W

Step 7: Balances 2: NaOH, H₂O, total (2 of the 3)

Steps 8 & 9:

$$\text{Total: } 2 = W + P$$

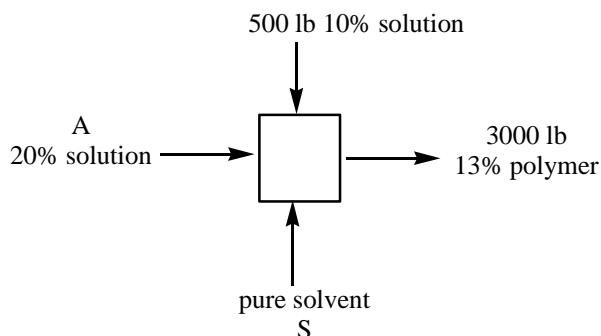
$$\text{NaOH: } 2 (.03) = P(.18)$$

$$P = 1/3 \text{ ton} \\ (666 \text{ lb})$$

$$W = 1 \frac{2}{3} \text{ ton} \\ (3334 \text{ lb})$$

4.1.6

Steps 2, 3, 4:



Step 5:

Basis: 3000 lb of final product

Steps 6 and 7: Unknowns: A and S; balances: total and polymer

Solutions Chapter 4

Steps 8 and 9:

$$\text{Total wt} \quad A + S + 500 = 3000$$

$$A + S = 2500$$

$$\text{Polymer} \quad 0.2A + 50 = 390$$

$$A = 5(340) = \boxed{1700}$$

$$S = 2500 - 1700 = \boxed{800}$$

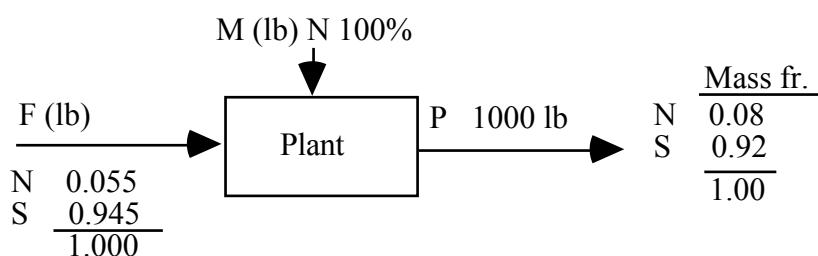
4.1.7

Steps 1, 2, 3 and 4:

N = nitrocellulose

S – solvent

Treat the problem as a steady state flow problem, or as an unsteady state batch system. As a flow system:



Step 5: Basis: 1000 lb P

Steps 6 and 7: Two unknowns, F and M. Two balances can be made, N and S.

Steps 8 and 9:

Solve to get

$$N: \quad F(0.055) + M(1.00) = 1000(0.008)$$

$$S: \quad F(0.945) + M(0) = 1000(0.92)$$

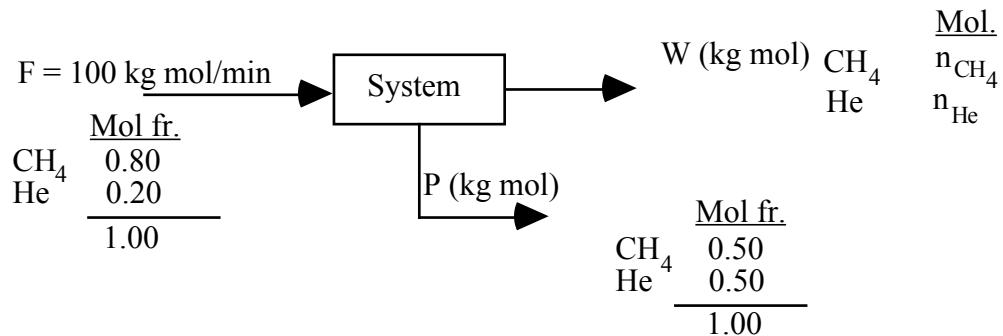
$$\left. \begin{array}{l} F = 973.5 \text{ lb} \\ M = 26.5 \text{ lb} \end{array} \right\}$$

$$P = 1000.0 \text{ lb}$$

Solutions Chapter 4

4.1.8

Steps 1, 2, 3 and 4:



Step 5: Basis 1 min $\rightarrow 100 \text{ kg mol F}$

Step 4: To get P, calculate first the average mol. wt. of F and P, or transform the mole fractions to mass fractions.

Step 5: Basis: 1.00 mol F

	<u>Mol</u>	<u>MW</u>	<u>kg</u>
CH ₄	0.80	16.03	12.8
He	0.20	4	0.8
	1.00		13.6

Basis : 1.00 mol P

	<u>Mol</u>	<u>MW</u>	<u>kg</u>
CH ₄	0.50	16.03	8.01
He	0.50	4	2.0
	1.00		10.01

$$\frac{100 \text{ kg mol F}}{1.00 \text{ kg mol F}} \left| \frac{13.6 \text{ kg F}}{1 \text{ kg F}} \right| \left| \frac{0.20 \text{ kg P}}{1 \text{ kg F}} \right| \left| \frac{1 \text{ kg mol P}}{10.01 \text{ kg P}} \right|$$

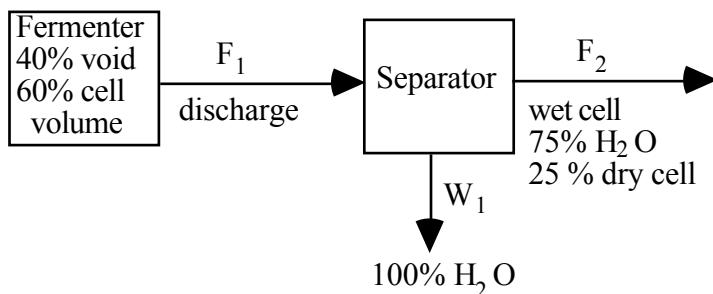
$$P = 27.2 \text{ kg mol}$$

Steps 6, 7, 8 and 9:

	<u>In W</u>	<u>Mol</u>	<u>Mol.fr.</u>
$100(0.80) = 27.2(0.50) + n_{\text{CH}_4}$		66.4	0.912
$100(0.20) = 27.2(0.50) + n_{\text{He}}$		6.4	0.088
		72.8	1.00

Solutions Chapter 4

4.1.9



Basis: $1000 \text{ cm}^3 F_1$

$$\text{Dry cells} = \frac{1000 \text{ cm}^3 \text{ in fermenter}}{100 \text{ cm}^3 \text{ in fermenter}} \left| \frac{60 \text{ cm}^3 \text{ cell}}{100 \text{ cm}^3 \text{ in fermenter}} \right| \left| \frac{1.1 \text{ g cell}}{1 \text{ cm}^3 \text{ cell}} \right| \left| \frac{25 \text{ g solids}}{100 \text{ g cell}} \right|$$

$$= 16.5 \text{ g Dry cell / } 1000 \text{ cm}^3 \text{ in fermenter}$$

4.1.10

a. Basis: 1 kg mole of mixture

Three components exist: $(\text{CH}_4)_x$, $(\text{C}_2\text{H}_6)_x$, $(\text{C}_3\text{H}_8)_x$

Let A, B, C respectively represent kg mol of each mixture; these are the unknowns.

Equations:

$$0.25A + 0.35B + 0.55C = 0.30 \quad (\text{CH}_4)_x \text{ balance}$$

$$0.35A + 0.20B + 0.40C = 0.30 \quad (\text{C}_2\text{H}_6)_x \text{ balance}$$

$$0.40A + 0.45B + 0.05C = 0.40 \quad (\text{C}_3\text{H}_8)_x \text{ balance}$$

There is a unique solution to the set of equations (in kg mol)

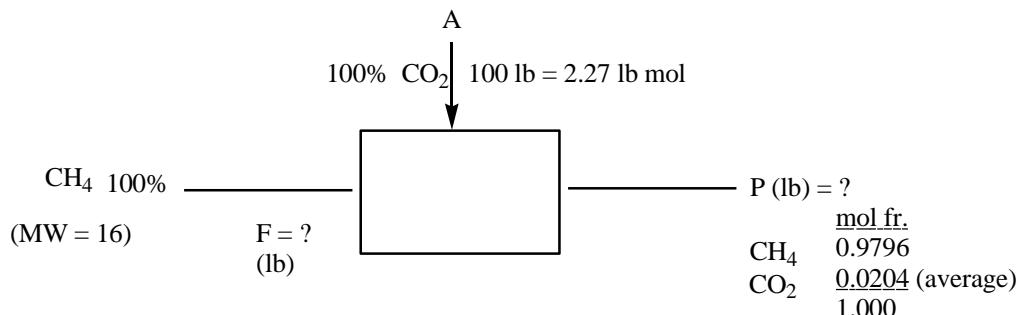
The solution is $A = 0.600 \quad B = 0.350 \quad C = 0.05$

b. It is proposed to prepare the final mixture by blending four different compounds (A, B, C, D); there will still be three equations, but now there will be four unknowns. Since the rank is now less than n, there will be an infinite number of possible blends of the four mixtures. Not required: (An optimization of a revenue function subject to the equations is needed.)

Solutions Chapter 4

4.1.11

a.



Steps 2, 3, 4:

$$\frac{100 \text{ lb}}{44 \text{ lb}} \left| \frac{1 \text{ lb mol}}{1 \text{ lb mol}} \right. = 2.27 \text{ lb mol}$$

Step 5: Basis 1 min

Step 6: Unknowns: F, P

Step 7: Balances: CH_4, CO_2

Steps 8 and 9: Balances in moles

$$\text{CH}_4: F(1.00) + A(0) = P(0.9796)$$

$$\text{CO}_2: F(0) + 2.27 = P(0.0204) \quad P = 111.41 \text{ lb mol}$$

$$F = \frac{111.27 \text{ lb mol}}{1 \text{ lb mol P}} \left| \frac{0.9796 \text{ lb mol CH}_4}{1 \text{ lb mol CH}_4} \right| \frac{16 \text{ lb CH}_4}{1 \text{ lb mol CH}_4} = \boxed{1746 \text{ lb/min}} \quad (\text{a})$$

b. Redo the problem with a new composition for F:

$$\begin{array}{rcl}
 \text{CH}_4 & 0.99 \\
 \text{CO}_2 & \frac{0.01}{1.00} \\
 \end{array}$$

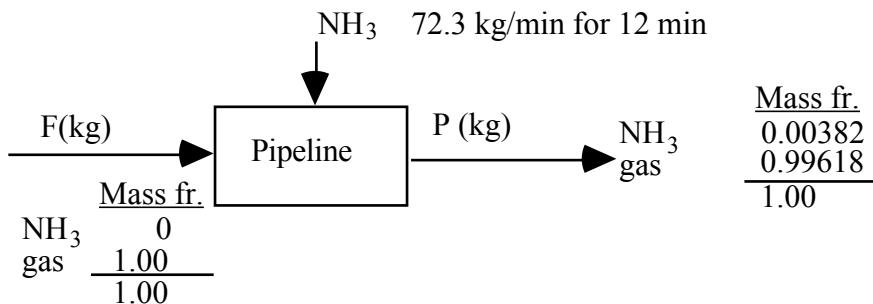
$$\begin{aligned}
 \text{CH}_4: F(0.99) + A(0) &= P(0.9796) \\
 \text{CO}_2: F(0.01) + 2.72 &= P(0.0204)
 \end{aligned}
 \left\} \begin{array}{l} F = 3520 \text{ lb/min} \\ \end{array} \right.$$

$$\text{error } \frac{3520 - 1744}{3520} 100 = \boxed{50\%} \quad (\text{b})$$

Solutions Chapter 4

4.1.12

Steps 1, 2, 3, and 4:



Step 5: Basis: 1 min

Steps 6 and 7: Two unknowns, F and P . Two balances can be made, NH_3 and gas. You can use the total balance as a substitute.

Steps 8 and 9:

$$\text{Total} \quad F + 72.3 = P$$

$$\text{NH}_3 \quad F(0) + 72.3 = P(0.00382)$$

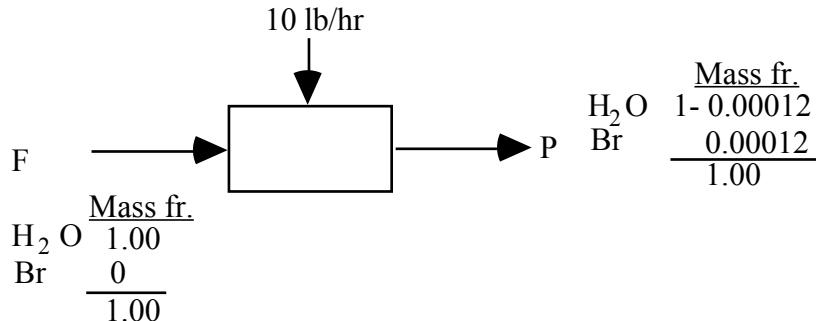
$$P = 18,900 \text{ kg / min}$$

$$F = 18,900 \text{ kg/min or } 1.14 \times 10^6 \text{ kg/hr}$$

Step 10: Check using the gas balance

4.1.13

Steps 1, 2, 3, and 4:



Step 5: Basis: 1 hr

Step 6: Unknowns: F, P

Solutions Chapter 4

Step 7: Balances: H_2O , Br

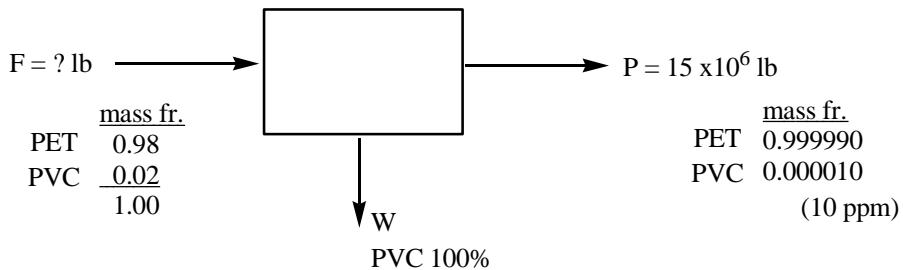
Steps 8 and 9:

Total:	$F + 10 =$	P
Br:	$F(0) + 10 =$	$P(0.00012)$; $P = 8.33 \times 10^4 \text{ lb/hr}$
$\text{H}_2\text{O}:$	$F(1.00) + 0 =$	$P(1 - 0.00012)$
$F = 8.33 \times 10^4 - 10 = 8.33 \times 10^4 \text{ lb / hr}$		

4.1.14

Step 5: Basis: 1 year

Steps 2, 3, 4:



Steps 6 and 7:

Two unknowns: F , W

Two balances: PET, PVC

Steps 8 and 9:

$$\text{PET balance: } F(0.98) = P(0.999990) \approx 15 \times 10^6$$

$$\begin{aligned} \text{PVC balance: } F(0.02) &= W(1.00) + P(0.000010) \\ &= W + (15 \times 10^6)(10^{-5}) \end{aligned}$$

Total balance could be used in lieu of one of the above

$$F = 15 \times 10^6 + W$$

From PET: $F \approx 15.3 \times 10^6 \text{ lb}$

$$W = (15.3 \times 10^6)(0.02) - 15 \times 10^6(10^{-5}) = \boxed{0.31 \times 10^6 \text{ lb}}$$

Solutions Chapter 4

4.1.15

Basis. 300 g initial solution

MW $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ is 322.2

(a)	In	g	MW	g mol	Out	g	g mol
	Na_2SO_4	100	142.05	0.704	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	100	0.310
	H_2O	200	18.016	11.10			

Material balances in g mol (in = out):

	g mol	g	%
Na_2SO_4 :	0.704 = 0.310 + $n_{\text{Na}_2\text{SO}_4}$	$n_{\text{Na}_2\text{SO}_4} = 0.394$	55.97 28
H_2O :	$11.10 = 0.310(10) + n_{\text{H}_2\text{O}}$	$n_{\text{H}_2\text{O}} = 8.0$	<u>144.1</u> <u>72</u>
Total	8.394	200.07	100

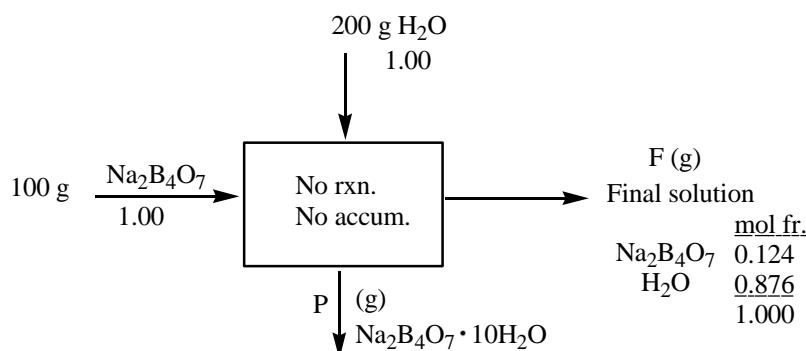
Mother liquor: $\boxed{\text{Na}_2\text{SO}_4 \text{ is } 28\% \text{ and } \text{H}_2\text{O} \text{ is } 72\%}$

$$(b) \frac{100 \text{ g crystals}}{300 \text{ g solution}} \left| \frac{100 \text{ g solution}}{100 \text{ g initial soln.}} \right. = \boxed{33.3 \text{ g crystals/100 g initial soln.}}$$

4.1.16

Assume steady state flow problem (alternate is unsteady state batch problem).

Steps 1-4:



Calculate composition of P: Basis: 100 mol $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$

Solutions Chapter 4

	<u>mol</u>	<u>MW</u>	<u>g</u>	<u>mol fr.</u>
Na ₂ B ₄ O ₇	1	201.27	201.27	0.528
H ₂ O	10	18	180.0	0.472
			381.27	1.00

Step 5: Basis: 200 g H₂O + 100 g Na₂B₄O₇

Step 6: Unknowns: F, B

Step 7: balances: Na₂B₄O₇, H₂O

$$\begin{array}{l} \text{Na}_2\text{B}_4\text{O}_7: \quad 100 = P(0.528) + F(0.124) \\ \text{H}_2\text{O}: \quad 200 = P(0.472) + F(0.876) \end{array} \left. \right\} \text{2 indept.}$$

$$\text{Total: } 100 + 200 = P + F$$

Step 9: Use H₂O and Total to get P = 155.5 g and F = 144.5 g

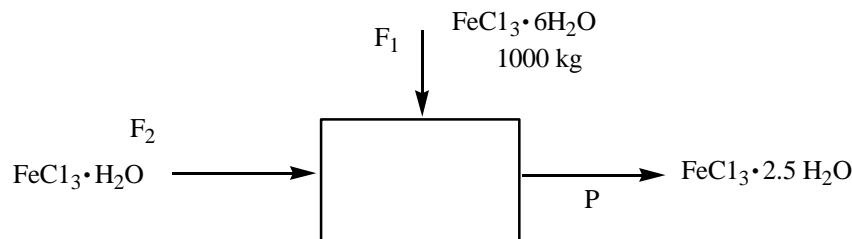
$$\text{ratio: } \frac{155.5}{300}(100) = \boxed{51.8 \text{ g Na}_2\text{B}_4\text{O}_7 / 100 \text{ g H}_2\text{O}}$$

Step 10: Check use Na₂B₄O₇
100.0 = 100.0 ok

4.1.17

Assume the process is a steady state one without reactions.

Steps 1, 2, 3, 4:

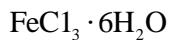


MW	Fe C1 ₃	162.22
	Fe C1 ₃ .6H ₂ O	270.32
	Fe C1 ₃ .H ₂ O	180.24
	Fe C1 ₃ .2.5 H ₂ O	207.26
	H ₂ O	18.02

Solutions Chapter 4

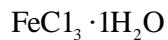
Calculate the compositions for just one iron compound. FeCl_3 is the simplest to use.

For F_1 : Basis: 1 kg mol



	<u>kg mol</u>	<u>MW</u>	<u>kg</u>
FeCl_3	1	162.22	162.22
H_2O	6	18.03	<u>108.18</u>
			270.40

For F_2 : Basis: 1 kg mol



	<u>kg mol</u>	<u>MW</u>	<u>kg</u>
FeCl_3	1	162.22	162.22
H_2O	1	18.03	<u>18.03</u>
			180.25

For P Basis: 1 kg mol

	<u>kg mol</u>	<u>MW</u>	<u>kg</u>
FeCl_3	1	162.22	162.22
H_2O	2.5	18.03	<u>45.08</u>
			207.30

Step 5: Basis: 1000 kg $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$

Step 6: Unknowns P, F

Step 7, 8, 9: Balances (kg)

$$\text{IN} \quad \text{OUT}$$

$$\text{FeCl}_3: 1000 \left(\frac{162.22}{270.40} \right) + F_2 \left(\frac{162.22}{180.25} \right) = P \left(\frac{162.22}{207.30} \frac{\text{kg FeCl}_3}{\text{kg tot}} \right)$$

$$\text{Total: } 1000 + F_2 = P$$

soln

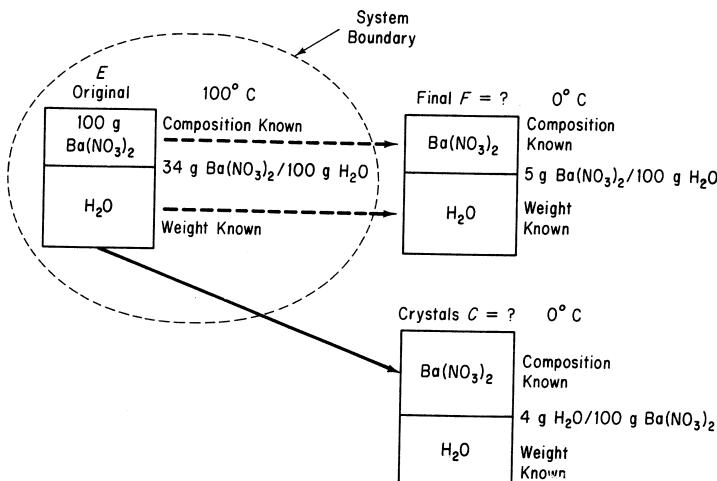
$F_2 = 1555.7 \text{ kg}$
$P = 2555.7 \text{ kg}$

Step 10: Check: $F_2 + F_1 = 1554.5 + 1000 = 2554.5 \quad \text{ok}$

Solutions Chapter 4

4.1.18

Steps 2, 3, 4:



The process can be viewed as an unsteady process without reaction, or as a flow process.

Step 5: Take as a basis 100 g of $\text{Ba}(\text{NO}_3)_2$.

Step 4:

The maximum solubility of $\text{Ba}(\text{NO}_3)_2$ in H_2O at 100°C is a saturated solution, 34 g/100 g of H_2O . Thus the amount of water required at 100°C is

$$\frac{100 \text{ g H}_2\text{O}}{34 \text{ g Ba}(\text{NO}_3)_2} \left| \frac{100 \text{ g Ba}(\text{NO}_3)_2}{100 \text{ g H}_2\text{O}} \right. = 294.1 \text{ g H}_2\text{O}$$

If the 100°C solution is cooled to 0°C , the $\text{Ba}(\text{NO}_3)_2$ solution will still be saturated so that the composition of the final solution is

$$\text{Ba}(\text{NO}_3)_2: \quad \frac{5}{100 + 5} = 0.0476$$

$$\text{H}_2\text{O}: \quad \frac{100}{100 + 5} = 0.9524$$

The composition of the crystals is

$$\text{Ba}(\text{NO}_3)_2: \quad \frac{100}{100 + 4} = 0.9615$$

Solutions Chapter 4

$$\text{H}_2\text{O}: \quad \frac{4}{100 + 4} = 0.0385$$

The composition of the original solution is

		<u>mass fr.</u>
BaNO ₃	100g	0.254
H ₂ O	294.1g	0.746

Steps 6 and 7:

We have two unknowns, F and C , and can make two independent mass balances so that the problem has a unique solution.

Steps 8 and 9:

<u>Balance</u>	<u>Final solution</u>	<u>Initial solution</u>	<u>Transport through boundary (out)</u>
Ba(NO ₃) ₂ :	F(0.0476)	- 100	= -C(0.9615)
H ₂ O:	F(0.9524)	- 294.1	= -C(0.0385)
Total:	F	- (100 + 294.1)	= -C

Solve the Ba(NO₃)₂ and total balance to get

$$F = 305.2 \text{ g} \quad C = 88.89 \text{ g}$$

Step 10: Check using the water balance

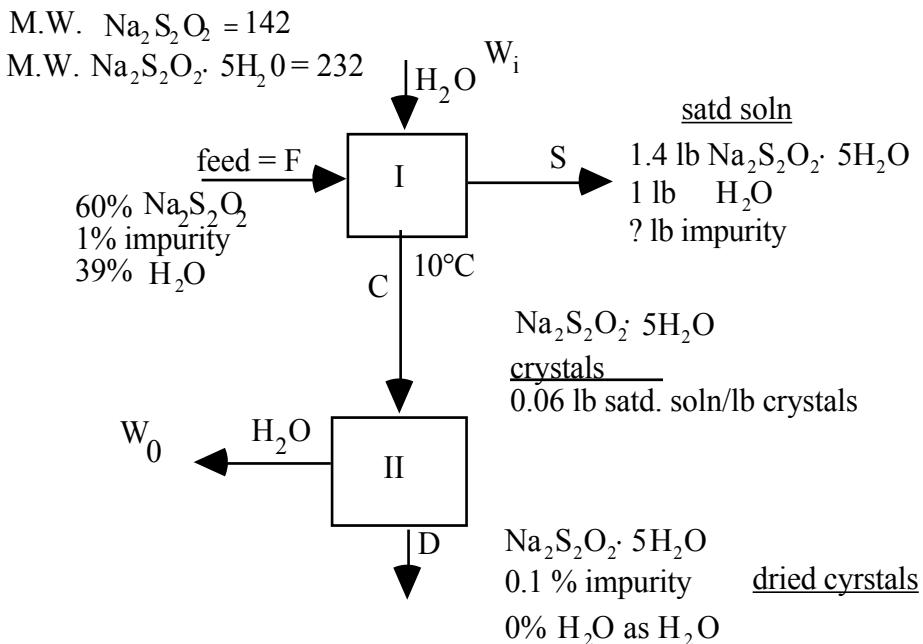
$$305.2(0.9524) - 294.1 \stackrel{?}{=} -88.89(0.0385) \\ - 3.42 = -3.42$$

The Ba(NO₃)₂ that precipitates out on a dry basis is

$$\frac{88.89 \text{ g } C}{1 \text{ g } C} \left| \frac{0.9615 \text{ g Ba(NO}_3)_2}{1 \text{ g } C} \right| = \boxed{85.5 \text{ g Ba(NO}_3)_2}$$

Solutions Chapter 4

4.1.19



Process II Compositions:

a) Stream D Basis: 1 lb mol $\text{Na}_2\text{S}_2\text{O}_2 \cdot 5\text{H}_2\text{O}$, impurity free

<u>Comp.</u>	<u>lb mol</u>	<u>mol wt</u>	<u>lb</u>	<u>wt fr</u>
$\text{Na}_2\text{S}_2\text{O}_2$	1	142	142	0.612
H_2O	5	18	90	0.388
Total	6		232	1.000

Basis: 100 lb D ($\text{Na}_2\text{S}_2\text{O}_2 \cdot 5\text{H}_2\text{O} = 99.9 \text{ lb}$)

<u>Comp.</u>		<u>lb</u>
$\text{Na}_2\text{S}_2\text{O}_2$	99(0.612)	= 61.1
H_2O	99(0.388)	= 38.8
impurity		0.1
Total		100.0

Stream C Let $y = \text{lb impurity}/100 \text{ lb free water in saturated solution}$

Basis: 100 lb dry crystals, impurity free

$$\text{lb from dry} \quad + \quad \text{lb from adhering soln}$$

Comp. crystals from calculation below = Total

Solutions Chapter 4

$\text{Na}_2\text{S}_2\text{O}_2$	61.2	$(6)\left(\frac{85.7}{240 + y}\right)$	$61.2 + 6\left(\frac{85.7}{240 + y}\right)$
H_2O	38.8	$(6)\left(\frac{154.3}{240 + y}\right)$	$38.8 + \left(\frac{154.3}{240 + y}\right)$
impurity	----	$(6)\left(\frac{y}{240 + y}\right)$	$\left(\frac{y}{240 + y}\right)$
Totals	100.0	6	106

Stream S Basis: 100 lb free water in satd. soln., impurity free

<u>Comp.</u>	<u>lb from salt</u>	<u>lb from free water</u>	<u>Total</u>	<u>wt. fr.</u>	<u>wt.fr.total</u>
$\text{Na}_2\text{S}_2\text{O}_2$	$1.4(61.2) = 85.68$		85.7	0.357	$\frac{85.7}{(240 + y)}$
H_2O	$1.4(38.8) = 54.32$	100	154.3	0.643	$\frac{154.3}{(240 + y)}$
	140.00	100	240.0	1.000	

$$\text{impurity} = \frac{y}{240 + y}$$

Total

Basis: 100 lb F

(Rather than use the impurity balance, use the total balance instead if you want)

Water in, W_i , comes from balances on Unit I.

$$\text{Total: } 100 + W_i = S + C$$

Solutions Chapter 4

$$\begin{array}{l}
 \text{Na}_2\text{S}_2\text{O}_2 \quad 60 = \left(\frac{85.7}{240+y} \right) S + \left(\frac{61.2 + 6 \left(\frac{85.7}{240+y} \right)}{106} \right) C \\
 \text{H}_2\text{O} \quad 39 + W_i = \left(\frac{154.3}{240+y} \right) S + \left(\frac{38.8 + 6 \left(\frac{154.3}{240+y} \right)}{106} \right) C
 \end{array}
 \left. \begin{array}{l}
 \text{Unknowns: } W_i, S, C, y \\
 \text{Total: 4}
 \end{array} \right\}$$

Balances on Unit II needed as well because 4 unknowns exist.

$$\text{Total: } C = W_0 + D$$

$$\begin{array}{l}
 \text{Na}_2\text{S}_2\text{O}_2 \quad \frac{61.2 + 6 \left(\frac{85.7}{240+y} \right) C}{106} = 0.611D \\
 \text{H}_2\text{O} \quad \frac{38.8 + 6 \left(\frac{154.3}{240+y} \right) C}{106} = W_o + 0.388D
 \end{array}
 \left. \begin{array}{l}
 \text{Unknowns: } W_o, D \\
 \text{Total: 2}
 \end{array} \right\}$$

6 equations and 6 unknowns

Note that the complex term involving y can be eliminated to solve for D , W_0 , W_i , and S , i.e., in effect making total $\text{Na}_2\text{S}_2\text{O}_2$ and H_2O balances overall the process.

The solution is (a) $W_i = 23.34 \text{ lb}$ (b)66.5%

4.1.20

Basis: 100 lb pulp as received

Comp	lb = %
H_2O	22
Pulp	78
Total	100

Freight cost = $\frac{\$1.00}{100 \text{ lb}} \left| \frac{2000 \text{ lb}}{1 \text{ ton}} \right. = \$20.00/\text{ton}$

Assume air dried pulp means the 12% moisture pulp.

$$\text{Allowed water} = \frac{78 \text{ lb pulp}}{88 \text{ lb pulp}} \left| \frac{12 \text{ lb H}_2\text{O}}{88 \text{ lb pulp}} \right. = 10.65 \text{ lb H}_2\text{O}$$

Solutions Chapter 4

Pulp on contract basis = $78 + 10.65 = 88.65 \text{ lb}$

Basis: 1 ton pulp as received

$$\text{Cost} = \frac{88.65 \text{ lb } 12\% \text{ pulp rec'd}}{100 \text{ lb shipped}} \left| \begin{array}{c} 1 \text{ ton shipped} \\ \hline 1 \text{ ton} \end{array} \right| \frac{\$60.00}{\$53.19/\text{ton}}$$

4.1.21

You pay for soap plus transportation.

Basis: 100 kg soap with 30% water

Convert soap in wet soap to soap in dry soap. Data:

<u>W (wet soap)</u>	<u>D(dry soap)</u>
H ₂ O	30 kg
soap	<u>70 kg</u>
100 kg	100

$$\text{Soap balance: } 0.70W = 0.95D \quad \text{or } 0.70(100) = 0.95D$$

D = 73.68 kg of which 70 kg is soap

$$\text{Cost of W at your site (containing 70 kg soap): } 100 (\$0.30 + \frac{\$6.05}{100}) = \$36.05$$

$$\text{Cost of D at your site (containing 70 kg soap): } 73.68 \left(\frac{x\$}{\text{kg}} + \frac{\$6.05}{100} \right) = \$36.05$$

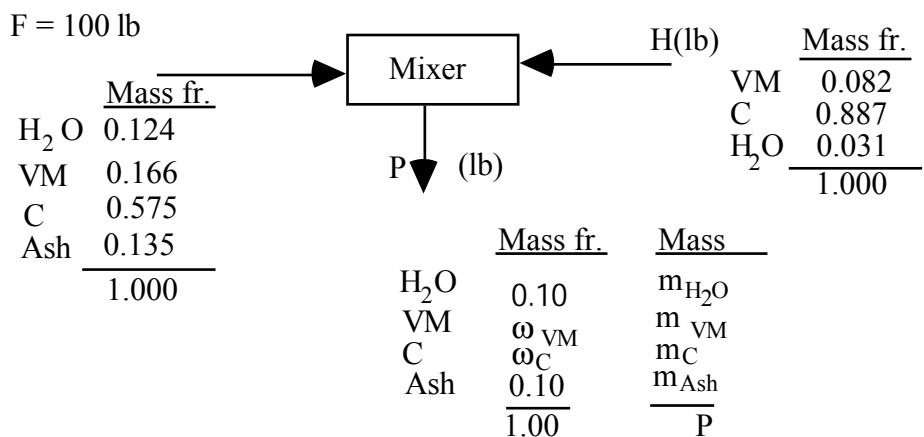
$$x = \$0.43/\text{kg}$$

Solutions Chapter 4

4.1.22

The problem here is to decide on the balances to make. Not all will be indept balances.

Steps 1, 2, 3, and 4:



Step 5: Basis: $F = 100 \text{ lb}$

Step 6: Unknowns: m_{H_2O} , m_{VM} , m_C , m_{Ash} , P , H (6)

Step 7: Balances: $\text{H}_2\text{O}, \text{VM}, \text{C}, \text{Ash}, \sum m_i = P, m_{\text{H}_2\text{O}}/P = 0.10$
 $m_{\text{Ash}}/P = 0.10$: (7), and presumably 6 are independent

Steps 8 and 9:

	In		Out
H ₂ O (lb):	$100(0.124) + H(0.082)$	=	m_{H_2O}
VM : (lb)	$100(0.166) + H(0.082)$	=	m_{VM}
C (lb):	$100(0.575) + H(0.887)$	=	m_C
Ash (lb)	$100(0.135) + H(0)$	=	m_{Ash}
Total	$100 + H$	=	P

Solutions Chapter 4

Solution:

$$m_{\text{Ash}} = 13.5 \text{ lb} \quad m_{\text{H}_2\text{O}} = 13.51$$

Not all of the equations have to be written down as above. Note that ash is a tie element to P, so that the ash balance gives

$$100(0.135) + H(0) = P(0.10) \quad P = 135 \text{ lb} \quad \text{and } m_{\text{Ash}} = 13.5 \text{ lb}$$

From a total balance

$$H + 100 = P \quad \boxed{H = 35 \text{ lb}}$$

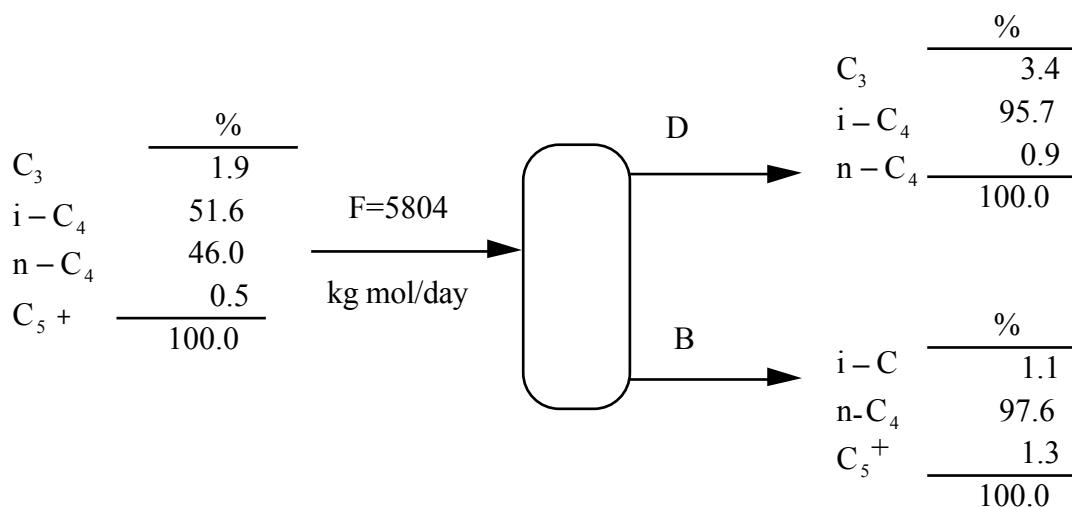
Step 10: Check via H_2O balance

$$\begin{aligned} 12.4 + 35(0.031) &= 13.5 \\ 13.49 &= 13.5 \end{aligned} \quad \left. \right\} \text{ok}$$

4.1.23

Step 5: Basis: 1 day

Steps 2, 3, and 4:



Steps 6 and 7:

There are two unknowns, and we have 4 independent equations, but the precision of measurement is not the same in each equation, hence different results are obtained depending on the equations used. Choose the most accurate to use.

Solutions Chapter 4

	In	Out
C ₃	(0.019)(5804) =	110 = 0.034D
i-C ₄	2992 =	0.057D + 0.011B
n-C ₄	2667 =	0.009D + 0.976B
C ₅ ⁺	37 =	0.013B
Total:	5804 =	D + B

Steps 8 and 9:

Use total + i-C₄ balances: $\frac{\text{kg mol/day}}{\boxed{\begin{array}{l} B = 2563 \\ D = 3240 \end{array}}}$

$$2992 = 0.975(5804 - B) + 0.011 B$$

Use total + n-C₄ balances: $\frac{\text{kg mol/day}}{\boxed{\begin{array}{l} B = 2704 \\ D = 3100 \end{array}}}$

$$2667 = 0.009 (5804 - B) + 0.976B$$

The other two balances give

C₃ as a tie component:

$$\frac{5804 \text{ kg mol F}}{1 \text{ day}} \left| \frac{0.019 \text{ kg mol C}_3}{1.00 \text{ kg mol F}} \right| \frac{1 \text{ kg mol D}}{0.034 \text{ kg mol C}_3} = 3243 \frac{\text{kg mol D}}{\text{day}}$$

C₅⁺ as a tie element:

$$\frac{5804 \text{ kg mol F}}{1 \text{ day}} \left| \frac{0.006 \text{ kg mol C}_5^+}{1.00 \text{ kg mol F}} \right| \frac{1 \text{ kg mol B}}{0.013 \text{ kg mol C}_5^+} = 2679 \text{ kg mol B / day}$$

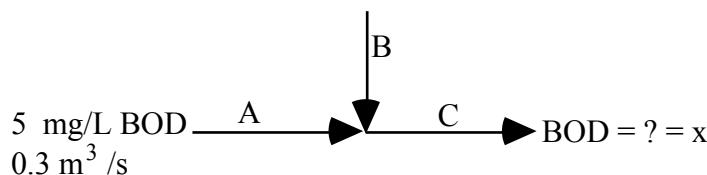
Solutions Chapter 4

4.1.24

Steps 1, 2, 3, and 4:

Assume the other components have the same density as water in all flows.

- a. $3.785 \times 10^6 \text{ L/day}$
 150 mg/L BOD



Step 5: Basis: 1 day

$$A = \frac{0.3 \text{ m}^3}{\text{s}} \left| \frac{3600 \text{ s}}{\text{hr}} \right| \left| \frac{24 \text{ hr}}{\text{day}} \right| \left| \frac{1000 \text{ L}}{\text{m}^3} \right| = 2.592 \times 10^7 \text{ L / day}$$

Steps 6 and 7:

Unknowns: C, x

Balances: H_2O , BOD

Steps 8 and 9:

Total mass balance $A + B = C$

$$\frac{1 \text{ day}}{\text{day}} \left| \frac{A \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg}}{\text{L}} \right| + \frac{1 \text{ day}}{\text{day}} \left| \frac{B \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg B}}{\text{L}} \right| = \frac{1 \text{ day}}{\text{day}} \left| \frac{C \text{ L}}{\text{day}} \right| \left| \frac{1 \text{ kg C}}{\text{L}} \right|$$

BOD mass balance

$$\frac{1 \text{ day}}{\text{day}} \left| \frac{A \text{ L}}{\text{day}} \right| \left| \frac{5 \times 10^{-3} \text{ g BOD}}{\text{L}} \right| + \frac{1 \text{ day}}{\text{day}} \left| \frac{B \text{ L}}{\text{day}} \right| \left| \frac{150 \times 10^{-3} \text{ g BOD}}{\text{day}} \right| = \frac{1 \text{ day}}{\text{day}} \left| \frac{C \text{ L}}{\text{day}} \right| \left| \frac{x \text{ g BOD}}{\text{L}} \right|$$

$$2.592 \times 10^7 \text{ kg} + 3.785 \times 10^6 \text{ kg} = C = 2.9705 \times 10^7 \text{ kg}$$

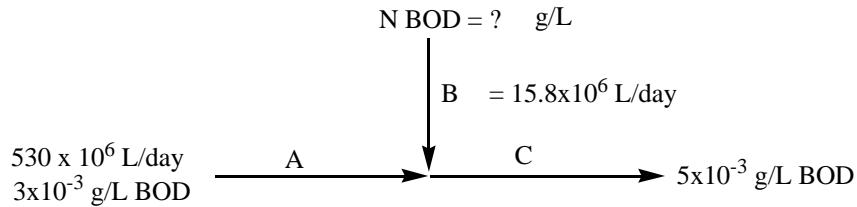
$$5 \times 10^{-3} A + 150 \times 10^{-3} B = xC$$

$$x = \frac{5 \times 10^{-3} A + 150 \times 10^{-3} B}{C}$$

Solutions Chapter 4

$$= \frac{5 \times 10^{-3}(2.592 \times 10^7) + 150 \times 10^{-3}(3.785 \times 10^6)}{2.9705 \times 10^7} = \boxed{23.475 \times 10^{-3} \text{ g/L}}$$

b.



Total mass balance A + B = C

$$\frac{1 \text{ day}}{\text{day}} \left| \begin{array}{l} \text{A L} \\ \hline \text{L} \end{array} \right| \left| \begin{array}{l} 1 \text{ kg} \\ \hline \text{L} \end{array} \right| + \frac{1 \text{ day}}{\text{day}} \left| \begin{array}{l} \text{B L} \\ \hline \text{L} \end{array} \right| \left| \begin{array}{l} 1 \text{ kg} \\ \hline \text{L} \end{array} \right| = \frac{1 \text{ day}}{\text{day}} \left| \begin{array}{l} \text{C L} \\ \hline \text{L} \end{array} \right| \left| \begin{array}{l} 1 \text{ kg} \\ \hline \text{L} \end{array} \right|$$

$$530 \times 10^6 \text{ kg} + 15.8 \times 10^6 \text{ kg} = C = 5.458 \times 10^8 \text{ kg}$$

BOD mass Balance

$$\frac{1 \text{ day}}{\text{day}} \left| \begin{array}{l} \text{A L} \\ \hline \text{L} \end{array} \right| \left| \begin{array}{l} 3 \times 10^{-3} \text{ g BOD} \\ \hline \text{L} \end{array} \right| + \frac{1 \text{ day}}{\text{day}} \left| \begin{array}{l} \text{B L} \\ \hline \text{L} \end{array} \right| \left| \begin{array}{l} N \times 10^{-3} \text{ g} \\ \hline \text{L} \end{array} \right| = \frac{1 \text{ day}}{\text{day}} \left| \begin{array}{l} \text{C L} \\ \hline \text{L} \end{array} \right| \left| \begin{array}{l} 5 \times 10^{-3} \text{ g} \\ \hline \text{L} \end{array} \right|$$

$$3 \times 10^{-3} A + N \times 10^{-3} B = 5 \times 10^{-3} C$$

$$N = \frac{5 \times 10^{-3} C - 3 \times 10^{-3} A}{B}$$

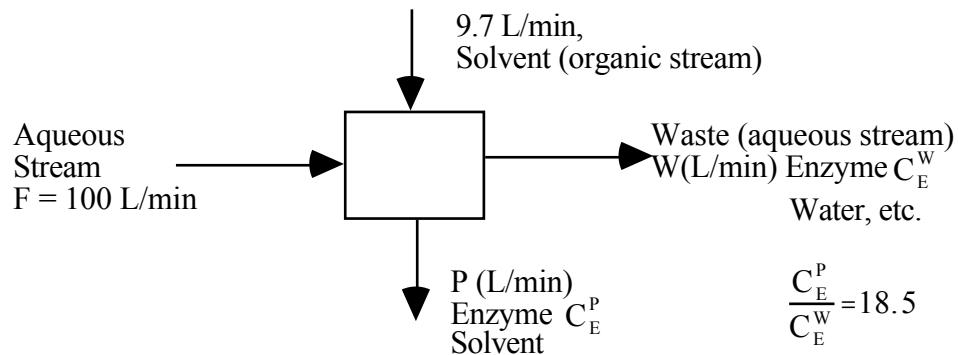
$$= \frac{(5 \times 10^{-3})(5.458 \times 10^8) - (3 \times 10^{-3})(5.30 \times 10^8)}{1.58 \times 10^7} \boxed{\approx 72.1 \times 10^{-3} \text{ g/L}} \quad \text{ok}$$

Solutions Chapter 4

4.1.25

The extractor is assumed to be a steady state process.

Steps 1, 2, 3, and 4: All the known data have been placed in the figure.



Step 5: Basis: 1 min ($F = 100\text{L}$)

Step 6: Unknowns are P and W and their concentrations.

Steps 7 and 8: We can make enzyme, solvent, and aqueous balances, plus we have

$$C_E^P = 18.5 C_E^W$$

The solvent and aqueous phases are tie components.

Balances	In	Out
Enzyme (g)	$\frac{100\text{ L}}{\text{L}} \left \frac{10.2\text{ g}}{\text{L}} \right. = \frac{(P\text{ L})}{\text{L}} \left \frac{C_E^P\text{ g}}{\text{L}} \right. + \frac{(W\text{ L})}{\text{L}} \left \frac{C_E^W\text{ g}}{\text{L}} \right.$	
Phase relation (g/L) (D = 18.5)	$C_E^P = 18.5 C_E^W$	
Balances	In	Out
Solvent	$\frac{9.7\text{ L}}{\text{L}} \left \frac{\rho_S\text{ g}}{\text{L}} \right. = \frac{(P\text{ L})}{\text{L}} \left \frac{\rho_P\text{ g}}{\text{L}} \right.$	
Aqueous	$\frac{100\text{ L}}{\text{L}} \left \frac{\rho_F\text{ g}}{\text{L}} \right. = \frac{W\text{ L}}{\text{L}} \left \frac{\rho_W\text{ g}}{\text{L}} \right.$	$\rho_F \approx \rho_W \text{ and } \rho_{\bar{g}} \approx \rho_P$

$$\boxed{P = 9.7\text{L}}$$

$$W = 100\text{ L}$$

$$1020 = 97 C_E^P + 100 C_E^W = 9.7 (18.5) C_E^P + 100 C_E^W$$

$$C_E^W = 3.65 \frac{\text{g}}{\text{L}}$$

$$C_E^P = \boxed{67.53}$$

Solutions Chapter 4

$$\boxed{\text{Fraction recovery}} = \frac{\frac{67.53 \text{ g}}{\text{L}} \left| \frac{9.7 \text{ L}}{10.2 \text{ g}} \right| \frac{100\text{L}}{\text{L}}}{\frac{10.2 \text{ g}}{\text{L}} \left| \frac{100\text{L}}{\text{L}} \right|} = 0.642(1020) = \boxed{655 \text{ g/min}}$$

4.1.26

Assume the process is in the steady state, and no reaction occurs. Solution assumes no S is in stream A and no N₂ in stream B.

Steps 1, 2, 3 and 4:

mass fr.	NH ₃	mol fr.	A(kg)	mass fr.
$\omega_{\text{NH}_3}^A$		$x_{\text{NH}_3}^A$	$1000 \text{ kg S}_{\text{NH}_3}$	$\omega_{\text{NH}_3}^B$
$\omega_{\text{N}_2}^A$	N ₂	$x_{\text{N}_2}^A$	S	ω_{S}^B
1.00		1.00		1.00

Gas	1000 kg			
mass fr.	NH ₃	mol fr.		
0.0633		0.10		
0.9367	N ₂	0.90		
1.00		1.00		

Step 5: Basis 1.0 hr

Step 6: The unknowns are A, B, $\omega_{\text{NH}_3}^A$, $\omega_{\text{N}_2}^A$, $\omega_{\text{NH}_3}^B$, ω_{S}^B , a total of 6.

Steps 7 and 8: Three compound balances can be made, N₂, NH₃, and S. One relation is given:

$$\omega_{\text{NH}_3}^A = 2\omega_{\text{NH}_3}^B$$

Solutions Chapter 4

Two summations exist: $\sum \omega_i^A = 1$ and $\sum \omega_i^B = 1$

hence, we have an adequate number of balances (unless some are not independent) to solve the problem.

Material balance equations in grams

$$\begin{array}{ll} \text{Total:} & F + S = A + B \\ & 1000 + 1000 = A + B \end{array}$$

$$\underline{\text{NH}_3}: \quad 1000(0.0633) + 0 = A\omega_{\text{NH}_3}^A + B\omega_{\text{NH}_3}^B$$

$$\underline{\text{N}_2}: \quad 1000(0.9367) + 0 = A\omega_{\text{N}_2}^A + 0$$

$$\underline{S}: \quad 0 + 1000 = 0 + B\omega_S^B$$

Constraints

$$\omega_{\text{NH}_3}^A + \omega_{\text{N}_2}^A = 1$$

$$\omega_{\text{NH}_3}^B + \omega_S^B = 1$$

$$\omega_{\text{NH}_3}^A = 2\omega_{\text{NH}_3}^B$$

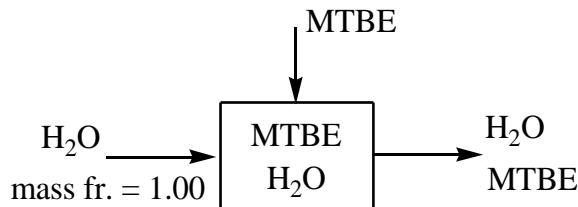
Solve in Polymath

Note: The equations can be converted to linear equations by letting $m_{\text{NH}_3}^A = \omega_{\text{NH}_3}^A A$, $m_{\text{N}_2}^A = \omega_{\text{N}_2}^A A$, etc. The set can be solved in Polymath or reduced to a quadratic equation in $m_{\text{NH}_3}^B$ or $m_{\text{NH}_3}^A$.

4.1.27

Basis: 12 hours

The process is illustrated in the figure



Solutions Chapter 4

The MTBE entering the pond in 12 hours is

$$\frac{25 \text{ boats}}{1 \text{ boat}} \left| \frac{0.5 \text{ L gasoline}}{1 \text{ boat}} \right| \left| \frac{1000 \text{ cm}^3}{1 \text{ L}} \right| \left| \frac{0.72 \text{ g}}{1 \text{ cm}^3} \right| \left| \frac{0.10 \text{ g MTBE}}{1 \text{ g gasoline}} \right| = 900 \text{ g MTBE}$$

The pond holds (ignoring the MTBE in the pond which is negligible)

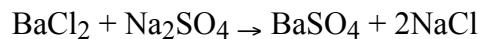
$$\frac{3000 \text{ m}}{1,000 \text{ m}} \left| \frac{3 \text{ m}}{1 \text{ m}^3 \text{ H}_2\text{O}} \right| \left| \frac{1000 \text{ kg H}_2\text{O}}{1 \text{ m}^3 \text{ H}_2\text{O}} \right| = 9 \times 10^9 \text{ kg H}_2\text{O}$$

The increase in the concentration of MTBE is

$$\frac{900 \text{ g MTBE}}{9 \times 10^9 \text{ kg H}_2\text{O}} \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| = \boxed{1 \times 10^{-10} \text{ g MTBE/g H}_2\text{O}}$$

Solutions Chapter 5

5.1.1



Mol. wt.: 208.3 142.05 233.4 58.45

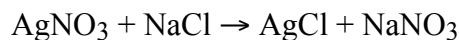
a. Basis: 5.0 g Na₂SO₄

$$\text{Example: } \frac{5 \text{ g Na}_2\text{SO}_4}{142.05 \text{ g Na}_2\text{SO}_4} \left| \begin{array}{c} 1 \text{ g mol Na}_2\text{SO}_4 \\ 1 \text{ g mol Na}_2\text{SO}_4 \end{array} \right| \left| \begin{array}{c} 1 \text{ g mol BaCl}_2 \\ 1 \text{ g mol Na}_2\text{SO}_4 \end{array} \right| \left| \begin{array}{c} 208.3 \text{ g BaCl}_2 \\ 1 \text{ g mol BaCl}_2 \end{array} \right| =$$

$$\boxed{7.33 \text{ g BaCl}_2}$$

<u>Problem</u>	<u>Basis</u>	<u>Answer</u>
b.	5 g BaSO ₄	4.47 g BaCl ₂
c.	5 g NaCl	8.91 g BaCl ₂
d.	5 g BaCl ₂	3.41 g Na ₂ SO ₄
e.	5 g BaSO ₄	3.04 g Na ₂ SO ₄
f.	5 lb NaCl	6.08 lb Na ₂ SO ₄
g.	5 lb BaCl ₂	5.59 lb BaSO ₄
h.	5 lb Na ₂ SO ₄	8.21 lb BaSO ₄
i.	5 lb NaCl	9.98 lb BaSO ₄

5.1.2



Mol. wt.: 169.89 58.45 143.3 85.01

a. Basis: 5.0 g NaCl

$$\text{Example: } \frac{5.0 \text{ NaCl}}{58.45 \text{ g NaCl}} \left| \begin{array}{c} 1 \text{ g mol NaCl} \\ 1 \text{ g mol NaCl} \end{array} \right| \left| \begin{array}{c} 1 \text{ g mol AgNO}_3 \\ 1 \text{ g mol NaCl} \end{array} \right| \left| \begin{array}{c} 169.89 \text{ g AgNO}_3 \\ 1 \text{ g mol AgNO}_3 \end{array} \right| =$$

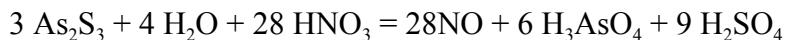
$$\boxed{14.53 \text{ g AgNO}_3}$$

<u>Problem</u>	<u>Basis</u>	<u>Answer</u>
b.	5 g AgCl	5.92 g AgNO ₃
c.	5 g NaNO ₃	10.00 g AgNO ₃
d.	5 g AgNO ₃	1.721 g NaCl
e.	5 g AgCl	2.04 g NaCl
f.	5 lb NaNO ₃	3.44 lb NaCl
g.	5 lb AgNO ₃	4.22 lb AgCl
h.	5 lb NaCl	12.27 lb AgCl
i.	5 lb AgNO ₃	4.22 lb AgCl

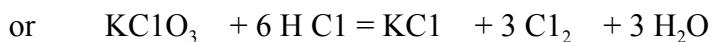
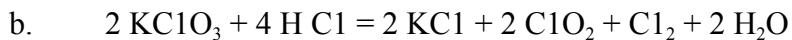
Solutions Chapter 5

5.1.3

a. The balanced equation is:



and the reaction is unique within relative proportions.



We classify these reactions as non-unique since they are not simply proportional equations, but are linearly independent, and infinitely many equations can be obtained by linear combination.

5.1.4

Basis: 2 g mol

$$\begin{array}{lll} \text{C: } 6 \times 12 = 72 & \text{H: } 8 \times 1 = 8 & \text{O: } 6 \times 16 = 96 \\ \text{mol. wt.} = 72 + 8 + 96 = 176 & & \end{array}$$

$$\frac{2 \text{ g mol}}{1 \text{ g mol}} \left| \frac{176 \text{ g}}{454 \text{ g}} \right| \frac{1 \text{ lb}}{} = \boxed{0.775 \text{ lb}}$$

Solutions Chapter 5

5.1.5

a)	LHS	RHS
C	4	4
H	10	10
Zn	1	1
O	14	14

Yes, the equation is balanced.

b) Basis: 1.5 kg ZnO

$$\frac{1.5 \text{ kg ZnO}}{1.0 \text{ kg ZnO}} \left| \begin{array}{c} 1000 \text{ g ZnO} \\ 81.40 \text{ g ZnO} \end{array} \right| \frac{1 \text{ gmol ZnO}}{1 \text{ gmol ZnO}} \left| \begin{array}{c} 123.4 \text{ gDEZ} \\ 1 \text{ gmol DEZ} \end{array} \right| \frac{123.4 \text{ gDEZ}}{1 \text{ gmol DEZ}}$$

$$\times \frac{1.0 \text{ kg DEZ}}{1000 \text{ g DEZ}} = \boxed{2.27 \text{ kg DEZ}}$$

$$\text{c) } \frac{20 \text{ cm}^3 \text{ H}_2\text{O}}{1 \text{ cm}^3 \text{ H}_2\text{O}} \left| \begin{array}{c} 1.0 \text{ g H}_2\text{O} \\ 18.0 \text{ g H}_2\text{O} \end{array} \right| \frac{1.0 \text{ gmol H}_2\text{O}}{5 \text{ gmol H}_2\text{O}} \left| \begin{array}{c} 123.4 \text{ g DEZ} \\ 1 \text{ gmol DEZ} \end{array} \right| \frac{123.4 \text{ g DEZ}}{1 \text{ gmol DEZ}}$$

$$= \boxed{27.4 \text{ g DEZ}}$$

5.1.6

Basis: Data given in problem statement

$$\frac{55.847 \text{ gFe}}{1} \left| \begin{array}{c} 1 \text{ gmol Fe} \\ 55.847 \text{ gFe} \end{array} \right| \frac{1 \text{ gmol X}_2\text{O}_3}{2 \text{ gmol Fe}} \left| \begin{array}{c} 2 \text{ gmol X} \\ 1 \text{ gmol X}_2\text{O}_3 \end{array} \right| = 1 \text{ gmol X}$$

$$\frac{55.847 \text{ gFe}}{1} \left| \begin{array}{c} 1 \text{ gmol Fe} \\ 55.847 \text{ gFe} \end{array} \right| \frac{1 \text{ gmol X}_2\text{O}_3}{2 \text{ gmol Fe}} \left| \begin{array}{c} 3 \text{ gmol O} \\ 1 \text{ gmol X}_2\text{O}_3 \end{array} \right| \frac{16 \text{ g O}}{1 \text{ gmol O}} = 240 \text{ g O}$$

$$50.982 \text{ g X}_2\text{O}_3 - 24.0 \text{ g O} = 26.982 \text{ g X}$$

$$\frac{26.982 \text{ g X}}{1 \text{ gmol X}} = 26.982 \frac{\text{g}}{\text{gmol}} \text{ hence X = A1}$$

Solutions Chapter 5

5.1.7

Basis: Data given in problem statement

$$\frac{1.603 \text{ g CO}_2}{1} \left| \frac{1 \text{ gmol CO}_2}{44.01 \text{ g CO}_2} \right| \frac{1 \text{ gmol C}}{1 \text{ gmol CO}_2} \left| \frac{12.00 \text{ g C}}{1 \text{ gmol C}} \right| = 0.437 \text{ g C}$$

$$\frac{0.2810 \text{ g H}_2\text{O}}{1} \left| \frac{1 \text{ gmol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \right| \frac{2 \text{ gmol H}}{1 \text{ gmol H}_2\text{O}} \left| \frac{1.008 \text{ g H}}{1 \text{ gmol H}} \right| = 0.03144 \text{ g H}$$

$$0.6349 \text{ g C}_x\text{H}_y\text{O}_z - 0.437 \text{ g C} - 0.03144 \text{ g H} = 0.1661 \text{ g O}$$

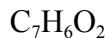
Based on O:

$$\frac{0.1661 \text{ g O}}{1} \left| \frac{1 \text{ gmol O}}{16.00 \text{ g O}} \right| = \frac{0.01038 \text{ gmol O}}{0.01038} = 1 \text{ gmol O}$$

$$\frac{0.437 \text{ g C}}{1} \left| \frac{1 \text{ gmol C}}{12.00 \text{ g C}} \right| = \frac{0.03642 \text{ gmol C}}{0.01038} = 3.5 \text{ gmol C}$$

$$\frac{0.03144 \text{ g H}}{1} \left| \frac{1 \text{ gmol H}}{1.008 \text{ g H}} \right| = \frac{0.03119 \text{ gmol H}}{0.01038} = 3 \text{ gmol H}$$

The formula in integers is



5.1.8

Basis: Data given in the problem

Mass of hydrate 10.407 g

Mass of dry sample -9.520 g

Mass of water 0.887 g

$$\frac{9.520 \text{ g BaI}_2}{391 \text{ g BaI}_2} \left| \frac{1 \text{ g mol BaI}_2}{391 \text{ g BaI}_2} \right| = 0.0243 \text{ g mol BaI}_2$$

$$\frac{0.887 \text{ g H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \left| \frac{1 \text{ g mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \right| = 0.0493 \text{ g mol H}_2\text{O}$$

$\frac{0.0243}{0.0493} = 0.49$, or 2 H₂O for 1 BaI₂. Thus the hydrate is BaI₂ · 2H₂O.

Solutions Chapter 5

5.1.9

Basis: 2000 tons 93.2% H₂SO₄ (1 day)

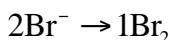
$$\text{a. } \frac{2000 \text{ tons soln}}{1 \text{ ton soln}} \left| \begin{array}{c} 0.932 \text{ ton H}_2\text{SO}_4 \\ \hline 1 \text{ ton soln} \end{array} \right| \frac{1 \text{ ton mole H}_2\text{SO}_4}{98 \text{ ton H}_2\text{SO}_4} \left| \begin{array}{c} 1 \text{ mol S} \\ \hline 1 \text{ mol H}_2\text{SO}_4 \end{array} \right| \frac{32 \text{ ton S}}{1 \text{ ton mol S}} = [609 \text{ ton S}]$$

$$\text{b. } \frac{609 \text{ ton S}}{32 \text{ ton S}} \left| \begin{array}{c} 1 \text{ ton mol S} \\ \hline 1 \text{ mol S} \end{array} \right| \frac{1.5 \text{ mol O}_2}{1 \text{ mol S}} \left| \begin{array}{c} 32 \text{ ton O}_2 \\ \hline 1 \text{ ton mol O}_2 \end{array} \right| = [913.5 \text{ ton O}_2]$$

$$\text{c. } \frac{609 \text{ ton S}}{32 \text{ ton S}} \left| \begin{array}{c} 1 \text{ ton mole S} \\ \hline 1 \text{ mol S} \end{array} \right| \frac{1 \text{ mole H}_2\text{O}}{1 \text{ mol S}} \left| \begin{array}{c} 18 \text{ ton H}_2\text{O} \\ \hline 1 \text{ ton mol H}_2\text{O} \end{array} \right| = [342.6 \text{ ton H}_2\text{O}]$$

5.1.10

Basis: 1 lb Br₂



$$\text{MW: } \begin{array}{ll} 70.9 & 159.8 \end{array}$$

$$\text{Br}_2 + \text{C}_2\text{H}_4 \rightarrow \text{C}_2\text{H}_4\text{Br}_2$$

$$\text{MW: } \begin{array}{ll} 28 & 187.9 \end{array}$$

$$\text{a. } \frac{0.27 \text{ lb acid}}{2000 \text{ lb seawater}} \left| \begin{array}{c} 1 \times 10^6 \text{ lb seawater} \\ \hline 65 \text{ lb Br}_2 \end{array} \right| = [2.08 \text{ lb 98% H}_2\text{SO}_4 / \text{lb Br}_2]$$

$$\text{b. } \frac{1 \text{ lb Br}_2}{159.9 \text{ lb Br}_2} \left| \begin{array}{c} \text{mole Br}_2 \\ \hline 1 \text{ mole Br}_2 \end{array} \right| \frac{1 \text{ mole Cl}_2}{1 \text{ mole Br}_2} \left| \begin{array}{c} 70.9 \text{ lb Cl}_2 \\ \hline 1 \text{ mole Cl}_2 \end{array} \right| = [0.445 \text{ lb Cl}_2]$$

$$\text{c. } \frac{1 \text{ lb Br}_2}{65 \text{ lb Br}_2} \left| \begin{array}{c} 1 \times 10^6 \text{ lb sea water} \\ \hline 15,400 \text{ lb seawater} \end{array} \right| = [15,400 \text{ lb seawater}]$$

$$\text{d. } \frac{1 \text{ lb Br}_2}{159.9 \text{ lb Br}_2} \left| \begin{array}{c} \text{mol Br}_2 \\ \hline 1 \text{ mol Br}_2 \end{array} \right| \frac{1 \text{ mol C}_2\text{H}_4\text{Br}_2}{1 \text{ mol Br}_2} \left| \begin{array}{c} 187.9 \text{ lb C}_2\text{H}_4\text{Br}_2 \\ \hline 1 \text{ mol C}_2\text{H}_4\text{Br}_2 \end{array} \right| = [1.176 \text{ lb C}_2\text{H}_4\text{Br}_2]$$

Solutions Chapter 5

5.1.11

	<u>MW</u>		<u>MW</u>
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	277.9	$\text{FeSO}_4 \cdot \text{H}_2\text{O}$	169.9
$\text{FeSO}_4 \cdot 4\text{H}_2\text{O}$	223.9	FeSO_4	151.9

It is best to evaluate the three types of ferrous sulfate in terms of the cost/ton of FeSO_4

Basis: 475 ton material

a. $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$:

$$\frac{\$83,766.25}{475 \text{ ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} = \$176.35/\text{ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}, \text{ which is equivalent to}$$

$$\frac{\$176.35}{1 \text{ ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} \left| \frac{277.9 \text{ ton } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}}{1 \text{ ton mol } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}} \right| \frac{1 \text{ ton mol } \text{FeSO}_4 \cdot 7\text{H}_2\text{O}}{1 \text{ ton mol } \text{FeSO}_4}$$

$$\frac{1 \text{ ton mol } \text{FeSO}_4}{151.9 \text{ ton } \text{FeSO}_4} = \$323/\text{ton } \text{FeSO}_4$$

b. $\text{FeSO}_4 \cdot 4\text{H}_2\text{O}$:

$$\frac{\$323}{\text{ton } \text{FeSO}_4} \left| \frac{151.9 \text{ ton } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4} \right| \frac{1 \text{ ton mol } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}} \left| \frac{1 \text{ ton mol } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}}{223.9 \text{ ton } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}} \right.$$

$$= \boxed{\$219 / \text{ton } \text{FeSO}_4 \cdot 4\text{H}_2\text{O}}$$

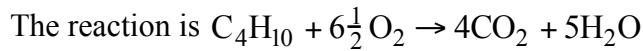
c. $\text{FeSO}_4 \cdot \text{H}_2\text{O}$:

$$\frac{\$323}{\text{ton } \text{FeSO}_4} \left| \frac{151.9 \text{ ton } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4} \right| \frac{1 \text{ ton mol } \text{FeSO}_4}{1 \text{ ton mol } \text{FeSO}_4 \cdot \text{H}_2\text{O}} \left| \frac{1 \text{ ton mol } \text{FeSO}_4 \cdot \text{H}_2\text{O}}{169.9 \text{ ton } \text{FeSO}_4 \cdot \text{H}_2\text{O}} \right.$$

$$= \boxed{\$289 / \text{ton } \text{FeSO}_4 \cdot \text{H}_2\text{O}}$$

Solutions Chapter 5

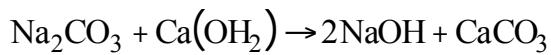
5.1.12



Basis: 1 mol C₄H₁₀

$$\begin{aligned} \text{Minimum O}_2 &\cong (\text{LFL}) \left(\frac{\text{mol O}_2 \text{ for complete combustion}}{\text{mol C}_4\text{H}_{10}} \right) \\ &\cong (1.9\%) (6.5/1) = \boxed{12.4\%} \end{aligned}$$

5.1.13



Basis: 1 ton of soda ash (Na₂CO₃)

$$\begin{array}{c|c|c|c|c} 1 \text{ ton Na}_2\text{CO}_3 & | & 1 \text{ ton mol Na}_2\text{CO}_3 & | & 2 \text{ ton mol NaOH} \\ | & & | & & | \\ 106 \text{ ton Na}_2\text{CO}_3 & | & 1 \text{ ton mol Na}_2\text{CO}_3 & | & 40.0 \text{ ton NaOH} \\ | & & | & & | \\ 1 \text{ ton mol NaOH} & & & & 1 \text{ ton mol NaOH} \end{array} =$$

0.755 ton NaOH

$$\frac{\$130}{1 \text{ ton Na}_2\text{CO}_3} \left| \frac{1 \text{ ton Na}_2\text{CO}_3}{0.755 \text{ NaOH}} \right. = \boxed{\$172 / \text{ton Na}_2\text{CO}_3}$$

The above result is for the case of free Ca(OH)₂. Otherwise, the value must be reduced to compensate for the cost of the CA(OH)₂—which might come from the CaCO₃ produced, and possibly be cheaper than Ca(OH)₂ purchased directly.

Solutions Chapter 5

5.1.14

Basis: 1 ton dolomite



Assume complete reactions



<u>Comp.</u>	<u>%</u>	<u>lb</u>	<u>mol.wt.</u>	<u>lb mol that react</u>
CaCO ₃	68	1360	100.0	13.60
MgCO ₃	30	600	84.3	<u>7.13</u>
SiO ₂	<u>2</u>	<u>40</u>	60.0	
Total	100	2000		20.73

a. $\frac{20.73 \text{ lb mol react}}{\text{ton dolomite}} \left| \frac{1 \text{ mol CO}_2 \text{ produced}}{1 \text{ mol react}} \right| \frac{44 \text{ lb}}{1 \text{ lb mol CO}_2} = [912 \text{ lb CO}_2]$

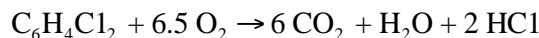
b. $\frac{20.73 \text{ lb mol react}}{\text{ton dolomite}} \left| \frac{1 \text{ mol H}_2\text{SO}_4 \text{ reqd}}{1 \text{ mol react}} \right| \frac{98 \text{ lb H}_2\text{SO}_4}{1 \text{ mole H}_2\text{SO}_4} \left| \frac{100 \text{ lb acid}}{94 \text{ lb H}_2\text{SO}_4} \right. = [2160 \text{ lb acid}]$

Solutions Chapter 5

5.1.15

Basis: 1 kg dichlorobenzene (DCB)

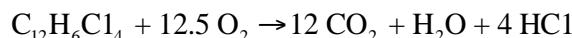
The balanced stoichiometric reaction for dichlorobenzene is shown below:



Therefore, for 1 kg of dichlorobenzene, the following moles of HC1 are produced:

$$\frac{1 \text{ kg DCB}}{147 \text{ kg DCB}} \left| \frac{1 \text{ kg mol DCB}}{1 \text{ kg mol DCB}} \right| \frac{2 \text{ kg mol HC1}}{1 \text{ kg mol DCB}} = 0.0136 \text{ kg mol HC1}$$

The balanced stoichiometric reaction for tetrachlorobiphenyl is as shown below:



Therefore, for 1 lb of tetrachlorobiphenyl (TCB), the following moles of HC1 are produced:

Basis: 1 kg TCB

$$\frac{1 \text{ kg TCB}}{290 \text{ kg TCB}} \left| \frac{1 \text{ kg mol TCB}}{1 \text{ kg mol TCB}} \right| \frac{4 \text{ kg mol HC1}}{1 \text{ kg mol TCB}} = 0.0138 \text{ kg mol HC1}$$

Thus, the amount of acid produced does not change significantly ($\approx 1.5\%$), and neither will the amount of base required for neutralization.

5.2.1

Basis: 1 L solution = 1000 g H₂O

$$\frac{50 \text{ g H}_2\text{S}}{10^6 \text{ g soln}} \left| \frac{1 \text{ g mol H}_2\text{S}}{34 \text{ g H}_2\text{S}} \right| \frac{1 \text{ g mol HOCl}}{1 \text{ g mol H}_2\text{S}} \left| \frac{52.45 \text{ g HOCl}}{1 \text{ g mol HOCl}} \right| \frac{100 \text{ g HOCl soln}}{5 \text{ g HOCl}}$$

$$\frac{1000 \text{ g soln}}{1 \text{ L soln}} \left| \frac{2}{-} \right| = \boxed{3.08 \text{ g HOCl solution}}$$

You can use the density of H₂O for the density of the solution as the H₂S content has negligible effect on the density.

Solutions Chapter 5

5.2.2

Basis: 10 lb moles phosgene

For phosgene:

$$\xi = \frac{n_f - n_i}{v} = \frac{10 - 0}{1} = [10] \text{ reacting moles}$$

$$n_{CO,i} = n_{CO,f} - v_{CO}\xi = 7 - (-1)(10) = [17 \text{ lb mol}]$$

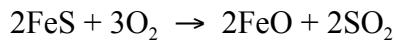
$$n_{Cl_2,i} = n_{Cl_2,f} - v_{Cl_2,i}\xi = 3 - (-1)10 = [13 \text{ lb mol}]$$

5.2.3

Basis: 135 mol CH₄

$$\xi = \frac{0 - 135}{-6} = [22.5 \text{ reacting mols}]$$

5.2.4



MW 87.85 32 71.85 64

Basis: Use 100 g slag

<u>Component</u>	<u>g = %</u>	<u>MW</u>	<u>g/mol</u>
FeO	80	71.85	1.113
FeS	20	87.85	0.228
	100		

For the FeO:

$$\xi = \frac{n_f - n_i}{v} = \frac{1.113 - 0}{2} = 0.557 \text{ reacting moles}$$

For the FeS:

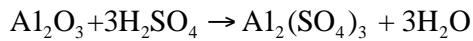
$$\xi = \frac{n_f - n_i}{v} = \frac{0.228 - n_i}{-2} = 0.557$$

$$n_{initial \text{ FeS}} = [1.341 \text{ g mol}]$$

Solutions Chapter 5

5.2.5

Basis: 1080 lb bauxite



$$\frac{1080 \text{ lb bauxite}}{100 \text{ lb bauxite}} \left| \frac{55.4 \text{ lb Al}_2\text{O}_3}{101.9 \text{ lb Al}_2\text{O}_3} \right| \frac{1 \text{ lb mol Al}_2\text{O}_3}{101.9 \text{ lb Al}_2\text{O}_3} = 5.87 \text{ lb mol Al}_2\text{O}_3$$

$$\xi = \frac{0 - 5.87}{-1} = 5.87 \text{ reacting moles}$$

Basis: 2510 lb H₂SO₄ (77%)

$$\frac{2510 \text{ lb H}_2\text{SO}_4 (77\%)}{1 \text{ lb H}_2\text{SO}_4(77\%)} \left| \frac{0.77 \text{ lb H}_2\text{SO}_4}{98.1 \text{ lb H}_2\text{SO}_4} \right| \frac{1 \text{ lb mol H}_2\text{SO}_4}{98.1 \text{ lb H}_2\text{SO}_4} = 19.70 \text{ lb mol H}_2\text{SO}_4$$

$$\xi = \frac{0 - 19.70}{-3} = 6.57 \text{ reacting moles}$$

(a) Al₂O₃ is the limiting reactant and H₂SO₄ is the excess reactant.

(b) %xs H₂SO₄: $\frac{(19.70)(1/3) - 5.87}{5.87} (100) = \frac{6.57 - 5.87}{5.87} (100) = \boxed{11.9\%}$

or H₂SO₄ (77%) required: $\frac{(5.87)(3)(98.1)}{0.77} = 2244 \text{ lb}$

$$\%_{\text{xs}} = \frac{2510 - 2244}{2244} = 12\%$$

Basis: 2000 lb Al₂(SO₄)₃

$$\frac{2000 \text{ lb Al}_2(\text{SO}_4)_3}{342.1 \text{ lb Al}_2(\text{SO}_4)_3} \left| \frac{1 \text{ lb mol Al}_2(\text{SO}_4)_3}{1 \text{ lb mol Al}_2\text{O}_3} \right| \frac{1 \text{ lb mol Al}_2\text{O}_3}{101.9 \text{ lb Al}_2\text{O}_3}$$

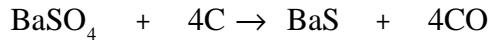
$$\frac{101.9 \text{ lb Al}_2\text{O}_3}{1 \text{ lb mol Al}_2\text{O}_3} \left| \frac{1 \text{ lb bauxite}}{0.554 \text{ lb Al}_2\text{O}_3} \right| = 1075 \text{ lb bauxite}$$

$$\frac{1075}{1080} \times 100 = \boxed{99.5\%}$$

Solutions Chapter 5

5.2.6

Basis: 100 kg of fusion mass



Comp.	Wt.% = kg	MW	kg mol
BaSO ₄	11.1	233.3	0.0476
BaS	72.8	169.3	0.430
C	13.9	12.0	1.16
Ash	2.2	—	—
	100.0		

$$\text{BaSO}_4 \text{ orig.} = 0.0476 + 0.430 = 0.4776 \text{ mol}$$

$$C_{\text{orig.}} = 1.16 + 4(0.430) = 2.88 \text{ mol} \quad \text{Carbon is the limiting reactant.}$$

$$\text{Needed C for complete reaction} = 4(0.4776) = 1.9104 \text{ mol}$$

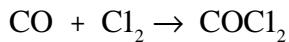
$$\% \text{ excess} = \frac{2.88 - 1.91}{1.91} \times 100 = \boxed{50.8\% \text{ excess C}}$$

$$\text{Degree of completion} = \frac{0.4776 - 0.0476}{0.4776} = \boxed{0.900}$$

You could calculate the extent of reaction from the BaSO₄, and use it to get the original amounts of reactants.

Solutions Chapter 5

5.2.7



Basis: 20 kg products

Comp.	kg	mol.wt.	kg	kg mol	kg mol
				C1 ₂ in	CO in
C1 ₂	3.00	70.91	0.0423	0.0423	
COCl ₂	10.00	98.91	0.1011	0.1011	0.1011
CO	7.00	28.01	0.250		0.250
	20.00		0.393	0.143	0.351

The extent of reaction is

$$\text{CO: } \frac{0 - 0.351}{-1} = 0.351$$

$$\text{C1}_2: \frac{0 - 0.143}{-1} = 0.143 \text{ (smallest } \xi \text{)}$$

C1₂ is the limiting reactant; CO is the excess reactant

a. $\frac{0.351 - 0.143}{0.143} (100) = \boxed{145\% \text{ excess CO}}$

b. $\frac{0.1011}{0.143} (100) = \boxed{70.7\% \text{ C1}_2 \text{ converted}}$

c. $\frac{0.1011 \text{ kg mol COCl}_2}{(0.143 + 0.351) \text{ kg mol reactants}} = \boxed{0.205}$

5.2.8

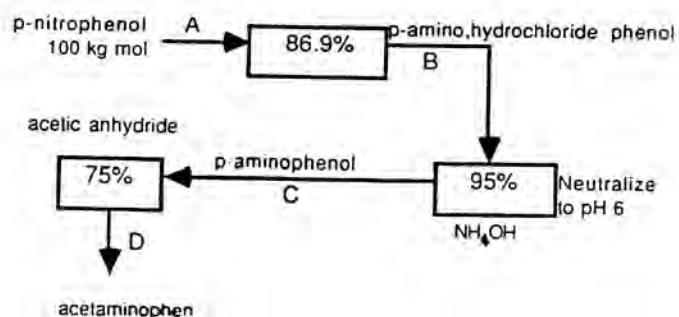
$$\text{Amount of o-n hydrolized: } \frac{0.10 \text{ m mol}}{1 \text{ m mol}} \left| \frac{1000 \mu \text{ mol}}{1 \text{ m mol}} \right. = 100 \mu \text{ mol}$$

$$\text{Total protein: } \frac{1.00 \text{ mg}}{1 \text{ mL}} \left| \frac{0.10 \text{ mL}}{1 \text{ mL}} \right. = 0.100 \text{ mg}$$

$$\text{Specific activity} = \frac{100 \mu \text{ mol}}{(5 \text{ min})(0.10 \text{ mg protein})} = 200 \mu \text{ mol}/(\text{min})(\text{mg protein})$$

Solutions Chapter 5

5.2.9



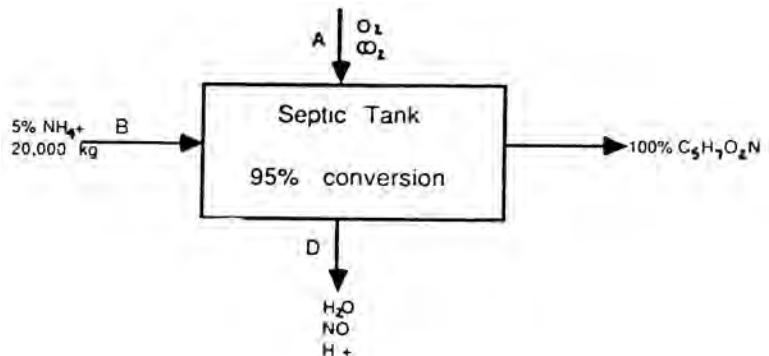
Basis: 100 kg mol A

$$\frac{100 \text{ kg mol } \text{C}_6\text{H}_5\text{NO}_2}{100 \text{ kg mol } \text{C}_6\text{H}_5\text{NO}_2} \left| \frac{86.9 \text{ kg mol } \text{C}_6\text{H}_8\text{NOCl}}{100 \text{ kg mol } \text{C}_6\text{H}_5\text{NO}_2} \right| \frac{0.95 \text{ kg mol } \text{C}_6\text{H}_7\text{NO}}{\text{kg mol } \text{C}_6\text{H}_8\text{NOCl}} \left| \frac{3 \text{ kg mol } \text{C}_8\text{H}_9\text{NO}_2}{4 \text{ kg mol } \text{C}_6\text{H}_7\text{NO}} \right|$$

→ **0.619 fraction overall conversion.**

Solutions Chapter 5

5.2.10



C ₅	60		
H ₇	7	NH ₄ ⁺	
O ₂	32	N	14
N	14	H ₄	4
113 kg/k mol			18

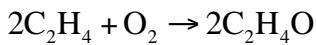
$$\frac{20,000 \text{ kg C}}{100 \text{ kg C}} \left| \frac{5 \text{ kg NH}_4^+}{1 \text{ kg mol NH}_4^+} \right. = 1000 \text{ kg NH}_4^+$$

$$\frac{1000 \text{ kg NH}_4^+}{18 \text{ kg NH}_4^+} \left| \frac{\text{kg mol NH}_4^+}{1 \text{ kg mol NH}_4^+} \right. = 55.556 \text{ k mol NH}_4^+$$

$$\frac{55.556 \text{ kg mol NH}_4^+}{55 \text{ kg mol NH}_4^+} \left| \frac{1 \text{ kg mol C}_5\text{H}_7\text{O}_2\text{N}}{1 \text{ kg mol NH}_4^+} \right. \left| \frac{95 \text{ kg mol NH}_4^+}{100 \text{ kg mol fed}} \right. \left| \frac{113 \text{ kg C}_5\text{H}_7\text{O}_2\text{N}}{\text{kg mol C}_5\text{H}_7\text{O}_2\text{N}} \right.$$

$$= \boxed{108.43 \text{ kg C}_5\text{H}_7\text{O}_2\text{N}}$$

5.2.11



For 100% conversion of C₂H₄ according to reaction (a):

$$\frac{2 \text{ mol C}_2\text{H}_4\text{O/time}}{2 \text{ mol C}_2\text{H}_4/\text{time}} = \boxed{1}$$

For reaction b3:

$$\frac{1 \text{ mol C}_2\text{H}_4\text{O/time}}{1.33 \text{ mol C}_2\text{H}_4/\text{time}} = \boxed{0.75}$$

Solutions Chapter 5

5.2.12

Step 4:

The molecular weights needed to solve the problem and the gram moles forming the basis are:

Component	kg	Mol. wt.	g mol
Sb ₂ S ₃	0.600	339.7	1.766
Fe	0.250	55.85	4.476
Sb	0.200	121.8	1.642
FeS		87.91	

The process is illustrated in Fig. P9.19

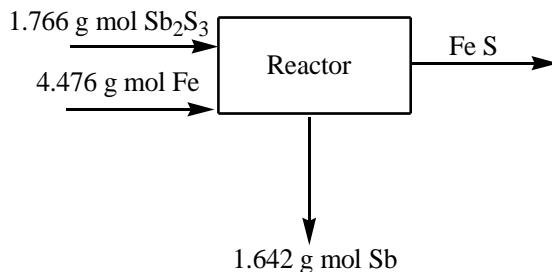


Figure P9.19

Step 5: Basis: Data given in problem statement

Steps 6-9:

- (a) To find the limiting reactant, we examine the chemical reaction equation. The ratio of Sb₂S₃ to Fe in the equation is 1/3 = 0.33. In the actual reaction the corresponding ratio is 1.766/4.476 = 0.395, hence Sb₂S₃ is the excess reactant and Fe is the limiting reactant. The Sb₂S₃ required to react with the limiting reactant is 4.476/3 = 1.492 g mol.
- (b) The percentage of excess reactant is

$$\% \text{ excess} = \frac{1.766 - 1.492}{1.492} (100) = \boxed{18.4\% \text{ excess Sb}_2\text{S}_3}$$

- (c) Although Fe is the limiting reactant, not all the limiting reactant reacts. We can compute from the 1.64 g mol of Sb how much Fe actually does react:

Solutions Chapter 5

$$\frac{1.64 \text{ g mol Sb}}{2 \text{ g mol Sb}} \left| \frac{3 \text{ g mol Fe}}{2 \text{ g mol Sb}} \right. = 2.46 \text{ g mol Fe}$$

If by the fractional degree of completion is meant the fraction conversion of Fe to products, then

$$\text{Fractional degree of completion} = \frac{2.46}{4.48} = \boxed{0.55}$$

- (d) Let us assume that the percent conversion refers to the Sb_2S_3 since the reference compound is not specified in the question posed.

$$\frac{1.64 \text{ g mol Sb}}{2 \text{ g mol Sb}} \left| \frac{1 \text{ g mol } \text{Sb}_2\text{S}_3}{2 \text{ g mol Sb}} \right. = 0.82 \text{ g mol } \text{Sb}_2\text{S}_3$$

$$\% \text{ conversion of } \text{Sb}_2\text{S}_3 \text{ to Sb} = \frac{0.82}{1.77} (100) = \boxed{46.3\%}$$

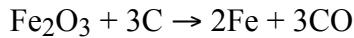
- (e) The yield will be stated as kilograms of Sb formed per kilogram of Sb_2S_3 that was fed to the reaction

$$\text{Yield} = \frac{0.200 \text{ kg Sb}}{0.600 \text{ kg } \text{Sb}_2\text{S}_3} = \boxed{\frac{0.33 \text{ kg Sb}}{1 \text{ kg } \text{Sb}_2\text{S}_3}}$$

Solutions Chapter 5

5.2.13

Reaction on which to base excess is



Basis: 1 ton Fe₂O₃

a. Theoretical C =

$$\frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{2000 \text{ lb Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \right| \left| \frac{1 \text{ lb mol Fe}_2\text{O}_3}{159.7 \text{ lb Fe}_2\text{O}_3} \right| \left| \frac{3 \text{ lb mol C}}{1 \text{ lb mol Fe}_2\text{O}_3} \right| \left| \frac{12 \text{ lb C}}{\text{lb mol C}} \right| = 451 \text{ lb}$$

$$\frac{600 - 451}{451} \times 100 = \boxed{33\% \text{ excess C}}$$

$$\text{b. } \frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{1200 \text{ lb Fe}}{1 \text{ ton Fe}_2\text{O}_3} \right| \left| \frac{\text{lb mol Fe}}{55.85 \text{ lb Fe}} \right| \left| \frac{1 \text{ lb mol Fe}_2\text{O}_3}{2 \text{ lb mol Fe}} \right| \left| \frac{159.7 \text{ lb Fe}_2\text{O}_3}{1 \text{ lb mol Fe}_2\text{O}_3} \right|$$

= 1720 lb Fe₂O₃ reacts

$$\frac{1720}{2000} \times 100 = \boxed{86.0\% \text{ Fe}_2\text{O}_3}$$

$$\text{c. (i) } \frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{183 \text{ lb FeO}}{71.85 \text{ lb FeO}} \right| \left| \frac{\text{lb mol FeO}}{2 \text{ lb mol FeO}} \right| \left| \frac{1 \text{ lb mol CO}}{1 \text{ lb mol CO}} \right| \left| \frac{28 \text{ lb CO}}{1 \text{ lb mol CO}} \right| = 35.62 \text{ lb CO}$$

$$\frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} \right| \left| \frac{1 \text{ lb mol Fe}}{2 \text{ lb mol Fe}} \right| \left| \frac{3 \text{ lb mol CO}}{1 \text{ lb mol CO}} \right| \left| \frac{28 \text{ lb CO}}{1 \text{ lb mol CO}} \right| = 902.4 \text{ lb CO}$$

$$\text{Total (35.62 lb CO + 902.4 lb CO)} = \boxed{938 \text{ lb CO}}$$

$$\text{(ii) } \frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} \right| \left| \frac{\text{lb mol Fe}}{2 \text{ lb mol Fe}} \right| \left| \frac{3 \text{ lb mol C}}{1 \text{ lb mol Fe}} \right| \left| \frac{12 \text{ lb C}}{\text{lb mol C}} \right| = 387.1 \text{ lb C}$$

$$\frac{1 \text{ ton Fe}_2\text{O}_3}{1 \text{ ton Fe}_2\text{O}_3} \left| \frac{183 \text{ lb FeO}}{71.85 \text{ lb FeO}} \right| \left| \frac{\text{lb mol FeO}}{2 \text{ lb mol FeO}} \right| \left| \frac{1 \text{ lb mol C}}{1 \text{ lb mol FeO}} \right| \left| \frac{12 \text{ lb C}}{\text{lb mol C}} \right| = 15.3 \text{ lb C}$$

$$387.1 + 15.3 = \boxed{402.4 \text{ lb C used / 1ton Fe}_2\text{O}_3}$$

Solutions Chapter 5

or use $\frac{938 \text{ lb CO}}{28 \text{ lb CO}} \left| \begin{array}{c} 1 \text{ lb mol CO} \\ 1 \text{ lb mol CO} \end{array} \right| \frac{12 \text{ lb C}}{1 \text{ lb mol C}}$

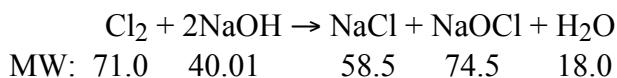
d. Selectivity: Mass basis: $\frac{1200 \text{ lb Fe formed}}{183 \text{ lb FeO formed}} = 6.56$

$$\frac{1200 \text{ lb Fe}}{55.85 \text{ lb Fe}} \left| \begin{array}{c} \text{lb mol Fe} \\ \text{55.85 lb Fe} \end{array} \right| = 21.49 \text{ lb mol Fe}$$

$$183 \text{ lb FeO} \times \frac{\text{lb mol FeO}}{71.85 \text{ lb FeO}} = 2.55 \text{ lb mol FeO}$$

$$\text{Mole Basis: } \frac{21.49 \text{ lb mol Fe}}{2.55 \text{ lb mol FeO}} = 8.44$$

5.2.14



Basis: 1145 lb_m NaOH + 851 lb Cl₂ (\rightarrow 618 lb_m NaOCl)

a. Determine limiting reactant

Assume all Cl₂ reacts, calculate lb of NaOH required

$$\text{NaOH required} = \frac{2 \text{ lb mol NaOH}}{1 \text{ lb mol Cl}_2} \left| \begin{array}{c} \text{lb mol Cl}_2 \\ 71 \text{ lb Cl}_2 \end{array} \right| \frac{851 \text{ lb Cl}_2}{40.01 \text{ lb NaOH}} \left| \begin{array}{c} 40.01 \text{ lb NaOH} \\ \text{lb mol NaOH} \end{array} \right|$$

$$= 959.11 \text{ lb NaOH required}$$

Cl₂ is limiting reactant

or use extent of reaction

$$\text{NaOH: } \frac{1145}{40} = 28.63 \text{ lb mol} \quad (0-28.63)/-2 = 14.3$$

$$\text{Cl}_2: \quad \frac{851}{71.0} = 11.99 \text{ lb mol} \quad (0-11.99)/-1 = 12.0 \text{ (minimum)}$$

Solutions Chapter 5

b. % excess NaOH = $\frac{\text{lb mol NaOH in excess}}{\text{lb mol NaOH for rxn}} \times 100$

$$= \frac{(1145 \text{ lb}_m/\text{NaOH}) \left(\frac{\text{lb mol NaOH}}{40.01 \text{ lb NaOH}} \right) \times (959.11) \left(\frac{1}{40.01} \right)}{(959.11) \left(\frac{1}{40.01} \right)} \times 100$$

$$= [19.4\% \text{ excess NaOH}]$$

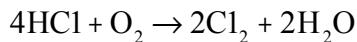
c. Degree of completion = $\frac{\text{lb mol Cl}_2 \text{ that reacted}}{\text{lb mol Cl}_2 \text{ available to react}} = \frac{\frac{618}{74.5}}{\frac{851}{71.0}} = 0.692$
 or $\frac{\xi}{\xi_{\min}} = \frac{8.30}{12.8} = 0.69$

d. Yield of NaOCl = $\frac{618 \text{ lb NaOCl}}{851 \text{ lb Cl}_2} = [0.726 \frac{\text{lb}}{\text{lb}}]$

e. $\frac{618}{745} = 8.30 \text{ lb mol NaOCl}$ $\xi = \frac{8.30 - 0}{1} = [8.30] \text{ reacting moles}$

Solutions Chapter 5

5.2.15



MW 35.45 32 71.0 18

Basis: 100 mol gas

<u>Exit comp.</u>	<u>% mol</u>	<u>Entering moles</u>	
		<u>HC1</u>	<u>O₂</u>
HC1	4.4	4.4	-
Cl ₂	19.8	(2)(19.8)	39.6
H ₂ O	19.8	(1/2)(19.8)	-
O ₂	4.0	-	4.0
N ₂	<u>52.0</u>	<u>-</u>	<u>-</u>
	100.0	44.0	13.9

(The N₂ balance gives the O₂ as 13.8).

Calculate the extent of reaction for complete reaction

$$\text{For HC1: } \frac{0 - 44.0}{-4} = 11.0 \text{ (the minimum)}$$

$$\text{For O}_2: \quad \frac{0 - 13.9}{-1} = 13.9$$

(a) HC1 is the limiting reactant

$$(b) \quad \% \text{ excess} = \frac{139 - \frac{44.0}{4}}{\frac{44.0}{4}} 100 = \boxed{26.36\%}$$

$$(c) \quad \text{degree of completion} = \frac{44 - 4.4}{44} = 0.90$$

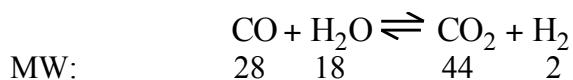
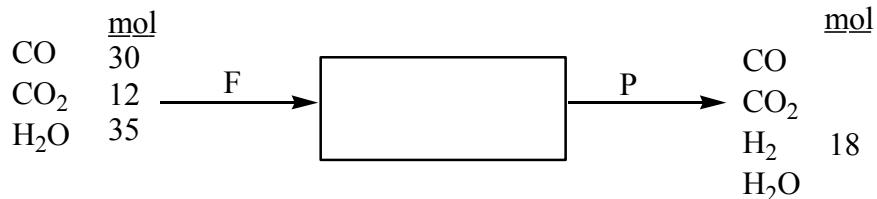
$$(\text{or } 9.9 \text{ from (d)/11.0}) = 0.90$$

$$(d) \quad \text{extent of reaction } \xi = \frac{19.8 - 0}{2} = \text{reacting moles}$$

Solutions Chapter 5

5.2.16

Basis: 30 mol CO, 12 mol CO₂, 35 mol H₂O feed = 1 hr



- a) $\frac{\text{fed CO}}{\text{H}_2\text{O}} = \frac{30}{35} = 0.86 < \frac{\text{in eqn CO}}{\text{H}_2\text{O}} = \frac{1}{1} = 1$ **CO is limiting reactant**
- b) **H₂O is the excess reactant**
- c) $\frac{18}{35} = \boxed{0.514}$
- d) $\frac{18}{30} = \boxed{0.60}$ (for each mol of H₂ produced, 1 mol CO reacts)
- e)
$$\frac{18 \text{ kg mol H}_2}{1 \text{ kg mol H}_2} \left| \frac{2.016 \text{ kg H}_2}{35 \text{ kg mol H}_2} \right| \frac{1 \text{ kg mol H}_2\text{O}}{18 \text{ kg H}_2\text{O}}$$

$$= \boxed{0.0576 \text{ kg H}_2}$$
- f) 1 mol of CO₂ is produced for each mol of H₂
- $\frac{18}{30} = \boxed{0.60 \frac{\text{mol CO}_2 \text{ produced}}{\text{mol CO fed}}}$
- (g) $\xi = \frac{18 - 0}{1} = \boxed{18 \text{ reacting moles}} \text{ using H}_2$

Solutions Chapter 5

5.2.17

Basis: 100 lb mesitylene (C_9H_{12}) C_9H_{12} $\frac{MW}{120.1}$
 The reactions are



The initial selectivity is: $C_8H_{10}/C_7H_8 = 0.7$ and 0.8

The number of moles of C_9H_{12} in the basis is

$$\frac{100 \text{ lb } C_9H_{12}}{120.1 \text{ lb } C_9H_{12}} \left| \frac{1 \text{ lb mol } C_9H_{12}}{1 \text{ lb mol } C_9H_{12}} \right. = 0.833 \text{ lb mol}$$

For the selectivity of 0.7 (the equations are in lb mol)

$$(1) C_8H_{10} + (1)C_7H_8 = 0.833 \\ C_8H_{10} / C_7H_8 = 0.7$$

with the results:

	(lb mol)	(in lb)
C_7H_8	0.490	45.1
C_8H_{10}	0.343	36.4

For the selectivity of 0.8 the results are

C_7H_8	= 0.463	42.6
C_8H_{10}	= 0.370	39.3

The catalyst used in the respective cases is

$$\text{Selectivity of 0.7} \quad \frac{1 \text{ lb catalyst}}{500 \text{ lb } C_7H_8} \left| \frac{0.490 \text{ lb mol } C_7H_8}{1 \text{ lb mol } C_7H_8} \right| \frac{92.06 \text{ lb } C_7H_8}{1 \text{ lb mol } C_7H_8} = 0.090 \text{ lb}$$

$$\text{Selectivity of 0.8:} \quad \frac{1 \text{ lb catalyst}}{500 \text{ lb } C_7H_8} \left| \frac{0.463 \text{ lb mol } C_7H_8}{1 \text{ lb mol } C_7H_8} \right| \frac{92.06 \text{ lb } C_7H_8}{1 \text{ lb mol } C_7H_8} = 0.085 \text{ lb}$$

The economic analysis of the change is

Solutions Chapter 5

Income change

$$\begin{array}{l} \text{Increase in C}_8\text{H}_{10}: \\ (39.3 - 36.4)(\$0.65) = +1.89 \end{array}$$

$$\text{Decrease in C}_7\text{H}_8: \quad (45.1 - 42.6) (\$22) = -0.55$$

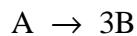
Expense change (decrease)

$$\text{Change in catalyst used: } (0.090 - 0.085) (\$25) = +0.13$$

Net change	\$1.47
------------	--------

5.3.1

Basis: 1 mol A



50 percent conversion gives as the product:

	<u>mol</u>
A	0.5
B	<u>1.5</u>
	2.0

(a) Mole fraction A = $0.5/2.0 = \boxed{0.25}$

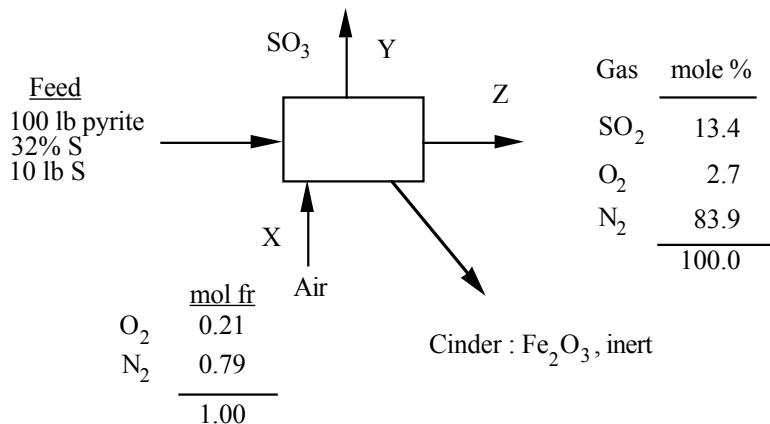
(b) Extent of reaction $\xi = \frac{0.5 - 1.0}{-1} = \boxed{0.5 \text{ using A}}$

Solutions Chapter 5

5.3.2

Step 5: Basis: 100 lb pyrites in $2 \text{FeS}_2 + \frac{11}{2} \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 + 4 \text{SO}_2$

Steps 2, 3, and 4:



Let X = mol air in, Y = mol SO₃ out, Z = mol flue gas out

Steps 6 and 7:

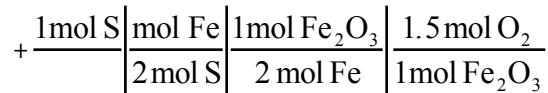
Using a reduced set of variables:

Unknowns (4): X, Y, Z, cinder
 Balances (4): O, N, S, cinder

Steps 8 and 9:

1. Sulfur Balance: $(32 + 10)/32 = Y + 0.134Z$

2. 2O Balance: $0.21X = 1.5Y + (0.134 + 0.027)Z$



3. 2N Balance: $0.79X = 0.839Z$

Solve (1), (2), (3): Y = 0.118 mol, Z = 8.9 mol

Step 10:

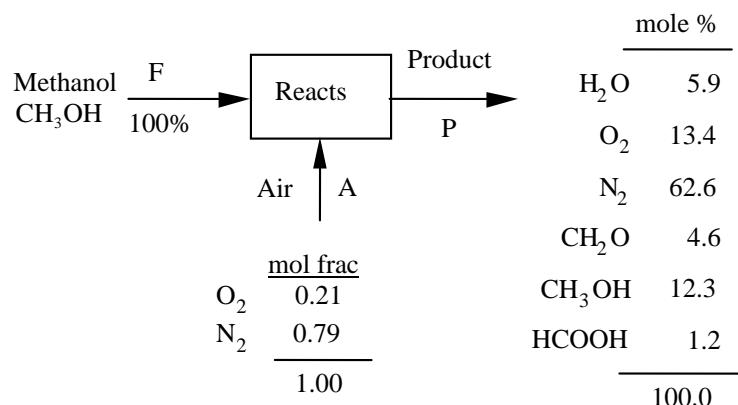
Check: mol S = 0.118 + 0.134(8.9) = 1.31

% conversion of S to SO₃ = (11.8)/(1.315) = 8.98%

Solutions Chapter 5

5.3.3

Steps 1, 2, 3 and 4:



Step 5: Basis: 100 mol P

Step 6: Unknown F, A

Step 7: Balances N, H, O, C

More balances than unknowns. Are they independent? Consistent?

Steps 8 and 9: Balances in moles

Check by first solving C, N (tie elements)

$$C: \quad F(1) = 4.6 + 12.3 + 1.2 = 18.1 \quad F = 18.1 \text{ mol}$$

$$2N: A(0.79) = 62.6 \quad A = 79.24 \text{ mol}$$

$$\begin{array}{rcl} \textcircled{A} & & \textcircled{F} \\ \text{Check via O: } (2)(79.24)(.21) + 18.1 & & ? \\ & & = 13.4(2) + 5.9 + 4.6 + 12.3 + 1.2(2) \\ & & \\ & 51.38 & ? \\ & & = 52.0 \end{array}$$

Close but not exactly the same, more oxygen out than in. Might be caused by round off.

Check via H:	4(18.1)	$\stackrel{?}{=} 5.9(2) + 4.6(2) + 12.3(4) + 1.2(2)$
	72.40	$\stackrel{?}{=} 72.6$

Not exactly the same; more hydrogen out than in, but again may be caused by round off. The conclusion is that probably no error exists in the measurements.

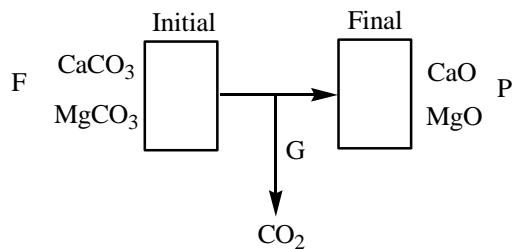
Solutions Chapter 5

5.3.4

- a. Additional information was the molecular weights of the compounds and the chemical reaction equations.

MW $\text{CaCO}_3 = 100.0$, MW $\text{MgCO}_3 = 84.3$, MW $\text{CO}_2 = 44$.

- b. Assume a batch process



- c. Basis: 1 g sample
- d. $F = 1.000 \text{ g}$; P is not explicitly given but can be calculated: $P = 0.550 \text{ g}$; G is not explicitly given and can be calculated, $G = 0.450 \text{ g}$
- e. Mass fraction of CaO in P and F , mass fraction MgO in P and F (or mass of each)
- f. Species balances
- g. It appears to be a carbon balance
- h. 0 degrees of freedom
- i. Yes

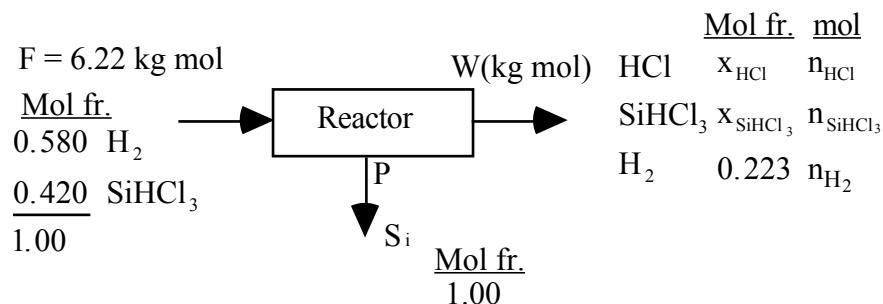
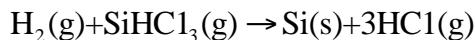
Solutions Chapter 5

5.3.5

Assume a steady state flow process with reaction.

Step 5: Basis: 1 hr (6.22 kg mol = F)

Steps 1, 2, 3 and 4:



$$\text{MW Si} = 28.086$$

$$n_{H_2}/W = 0.223$$

Step 6: Unknowns: W, P, 3n_i

Step 7: Balances: element balances are H, Si, Cl, $\sum n_i = W$, $n_{H_2}/W = 0.223$

Or, using the extent of reaction

Step 6: Unknowns = 6:

$$W, P, 3n_i, \xi$$

Step 7: Balances = 6

Species balances: H₂, SiHCl₃, HCl, Si

$$\sum n_i = W$$

$$n_{H_2}/W = 0.223$$

Steps 8 and 9: Balances are in kg mol.

Solutions Chapter 5

$$\text{Cl (kg mol):} \quad \frac{\text{In}}{6.22(0.420)(3)} = \frac{\text{Out}}{n_{\text{HCl}} + n_{\text{SiHCl}_3}(3)}$$

$$\text{Si (kg mol):} \quad 6.22(04.20)(1) = P(1) + n_{\text{SiHCl}_3}$$

$$\text{H (kg mol):} \quad 6.22[(0.580)(2) + 0.420(1)] = n_{\text{HCl}} + n_{\text{SiHCl}_3} + n_{\text{H}_2} \quad (2)$$

Balances using ξ :

$$\text{H}_2: [n_{\text{H}_2} - (0.580)(6.22)] = (-1)(\xi)$$

$$\text{SiHCl}_3: [n_{\text{SiHCl}_3} - (0.420)(6.22)] = (-1)(\xi)$$

$$\text{HCl:} [n_{\text{HCl}} - 0] = (+3)(\xi)$$

$$\text{Si:} [n_{\text{Si}} - 0] = (+1)(\xi)$$

$$\xi = 1.83$$

Solution: $W = 8.05$ $P = 1.83$

$$n_{\text{H}_2} = 1.78 \quad n_{\text{HCl}} = 5.49 \quad n_{\text{SiHCl}_3} = 0.7824$$

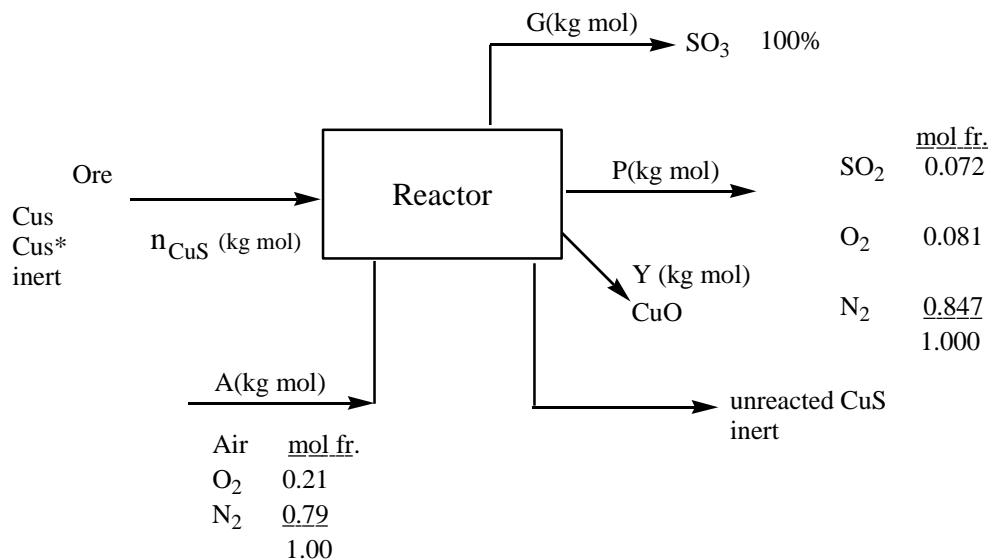
$$\frac{1.83 \text{ kg mol Si}}{1 \text{ hr}} \left| \frac{1 \text{ hr}}{60 \text{ min}} \right| \left| \frac{20 \text{ min}}{1 \text{ kg mol Si}} \right| \frac{28.086 \text{ kg Si}}{1 \text{ kg mol Si}} = 17.13 \text{ kg Si}$$

$$\frac{1.46 \text{ kg Si initial}}{18.59 \text{ kg final Si}}$$

Solutions Chapter 5

5.3.6

Steps 1, 2, 3, and 4:



*This CuS doesn't react.

This is a steady state open process with reaction.

Step 5: Basis: 100 kg mol P

Steps 6 and 7: Unknowns: n_{CuS}, A, G, Y
Element balances: S, O, N, Cu

Steps 8 and 9: Balances are in kg mol on the elements

$$S: \quad n_{CuS}(1) = G(1) + 0.072(100)$$

$$2O: \quad A(0.21) = G(1.5) + 100(0.072) + 100(0.081) + Y\left(\frac{1}{2}\right)$$

$$2N: \quad A(0.79) = 100(0.847)$$

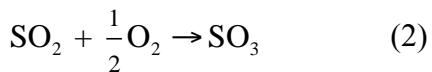
$$Cu: \quad n_{CuS}(1) = Y(1)$$

Solutions Chapter 5

Solution yields (in kg mol): $G = 1.81$, $n_{\text{CuS}} = Y = 9.01$

$$\frac{\frac{1.81 \text{ mol SO}_3}{1 \text{ mol SO}_3}}{\frac{9.01 \text{ mol CuS that reacts}}{1 \text{ mol CuS}}} = 0.20 \text{ of CuS that reacts goes to SO}_3 [20\%]$$

If you use the extent of reaction, you need to write down the balanced reactions



Steps 6 and 7:

The unknowns: 4 above plus ξ_1 and ξ_2

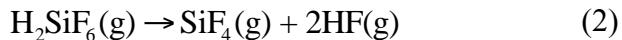
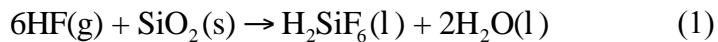
Balance: 6 species balances

Steps 8 and 9:

CuO:	Y	=	$0 + (1)(\xi_1)$
CuS	0	=	$n_{\text{CuS}} + (-1)(\xi_1)$
O ₂ :	P(0.081)	=	$A(0.21) + (-1)(\xi_1) - (\frac{1}{2})(\xi_2)$
N ₂	P(0.847)	=	$A(0.79)$
SO ₂	P(0.072)	=	$0 + (1)(\xi_1) + (-1)(\xi_2)$
SO ₃ :	G	=	$0 + (1)(\xi_2)$
$\xi_1 = 9.01$		$\xi_2 = 1.81$	

Solutions Chapter 5

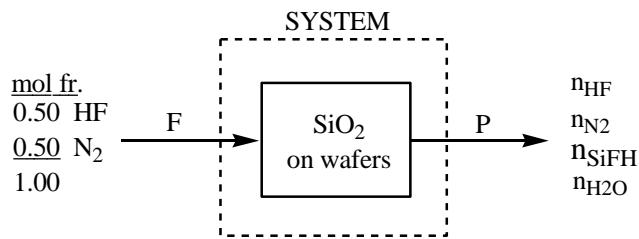
5.3.7



The net reaction is



Steps 2, 3, and 4:



The process is an unsteady state, open process

Step 5: Basis: 1 mol F entering

Steps 6 and 7:

Unknowns: $4 n_i$, $P_1 \xi$, loss SiO_2 from wafer (L)

Balances: HF, N₂, SiF₄, H₂O, SiO₂ (5 species)

Other equations: $\sum n_i = P$; 10% HF reacts

Steps 8 and 9:

$$\text{HF: } n_{\text{HF}} = 0.50 + (-4)\xi = 0.50(0.90) = 0.45$$

$$\xi = 1.25 \times 10^{-2} \text{ reacting moles}$$

$$\text{SiF}_4: \quad n_{\text{SiF}_4} = 0 + (1)(1.25 \times 10^{-2}) = 1.25 \times 10^{-2} \text{ mol}$$

$$\text{H}_2\text{O: } n_{\text{H}_2\text{O}} = 0 + (2)(1.25 \times 10^{-2}) = 2.50 \times 10^{-2} \text{ mol}$$

$$\text{N}_2: \quad n_{\text{N}_2} = 0.50 \text{ mol}$$

$$\text{SiO}_2: \quad n_{\text{SiO}_2,f} - n_{\text{SiO}_2,i} = (-1)(\xi) = -1.25 \times 10^{-2} \text{ mol}$$

Solutions Chapter 5

<u>Composition</u>	<u>mol</u>	<u>mol fr.</u>
HF	0.45	0.456
SiF ₄	1.25 10 ⁻²	0.013
H ₂ O	2.50 10 ⁻²	0.025
N ₂	<u>0.50</u>	<u>0.506</u>
	0.9875	1.000

If you use element balances:

Step 6 and 7:

The unknowns: 4n_i, P, L

The balances: H, F, Si, O, N (presumably 4 are independent)

Other equations: $\sum n_i = P$, 10% HF reacts

Steps 8 and 9:

$$H: \quad 0.50(1) = n_{HF} + 2n_{H_2O}$$

$$F: \quad 0.50(1) = n_{HF} + 4n_{SiF_4}$$

$$Si: \quad (n_{SiO_2,f} - n_{SiO_2,i}) = n_{SiF_4}$$

$$O: \quad 2(n_{SiO_2,f} - n_{SiO_2,i}) = n_{H_2O}$$

$$N: \quad 2(0.50) = 2n_{N_2}$$

$$n_{HF} = 0.90(0.50) = 0.45$$

Solutions Chapter 5

5.3.8

We will view this process as a steady state process in an open system with flow in and out, and a change in the material in the vessel from the initial to the final states. For component i, Equation (10.1) becomes Equation (10.6)

$$n_i^{\text{out}} = n_i^{\text{in}} + \sum_{j=1}^R v_{ij} \xi_j$$

The bioorganisms do not have to be included in the solution of the problem.

Steps 1, 2, 3, and 4

Figure P10.9 is a sketch of the process.

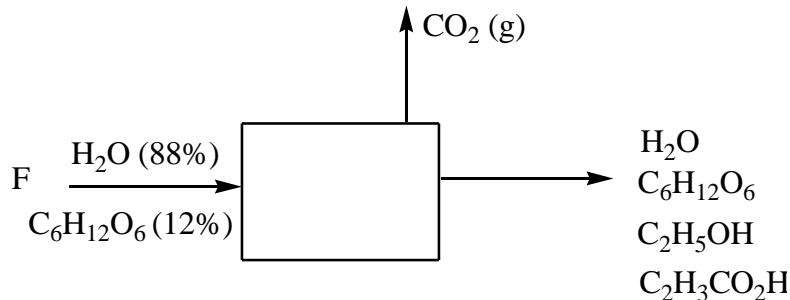


Figure P10.9

Step 5 Basis: 3500 kg F

Step 4

Convert the 3500 kg into moles of H_2O and $\text{C}_6\text{H}_{12}\text{O}_6$.

$$n_{\text{H}_2\text{O}}^{\text{initial}} = \frac{3500(0.88)}{18.02} = 170.9$$

$$n_{\text{C}_6\text{H}_{12}\text{O}_6}^{\text{initial}} = \frac{3500(0.12)}{180.1} = 2.332$$

Step 6 and 7

The degree of freedom analysis is as follows:

Number of variables: 9

Solutions Chapter 5

$$n_{H_2O}^{In}, n_{C_6H_{12}O_6}^{In}, n_{H_2O}^{Out}, n_{C_6H_{12}O_6}^{Out}, n_{C_2H_5OH}^{Out}, n_{C_2H_3CO_2H}^{Out}, n_{CO_2}^{Out}, \xi_1, \xi_2$$

Number of equations: 9

Basis: $F = 3500$ kg of initial solution (equivalent to initial moles of H_2O plus moles of sucrose)

Species material balances: 5



Specifications: 4 (3 independent)

$$n_{H_2O}^{In} = 170.4 \text{ or } n_{C_6H_{12}O_6}^{In} = 2.332 \text{ (one is independent, the sum is } F \text{ in mol)}$$

$$n_{C_6H_{12}O_6}^{Out} = \frac{90}{180.1} = 0.500 \quad n_{CO_2}^{Out} = \frac{120}{44} = 2.727$$

The degrees of freedom are zero.

Step 8

The material balance equations, after introducing the known values for the variables are:

$$H_2O: \quad n_{H_2O}^{Out} = 170.9 + (0)\xi_1 + (2)\xi_2 \quad (a)$$

$$C_6H_{12}O_6: \quad 0.500 = 2.332 + (-1)\xi_1 + (-1)\xi_2 \quad (b)$$

$$C_2H_5OH: \quad n_{C_2H_5OH}^{Out} = 0 + 2\xi_1 + (0)\xi_2 \quad (c)$$

$$C_2H_3CO_2H: \quad n_{C_2H_3CO_2H}^{Out} = 0 + (0)\xi_1 + (2)\xi_2 \quad (d)$$

$$CO_2: \quad 2.727 = 0 + (2)\xi_1 + (0)\xi_2 \quad (e)$$

If you do not use a computer to solve the equations, the sequence you should use to solve them would be

(e), plus (b), (a), (c), (d)

Step 9

The solution of Equations (a) – (e) is

$$\xi_1 = 1.364 \text{ kg moles reacting} \quad \xi_2 = 0.469 \text{ kg moles reacting}$$

Solutions Chapter 5

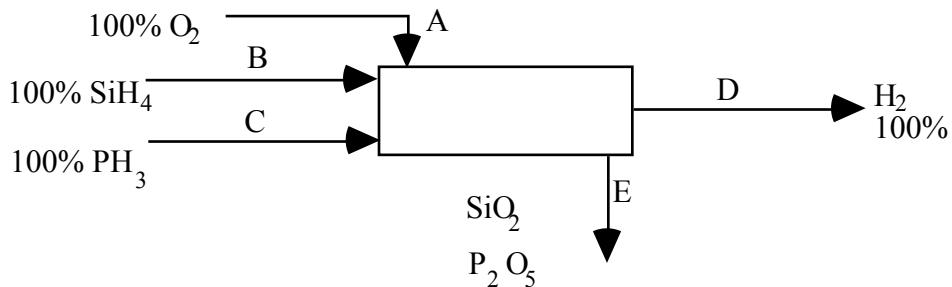
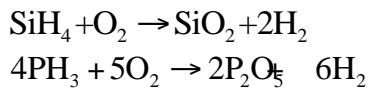
<u>Species</u>	<u>Results</u>	<u>Conversion to mass percent</u>		
	<u>kg moles</u>	<u>MW</u>	<u>kg</u>	<u>mass %</u>
H ₂ O	171.8	18.01	3094.1	89.0
C ₂ H ₅ OH	2.727	46.05	125.6	3.6
C ₂ H ₃ CO ₂ H	0.939	72.03	67.5	1.9
CO ₂	2.272	44.0	100.0	2.9
C ₂ H ₁₂ O ₅	0.500	180.1	<u>90.1</u> 3477.3	<u>2.6</u> 1.00

Step 10

The total mass of 3477 kg is close enough to 3500 kg of feed to validate the results of the calculations.

5.3.9

Steps 1, 2, 3 and 4:



Step 5: Basis: 1 g mol PH₃

Step 6: No. Unknowns: A, B, D, E, n_{P₂O₅}^E ⑤

Step 7: Element balances: Si, H, P, O, ω_{P₂O₅}^E ⑤

$$\text{Note: } n_{\text{P}_2\text{O}_5}^{\text{E}} + n_{\text{SiO}_2}^{\text{E}} = E$$

Steps 8 and 9:

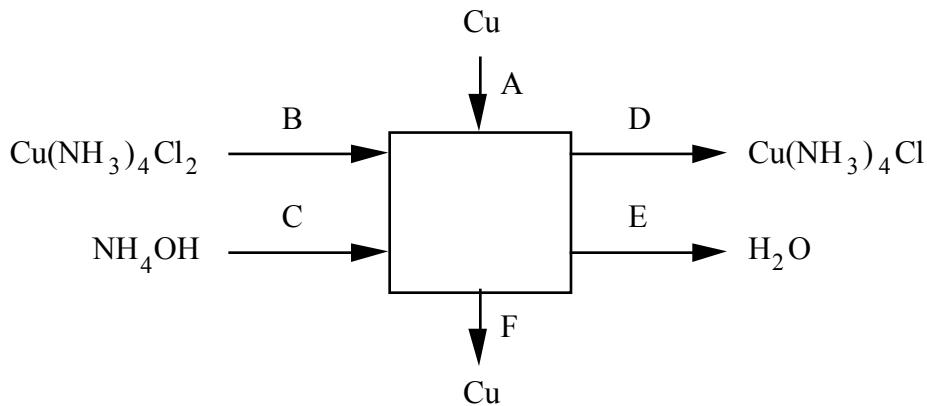
Solutions Chapter 5

<u>P Bal (in grams):</u>	<u>in</u>	<u>Out</u>
	$\frac{1 \text{ g mol PH}_3}{4 \text{ g mol PH}_3} \left \frac{2 \text{ g mol P}_2\text{O}_5}{1 \text{ g mol PH}_3} \right \frac{2 \text{ g mol P}}{1 \text{ g mol P}_2\text{O}_5} \left \frac{31 \text{ g P}}{1 \text{ mol P}} = 31 \text{ g P} \right.$	
	$\frac{1 \text{ g mol PH}_3}{4 \text{ g mol PH}_3} \left \frac{2 \text{ g mol P}_2\text{O}_5}{1 \text{ g mol PH}_3} \right \left. \frac{5 \text{ g mol O}}{1 \text{ g mol P}_2\text{O}_5} \right \frac{16 \text{ g O}}{1 \text{ g mol O}} = 40 \text{ g O} \right\}$	in P_2O_5
		Total: $\overline{71 \text{ g P}_2\text{O}_5}$
or since all the P is in stream E:	$\frac{1 \text{ g mol PH}_3}{4 \text{ g mol PH}_3} \left \frac{2 \text{ g mol P}_2\text{O}_5}{1 \text{ g mol PH}_3} \right \left. \frac{142 \text{ g P}_2\text{O}_5}{1 \text{ g mol P}_2\text{O}_5} \right. = 71 \text{ g P}_2\text{O}_5$	
<u>Si Bal:</u>		
	$\frac{\text{in}}{\text{B g mol SiH}_4} \left \frac{1 \text{ g mol SiO}_2}{1 \text{ g mol SiH}_4} \right \frac{1 \text{ g mol Si}}{1 \text{ g mol SiO}_2} \left \frac{28.1 \text{ g Si}}{1 \text{ g mol Si}} = 28.1 \text{ B g Si} \right.$	<u>Out</u>
	$\frac{\text{B g mol SiH}_4}{1 \text{ g mol SiH}_4} \left \frac{1 \text{ g mol SiO}_2}{1 \text{ g mol SiH}_4} \right \left. \frac{2 \text{ g mol O}}{1 \text{ g mol SiO}_2} \right \frac{16 \text{ g O}}{1 \text{ g mol O}} = 32 \text{ B g O}$	
	Total:	$\overline{60.1 \text{ B g SiO}_2}$
$\frac{71}{71 + 60.1 \text{ B}} = 0.05$	$3.55 + 3.0058 \text{ B} = 71$	$\text{B} = 23.5 \text{ g mol}$
$\frac{1 \text{ g mol PH}_3}{1 \text{ g mol PH}_3} \left \frac{34 \text{ g PH}_3}{1 \text{ g mol PH}_3} = 34 \text{ g PH}_3 \right.$		
$\frac{23.5 \text{ g mol SiO}_2}{1 \text{ g mol SiH}_4} \left \frac{32.1 \text{ g SiH}_4}{1 \text{ g mol SiH}_4} = 7.54 \text{ g SiO}_2\text{O}_2 \right.$		
$\frac{754}{34} = 22.2 \frac{\text{gSiO}_2}{\text{gPH}}$		

Solutions Chapter 5

5.3.10

Steps 1, 2, 3 and 4:



Step 5: Basis: 1 board

$$A: \text{ Cu foil } \frac{4 \text{ in}}{} \left| \frac{8 \text{ in}}{} \right| \left| \frac{0.03 \text{ in}}{} \right| \left| \frac{(2.54 \text{ cm})^3}{\text{in}^3} \right| \left| \frac{8.96 \text{ g}}{\text{cm}^3} \right| \left| \frac{1 \text{ g mol Cu}}{63.55 \text{ g Cu}} \right| = 2.219 \text{ g mol Cu}$$

$$F: \text{ Cu remaining } \frac{1 - 0.75}{2.219 \text{ g mol Cu}} = 0.555 \text{ g mol Cu}$$

Steps 6 and 7: Unknowns: B, C, D, E

Balances: Cu, N, Cl, H, O should be enough if one is redundant

Steps 8 and 9: (Balances to be solved:)

Cu Balance:

$$2.219 \text{ g mol Cu} + \frac{B \text{ g mol Cu(NH}_3)_4\text{Cl}_2}{1 \text{ g mol Cu(NH}_3)_4\text{Cl}_2} \left| \frac{1 \text{ g mol Cu}}{1 \text{ g mol Cu(NH}_3)_4\text{Cl}_2} \right.$$

$$= 1.664 \text{ g mol Cu} + \frac{D \text{ g mol Cu(NH}_3)_4\text{Cl}}{1 \text{ g mol Cu(NH}_3)_4\text{Cl}} \left| \frac{1 \text{ g mol Cu}}{1 \text{ g mol Cu(NH}_3)_4\text{Cl}} \right.$$

Solutions Chapter 5

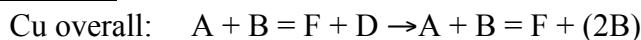
Cl Balance:

$$\frac{Bg \text{ mol Cu(NH}_3)_4\text{Cl}_2}{g \text{ mol Cu(NH}_3)_4\text{Cl}_2} \left| \frac{2 \text{ g mol Cl}}{g \text{ mol Cu(NH}_3)_4\text{Cl}_2} \right. = \frac{Dg \text{ mol Cu(NH}_3)_4\text{Cl}}{g \text{ mol Cu(NH}_3)_4\text{Cl}} \left| \frac{1 \text{ g mol Cl}}{g \text{ mol Cu(NH}_3)_4\text{Cl}} \right.$$

N Balance:

$$\begin{aligned} & \frac{Bg \text{ mol Cu(NH}_3)_4\text{Cl}_2}{g \text{ mol Cu(NH}_3)_4\text{Cl}_2} \left| \frac{4 \text{ g mol N}}{g \text{ mol Cu(NH}_3)_4\text{Cl}_2} \right. + \frac{Cg \text{ mol NH}_4\text{OH}}{g \text{ mol NH}_4\text{OH}} \left| \frac{1 \text{ g mol N}}{g \text{ mol NH}_4\text{OH}} \right. \\ &= \frac{Dg \text{ mol Cu(NH}_3)_4\text{Cl}}{g \text{ mol Cu(NH}_3)_4\text{Cl}} \left| \frac{4 \text{ g mol N}}{g \text{ mol Cu(NH}_3)_4\text{Cl}} \right. \end{aligned}$$

Solution:



$$2.219 + B = 0.555 + (2B)$$

$$B = 2.219 - 0.555 = 1.664 \text{ g mol Cu(NH}_3)_4\text{Cl}_2$$

Cl: $D = 2B = 2(1.664) = 3.328 \text{ g mol Cu(NH}_3)_4\text{Cl}$

N: $4B + C = 4D$

$$C = 4(D - B) = 4(3.328 - 1.664) = 6.656 \text{ g mol NH}_4\text{OH}$$

MW of NH₄OH

N	14
H ₄	4
O	16
H	<u>1</u>
	35

$$\frac{35 \text{ g NH}_4\text{OH}}{\text{g mol}} \left| \frac{6.656 \text{ g mol}}{\text{g mol}} \right. = \boxed{232.0 \text{ g NH}_4\text{OH}}$$

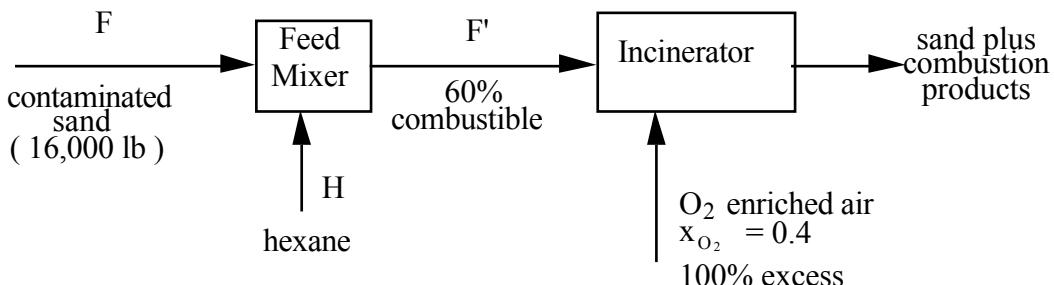
Cu(NH₃)₄Cl₂

Cu	63.55
N	56.00
H	12.00
Cl ₂	<u>70.90</u>

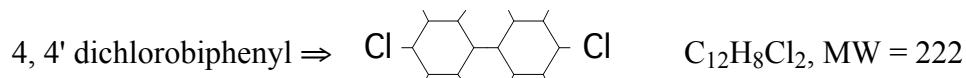
$$202.45 \text{ (g/gmol)} (1.664 \text{ g mol}) = \boxed{336.88 \text{ g Ca (NH}_3)_4\text{Cl}_2}$$

Solutions Chapter 5

5.3.11



a) Basis: 8 tons of contaminated sand containing 30% PCB

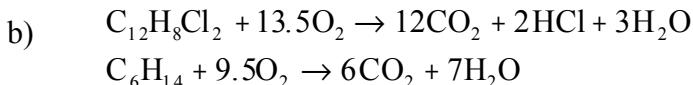


$$\frac{8 \text{ tons sand + PCB}}{\text{ton sand + PCB}} \left| \frac{0.3 \text{ ton PCB}}{\text{ton sand + PCB}} \right| \frac{2000 \text{ lb PCB}}{\text{ton PCB}} = 4800 \text{ lb PCB}$$

If we want the net feed to be 60% combustible, we see that the sand is a tie component:

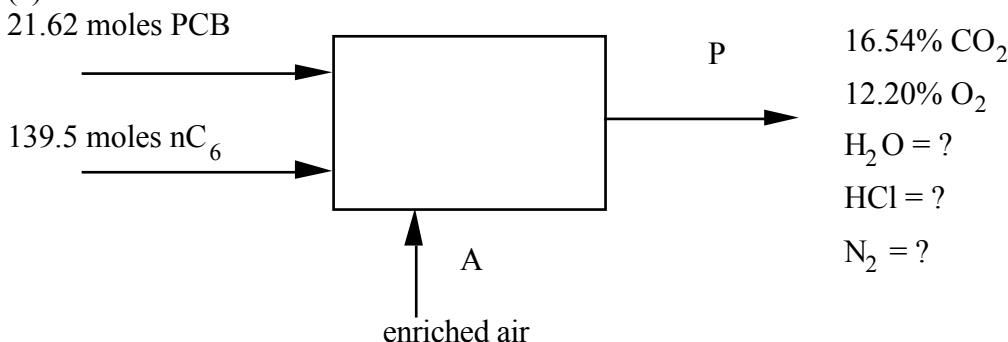
A sand balance around the feed mixer: $16000(0.7) = F'(0.4)$ so $F' = 28,000 \text{ lb}$.

A total balance around the feed mixer.: $F + H = F' \Rightarrow H = [12,000 \text{ lb}_m \text{ hexane}]$



Even with total combustion, we will produce undesirable HCl, which will adversely affect the environment if it is simply vented. Therefore, it would be wise to condense the HCl and H₂O by cooling. Perhaps the acid solution might be sold to help pay for the process.

(c)



(40% O₂, 60% N₂)

Solutions Chapter 5

By a tie component for CO₂, we know:

$$12(21.62) + 139.5(6) = 0.1654 P \text{ hence } P = 6629 \text{ mol}$$

By an O tie: 0.40(2)A = 0.1654(2)(6629) + 0.1220(2)(6629) + x_{H₂O}(1)(6629)

$$x_{H_2O}(6629) = \frac{21.62 \text{ PCB Reacted}}{1 \text{ PCB}} \left| \frac{3 H_2O}{1 \text{ PCB}} \right. = \frac{139.6 C_6 \text{ Reacted}}{1 \text{ PCB}} \left| \frac{7 H_2O}{1 C_6} \right. = 1042$$

$$\text{so } x_{H_2O} = 0.1572$$

From O tie balance: A = 6065.4 mol of 40% O₂ air

Thus: (N₂)_{in} = (N₂)_{out} = 0.6(6065.4) = 3639.2 mol N₂

$$x_{N_2} = \frac{3639.2}{6629.0} = 0.549$$

We can get HCl by a Cl balance: $\frac{21.6 \text{ PCB Reacted}}{1 \text{ PCB}} \left| \frac{2 HCl}{1 \text{ PCB}} \right. = 43.2 \text{ mol HCl in product}$

$$x_{HCl} = 0.0065$$

Component	x _i
CO ₂	0.1654
O ₂	0.1220
H ₂ O	0.1572
HCl	0.0065
N ₂	0.5490

We know % excess O₂ used is : % excess = $\frac{100 [O_2 \text{ fed} - O_2 \text{ req'd}]}{(O_2 \text{ req'd})}$

$$O_2 \text{ fed} = 0.4 \text{ (air fed)} = 0.4(6065.4) = 2426.2 \text{ mol O}_2$$

Also, since we have total combustion,

$$(O_2 \text{ req'd}) = (O_2 \text{ consumed}) = (O_2 \text{ fed} - O_2 \text{ out}) = 2426.2 - 0.1220(6629)$$

$$= 1617.5 \text{ moles req'd}$$

$$\text{Thus: \% O}_2 = 100 \left(\frac{2426.2 - 1617.5}{1617.5} \right) = \boxed{50\% \text{ excess O}_2 \text{ used}}$$

Solutions Chapter 5

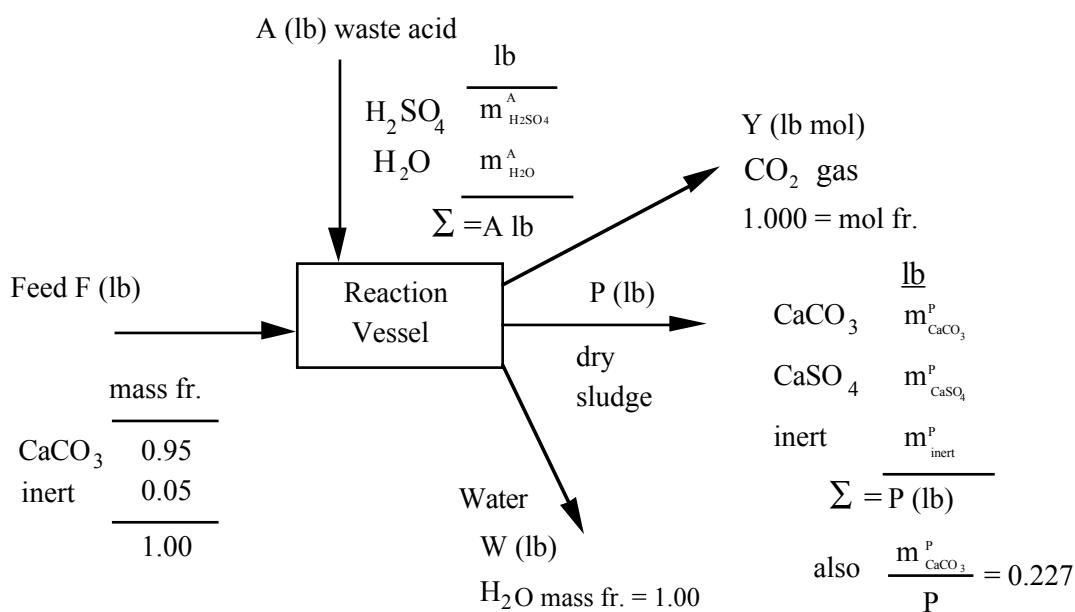
5.3.12 & 5.4.1

Steps 1, 2, 3, and 4: To solve this problem you must recall that CaCO_3 reacts with H_2SO_4 to form CaSO_4 and that CaCO_3 when heated yields CO_2 and CaO whereas when CaSO_4 is heated at the same time it does not decompose. Although the problem seems to be underspecified, when you draw a diagram of the process and place the known data on it, the situation becomes clearer. Assume the process is a steady state open one with reaction. Then the element balances are just $in = out$. If you use the extent of reaction, you make species balances.

Note that we have designated the composition of P and A in terms of the mass of each component, m_i^P , rather than the mass fraction ω_i^P , because this choice makes the element or species balances linear (avoids products such as ωP).

The CO_2 liberated from the sludge is equivalent to

$$\frac{1 \text{ lb CO}_2}{10 \text{ lb P}} \left| \frac{1 \text{ lb mol CO}_2}{44 \text{ lb CO}_2} \right| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CO}_2} \left| \frac{100.09 \text{ lb CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \\ = 0.227 \text{ lb CaCO}_3/\text{lb P}$$



Step 5: Basis: $F = 100 \text{ lb}$

Step 6: The variables whose values are unknown are A , $m_{\text{H}_2\text{SO}_4}^A$, $m_{\text{H}_2\text{O}}^A$, $m_{\text{CaCO}_3}^P$, $m_{\text{CaSO}_4}^P$, m_{inert}^P , P , W , and Y , a total of 9.

Solutions Chapter 5

Step 7: The element balances that can be made are Ca, C, O, S, H, inert (6 total) and we know $\sum m_i^A = A$, $\sum m_i^P = P$, and $(m_{CaCO_3}^P / P) = 0.227$ for a total of 9. If the equations are independent, we can find a unique solution.

Steps 8 and 9: The equations (*in* = *out*) are (except for the inert balance which is in lb) in moles

$$\begin{aligned}
 \text{Ca: } & \frac{95 \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \right| \frac{1 \text{ lb mol Ca}}{1 \text{ lb mol CaCO}_3} \\
 &= \frac{m_{CaCO_3}^P \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \right| \frac{1 \text{ lb mol Ca}}{1 \text{ lb mol CaCO}_3} \\
 &+ \frac{m_{CaCO_3}^P \text{ lb CaSO}_4}{136.15 \text{ lb CaSO}_4} \left| \frac{1 \text{ lb mol CaSO}_4}{136.15 \text{ lb CaSO}_4} \right| \frac{1 \text{ lb mol Ca}}{1 \text{ lb mol CaSO}_4} \\
 \text{C: } & \frac{0.95 \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \right| \frac{1 \text{ lb mol C}}{1 \text{ lb mol CaCO}_3} = \frac{Y \text{ lb mol CO}_2}{1 \text{ lb mol CO}_2} \left| \frac{1 \text{ lb mol C}}{1 \text{ lb mol CO}_2} \right. \\
 &+ \frac{m_{CaCO_3}^P \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \right| \frac{1 \text{ lb mol C}}{1 \text{ lb mol CaCO}_3} \\
 \text{S: } & \frac{m_{H_2SO_4}^A \text{ lb H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \left| \frac{1 \text{ lb mol H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \right| \frac{1 \text{ lb mol S}}{1 \text{ lb mol H}_2\text{SO}_4} \\
 &= \frac{m_{CaSO_4}^P \text{ lb CaSO}_4}{136.25 \text{ lb CaSO}_4} \left| \frac{1 \text{ lb mol CaSO}_4}{136.25 \text{ lb CaSO}_4} \right| \frac{1 \text{ lb mol S}}{1 \text{ lb mol CaSO}_4} \\
 \text{2H: } & \frac{m_{H_2SO_4}^A \text{ lb H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \left| \frac{1 \text{ lb mol H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \right| \frac{1 \text{ lb mol H}_2}{1 \text{ lb mol H}_2\text{SO}_4} \\
 &+ \frac{m_{H_2O}^A \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \right| \frac{1 \text{ lb mol H}_2}{1 \text{ lb mol H}_2\text{O}} \\
 &= \frac{W \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \right| \frac{1 \text{ lb mol H}_2}{1 \text{ lb mol H}_2\text{O}} \\
 \text{O: } & \frac{95 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{100.09 \text{ lb CaCO}_3} \right| \frac{3 \text{ lb mol O}}{1 \text{ lb mol CaCO}_3} \\
 &+ \frac{m_{H_2SO_4}^A \text{ lb H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \left| \frac{1 \text{ lb mol H}_2\text{SO}_4}{98.08 \text{ lb H}_2\text{SO}_4} \right| \frac{4 \text{ lb mol O}}{1 \text{ lb mol H}_2\text{SO}_4}
 \end{aligned}$$

Solutions Chapter 5

$$\begin{aligned}
 & + \frac{m_{H_2O}^A \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{1 \text{ lb mol H}_2\text{O}} \right| \left| \frac{1 \text{ lb mol O}}{1 \text{ lb mol H}_2\text{O}} \right. \\
 & = \frac{Y \text{ lb mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{2 \text{ lb mol O}}{1 \text{ mol CO}_2} \right. \\
 & + \frac{m_{CaCO_3}^P \text{ lb CaCO}_3}{100.09 \text{ lb CaCO}_3} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaCO}_3} \right| \left| \frac{3 \text{ lb mol O}}{1 \text{ lb mol CaCO}_3} \right. \\
 & + \frac{m_{CaSO_4}^P \text{ lb CaSO}_4}{136.15 \text{ lb CaSO}_4} \left| \frac{1 \text{ lb mol CaCO}_3}{1 \text{ lb mol CaSO}_4} \right| \left| \frac{4 \text{ lb mol O}}{1 \text{ lb mol CaSO}_4} \right. \\
 & + \frac{W \text{ lb H}_2\text{O}}{18.016 \text{ lb H}_2\text{O}} \left| \frac{1 \text{ lb mol H}_2\text{O}}{1 \text{ lb mol H}_2\text{O}} \right| \left| \frac{1 \text{ lb mol O}}{1 \text{ lb mol H}_2\text{O}} \right.
 \end{aligned}$$

Inert: $5 \text{ lb inert} = m_{\text{inert}}^P \text{ lb inert}$

The solution of these equations using a computer code would give all of the values of the unknown quantities. However, a review of the set of equations, after having gone into great detail about each equation, indicates that only 4 of the equations have to be solved to get the desired answer, namely the Ca balance, the $\sum m_i^P = P$, and the inert balance plus $m_{CaCO_3}^P = 0.227$:

$$\sum m_i^P = P: \quad m_{CaCO_3}^P + m_{CaSO_4}^P + 5 = P = m_{CaCO_3}^P / 0.227$$

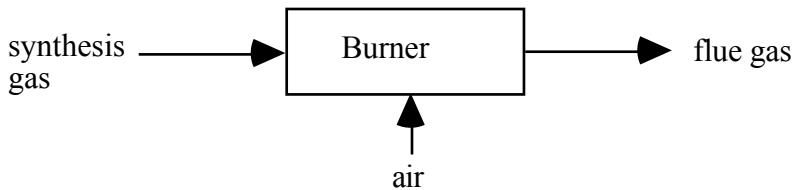
$$\text{Ca:} \quad 0.949 = 0.010 m_{CaCO_3}^P + 0.00734 m_{CaSO_4}^P$$

$$m_{CaCO_3}^P = 28.55 \text{ lb} \quad \text{and} \quad 100 \frac{28.55}{95} = 30\% \text{ unreacted.}$$

Solutions Chapter 5

5.5.1

Basis: 100 kg mol



One composition is unknown, the flue gas. After selection of a basis, the air flow is known. Hence, this problem can be solved by direct addition and subtraction

Unknowns: $(CO_2, H_2O, N_2, O_2) = 4$

Balances: $(C, H, O, N) = 4$

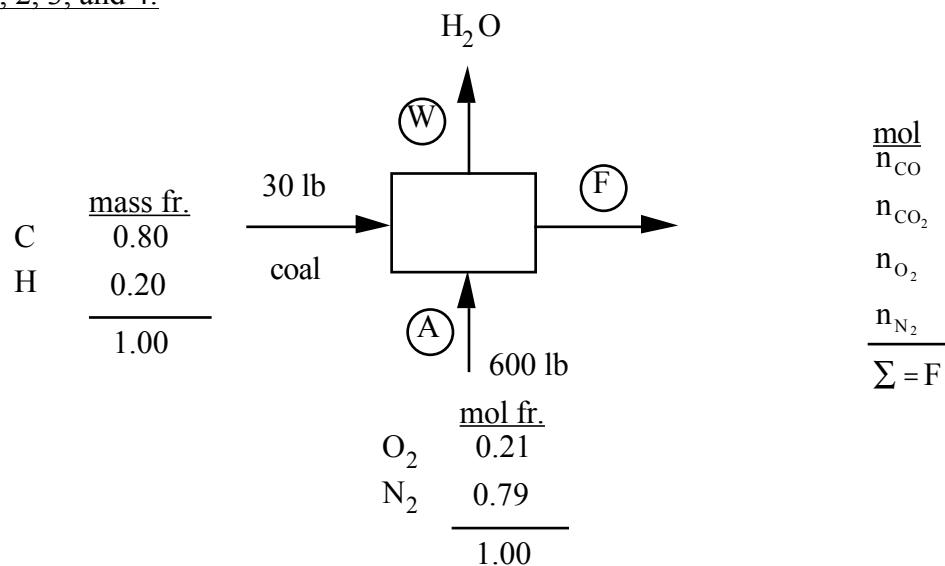
Comp.	%=mol	Reaction	reqd.O ₂	CO ₂	H ₂ O	N ₂	O ₂
CO ₂	6.4	-----	----	6.4			
O ₂	0.2	-----	-(0.2)				
CO	40.0	CO+1/2 O ₂ →CO ₂	20.0	40.0			
H ₂	50.8	H ₂ +1/2 O ₂ →H ₂ O	25.4		50.8		
N ₂	2.6	-----	----			2.6	
		XS O ₂ : (0.40)(45.2) =	<u>18.08</u>				18.08
		Total O ₂ in	<u>63.28</u>				
		N ₂ in with O ₂ (63.28)(79/21) =					<u>238.05</u>
		Totals		46.4	50.8	240.65	18.1

Comp.	mol	%
CO ₂	46.4	13.0
H ₂ O	50.8	14.3
N ₂	240.65	67.6
O ₂	<u>18.1</u>	<u>5.1</u>
Totals	356.0	100.0

Solutions Chapter 5

5.5.2

Steps 1, 2, 3, and 4:



Steps 5 and 6: With a basis of 30 lb coal, only n_{N_2} , n_{O_2} , n_{CO_2} , n_{CO} , F and W are unknown.

Total 6

Step 7: Can make C, H, O, N element balances.

$$\text{plus } \frac{n_{CO_2}}{n_{CO}} = \frac{3}{2} \text{ and } \sum n_i = F$$

Do calculations in moles, but you don't need to make all of the element balances

Comp.	lb	mol wt	lb mol	Rxn	reqd O ₂
C	24	12	2	C+O ₂ →CO ₂	2.0
2H	6	2	3	H ₂ +1/2O ₂ →H ₂ O	1.5
	30				3.5

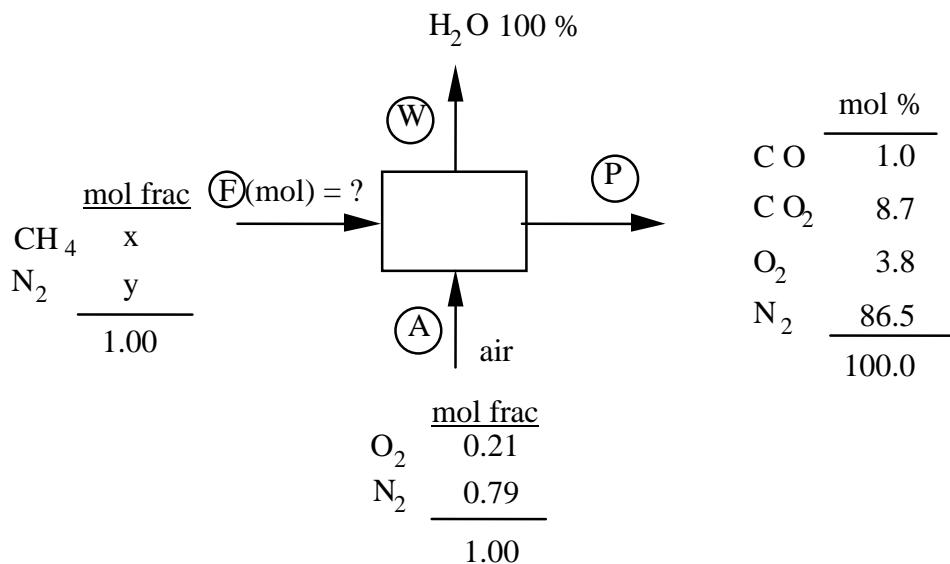
$$\frac{3.5 \text{ lb mol O}_2}{0.21 \text{ lb mol O}_2} \left| \frac{1.00 \text{ lb mole air}}{\text{0.21 lb mol O}_2} \right. = 16.67 \text{ lb mol air reqd.}$$

$$\text{or } \frac{4.35 - 3.5}{3.5} (100) \quad [= 24.3\%]$$

Solutions Chapter 5

5.5.3

Steps 1,2 3 and 4:



Step 5: Basis: 100 mol P

Step 6: Unknowns: x, y, A, W, F Total 5

A and P will be mol

Step 7: Element Balances: C, H, N, O
Equations:

a) If x and y are moles, not mole fractions,
add: x + y = F

b) If x, y are mole fr., add x + y = 1.00 Total 5

Steps 8 and 9: Use x and y as mol:

$$\text{C balance: } x = 8.7 + 1.0 = 9.7$$

$$2\text{N balance: } y + .79A = 86.5$$

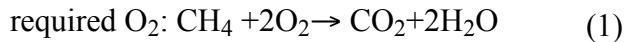
$$2\text{H balance: } 2x = W = 2(9.7) = 19.4$$

$$2\text{O balance: } 0.21A = (1/2)(W + 8.7) + 1.0 + 3.8$$

$$\text{Use 2O bal: } A = \frac{9.7 + 8.7 + 0.5 + 3.8}{0.21} = 108$$

Solutions Chapter 5

Use 2N bal: $y = 1.10$



$$(9.7)(2) = 19.4 \text{ mol}$$

$$\text{total O}_2 \text{ in: } (0.21)(108) = 22.7 \quad \text{excess O}_2 = 22.7 - 19.4 = 3.3 \text{ mol}$$

$$\% \text{ xs air} = \% \text{ xs O}_2 = \frac{3.3}{19.4}(100)$$

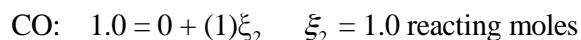
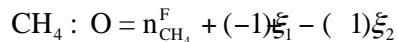
(a) $= \boxed{17\%}$

(b) Percentage of CH₄, N₂: CH₄ = $\frac{9.7}{9.7 + 1.1}(100) = \boxed{89.8\%}$ N₂ = $\frac{1.1}{9.7+1.1}(100) = \boxed{10.2\%}$

Alternate solution: Use extent of reaction and species balances.



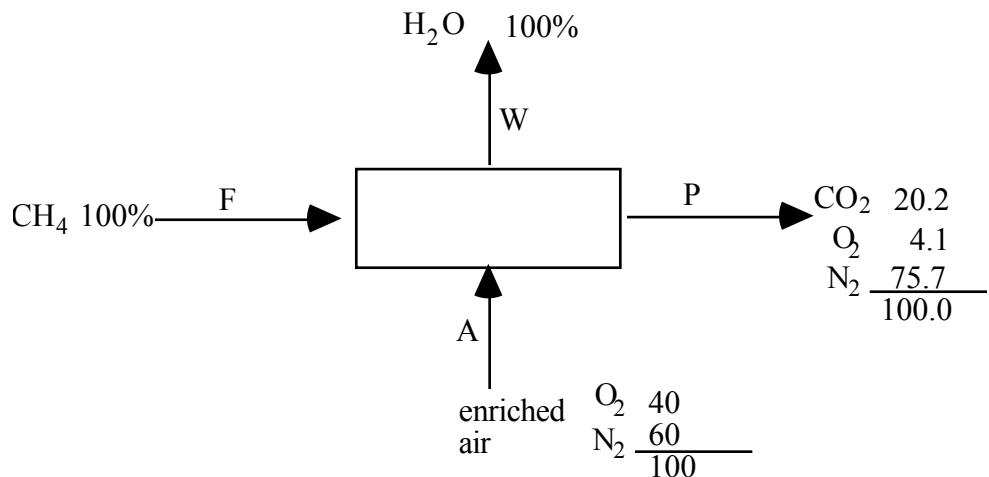
Species balances to get ξ_1 and ξ_2 :



Thus $n_{\text{CH}_4}^F = 8.7 + 1.0 = 9.7 \text{ mol}$ and other compounds follow.

5.5.4

Steps 1, 2, 3 and 4:



Step 5: Basis 100 mol P

Step 6: Unknowns: F, A, W (all compositions known)

Step 7: Element balances: C, H, O, N (1 extra balance)

Steps 8 and 9:

$$\text{C balance: } 20.2 = F$$

$$2\text{N balance: } 75.7 = 0.6A, A = 126.2$$

$$2\text{H balance: } 2F = W, W = 40.4$$

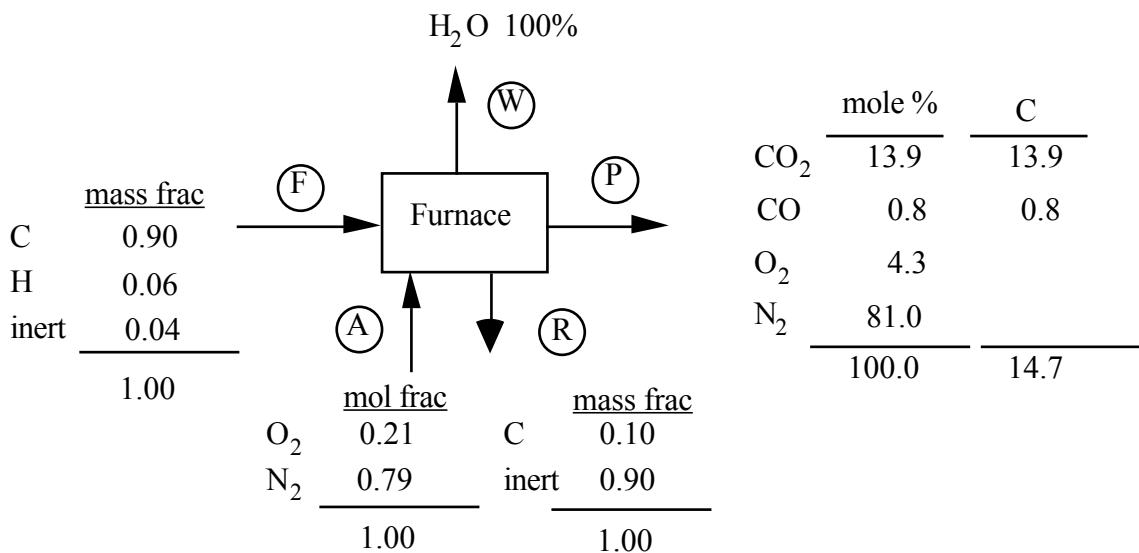
$$2\text{O balance: } 0.4A = 1/2 W + 20.2 + 4.1, 50.5 \neq 20.2 + 20.2 + 4.1 = 44.5$$

Analysis is not correct.

Solutions Chapter 5

5.5.5

Steps 2, 3, and 4:



Step 5: Basis: 100 kg mol P

Steps 6 and 7:

Unknowns: F, R, A, W ④

Probably ok but check for redundancy

Balances: C, H, O, inert, N₂ ⑤

Steps 8 and 9:

Balances (in moles):

$$\text{C: } \frac{\text{F}(0.90)}{12} = \text{P}(0.139 + 0.008) + \frac{\text{R}(0.10)}{12} + \text{W}(0)$$

$$\text{H: } \frac{\text{F}(0.06)}{1.005} = \text{P}(0) + \text{R}(0) + \text{W}(2)$$

$$2\text{N: } \text{A}(0.79) = \text{P}(0.81) + \text{R}(0) + \text{W}(0)$$

$$2\text{O: } \text{A}(0.21) = \text{P}(0.139 + \frac{0.008}{2} + 0.043) + \frac{\text{W}}{2}$$

$$\text{Inert (mass): } \text{F}(0.04) = \text{R}(0.90)$$

Solutions Chapter 5

From 2N, $A = \frac{100(0.81)}{0.79} = 102.53 \text{ kg mol}$

From 2O, $W = 5.863 \text{ kg mol}$

From H, $F = 196.98 \text{ kg}$

From inert, $R = 8.7548 \text{ kg}$

$$\text{H in: } \frac{196.98(0.06)}{2} = 5.94$$

$$\text{O}_2 \text{ in: } \frac{5.94}{2} = 2.96$$

$$\text{C in} = \frac{196.98(0.90)}{12} = 14.77$$

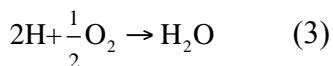
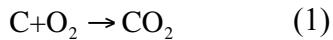
Step 10:

Check via C: $196.98 (0.90) / 12 = 100 (0.147) + (8.7548 (0.10) / 12)$ ok

Required O₂: $14.7 + (5.863/2) = 17.63 \text{ kg mol}$ Total O₂in = $102.53 (0.21) = 21.53$

Excess $(21.53 - 17.63) / 17.63 = 0.221$ or 22%

Alternate solution using extent of reaction:



CO₂: $n_{\text{CO}_2}^{\text{P}} = 13.9 = n_{\text{CO}_2}^{\text{F}} + (1) \xi_1 \quad \xi_1 = 13.9$

CO: $n_{\text{CO}}^{\text{P}} = 0.8 = n_{\text{CO}}^{\text{F}} + (1) \xi_2 \quad \xi_2 = 0.8$

N₂: $n_{\text{N}_2}^{\text{P}} = 81.0 = n_{\text{N}_2}^{\text{A}} \quad A = 102.5 \text{ mol}$

$$n_{\text{O}_2}^{\text{A}} = 0.21(102.5) = 21.5 \text{ mol}$$

O₂: $4.3 = 21.5 + (-1)(\xi_1) + (-\frac{1}{2})(\xi_2) + (-\frac{1}{2})(\xi_3) \quad \xi_3 = 2.90$

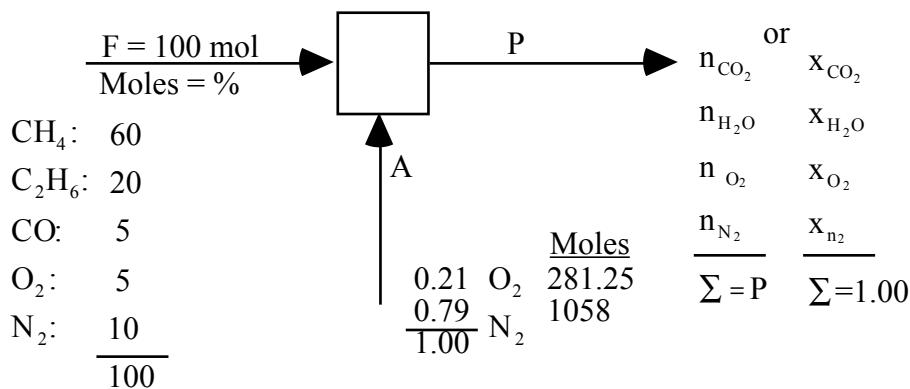
C: $0 = n_{\text{C}}^{\text{F}} + (-1)(13.9) + (-1)(0.8) \quad n_{\text{C}}^{\text{F}} = 14.7 \text{ mol}$

H: $0 = n_{\text{H}}^{\text{F}} + (-2)(2.90) \quad n_{\text{H}}^{\text{F}} = 5.80 \text{ mol}$ (some round off)

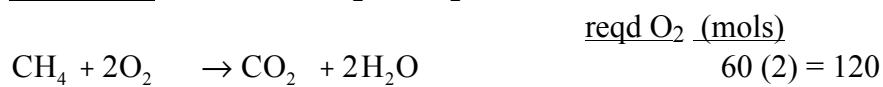
Solutions Chapter 5

5.5.6

Basis: 100 mol F



50% xs air: Calculate O₂ and N₂ in with the air in



Less O₂ in gas $\frac{5.00}{}$

Net required O ₂	187.5
xs O ₂ : 187.5 (.5) =	93.75
Total	281.25

$$N_2 \text{ in with } O_2 \quad \frac{281.25}{0.21} \left| \begin{array}{l} 0.79 \\ 0.21 \end{array} \right. = 1058$$

Material balances (elemental):

$$\begin{array}{ccccccc} \text{in (F)} & \text{_____} & + & \text{in (A)} & = & \text{out (P)} & \text{_____} \\ \text{C:} & 60 + 2(20) + 5 + & 0 & = & n_{CO_2} & & \\ \text{H:} & 60(4) + 20(6) + & 0 & = & n_{H_2O}(2) & & \\ \text{O as } O_2: & \frac{5}{2} + 5 & + & 281.25 = & n_{CO_2} + \frac{n_{H_2O}}{2} + n_{O_2} & & \end{array}$$

Solutions Chapter 5

$$\text{N as N}_2: \quad 10 \quad + \quad 1058 \quad = \quad n_{N_2}$$

$$n_{O_2} = 288.75 - 105 - \frac{180}{2} = 93.75$$

moles composition of stack in % moles

$n_{CO_2} = 105$	7.26
$n_{H_2O} = 180$	12.44
$n_{N_2} = 1068$	73.82
$n_{O_2} = 93.75$	6.48

$$\begin{array}{l} \text{Total moles} = 1446.75 \\ \text{out} \end{array} \quad \begin{array}{l} 100.00 \end{array}$$

5.5.7

Steps 1, 2, 3, 4:

<u>mol = %</u>	<u>O₂ reqd</u>		P	<u>mol fr.</u>	<u>mol fr.</u>	<u>mol calculated</u>
CO 13.54	6.77		CO ₂	x	0.143	31.96
CO ₂ 15.22	--		O ₂	y	0.037	8.27
H ₂ 15.01	7.505		N ₂	z	0.724	161.92
CH ₄ 3.20	6.40		H ₂ O	<u>1-x-y-z</u>	<u>0.096</u>	<u>21.41</u>
N ₂ 53.03	---			1.00	1.00	
100.00	20.675		A	0.21 O ₂		
				0.79 N ₂		
				1.00		

Step 5: Basis: 100 mol F

Step 6: Unknowns: P, x, y, z

Step 7: Balances C, H, O, N ok

Steps 8 and 9:

Air in is based on complete combustion



Solutions Chapter 5

$$\begin{aligned}
 \text{xs O}_2 &= 0.40 (20.675) = 8.27 \\
 \text{reqd O}_2 &= \frac{20.675}{\text{total O}_2} = \frac{20.675}{28.945} = 0.71 \\
 \text{N}_2 \text{ in with air} &= 28.945 - \left(\frac{0.71}{0.21} \right) = 108.89 \text{ mol} \\
 \text{Air} &= [137.84 \text{ mol}]
 \end{aligned}$$

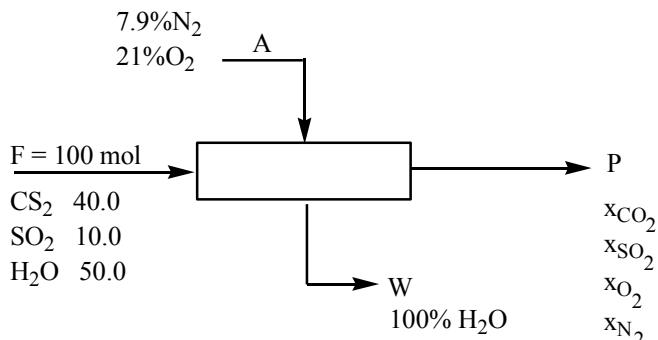
Balance

$$\begin{aligned}
 2\text{N} &\quad \text{N}_2 \text{ out} = 108.89 + 53.03 = 161.92 \text{ mol} \\
 \text{C} &\quad \text{CO}_2 \text{ out} = 13.54 + 15.22 + 3.20 = 31.96 \text{ mol} \\
 2\text{H} &\quad \text{H}_2\text{O out} = 15.01 + 2(3.20) = 21.41 \text{ mol} \\
 2\text{O} &\quad \text{O}_2 \text{ out} = 28.945 + \frac{13.54}{2} + 15.22 - 31.96 - \frac{21.41}{2} = 8.27 \text{ mol} \\
 &\quad (\text{as O}_2)
 \end{aligned}$$

Alternate solution: Use the extent of reaction and species balances

5.5.8

Steps 2, 3, and 4:

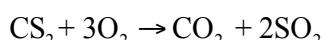


Step 5:

Basis: 100 mols feed; assume complete combustion

Step 4:

Equations:



$$\text{O}_2 \text{ required: } \frac{40 \text{ mol CS}_2}{1} \left| \frac{3 \text{ mol O}_2}{1 \text{ mol CS}_2} \right. = 120.0 \text{ mol O}_2$$

$$\% \text{ excess: } \frac{\text{O}_2 \text{ excess}}{\text{O}_2 \text{ required}} \times 100 = \% \text{ excess}$$

Steps 6, 7, 8 and 9:

5 unknowns and 5 equations → unique solution

Solutions Chapter 5

Element balances

<u>Component</u>	<u>Mol in</u>	<u>Mol out</u>
C	40.0	Px_{CO_2}
2S	$\frac{1}{2}(10.0) + 40.0$	$\frac{1}{2}(0.02)P$
2O	$10.0 + \frac{1}{2}(50.0) + .21A$	$(x_{CO_2} + 0.02 + x_{O_2})P + \frac{1}{2}W$
2N	.79A	$(1-x_{O_2} - 0.02 - x_{CO_2})P$
2H	50.0	W

$$P = \frac{2(45.0)}{.02} = 4500$$

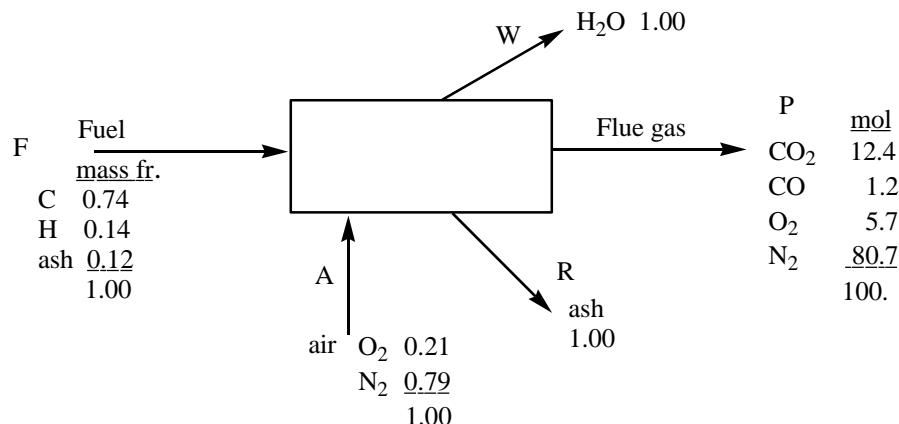
$$x_{CO_2} = 0.0089$$

$$\% \text{ Excess} = \frac{0.1829(4500 \text{ mol O}_2)}{120 \text{ mol}} (100) = \boxed{686\%}$$

Alternate solution: Use extent of reaction and species balances.

5.5.9

Steps 2, 3 and 4:



Step 5: Basis: P = 100 mol

Step 6: Unknowns: F, A, R, W } a discrepancy unless one

Step 7: Balances: C, H, O, N, ash } balance is not independent

Steps 8 and 9: all balances in moles

Solutions Chapter 5

C balance: $\frac{F(0.74)}{12} = 12.4 + 1.2 = 13.6$

$$F = \frac{(13.6)(12)}{0.74} = 220.5 \text{ lb}$$

2N balance: $A(0.79) = 80.7 \quad A = 102.2 \text{ mol}$

2H balance: $\frac{F(0.14)}{2} = W; \quad W = 15.44 \text{ mol}$

2O balance: $A (.21) = W \frac{(1.00)}{2} + 12.4 + \frac{1.2}{2} + 5.7$

$$21.46 = 26.42 \quad \text{not equal hence}$$

Some discrepancy exists

A total balance can be used, but must be in mass, and the mass of P calculated.

5.5.10

Basis: 100 moles exhaust gas

Comp	exhaust gas mol	tie element	exit gas %	mol
CO ₂	16.2		13.1	16.2
O ₂	4.8			
N ₂	79.0	83.8		
Total	100.0			
	$\frac{16.2 \text{ mol CO}_2}{100.0 \text{ mol exhaust gas}}$	$\frac{100.0 \text{ mol exit gas}}{13.1 \text{ mol CO}_2}$	= 123.6 mol exit gas	

$$\text{exhaust gas} = \underline{100.0 \text{ mol}}$$

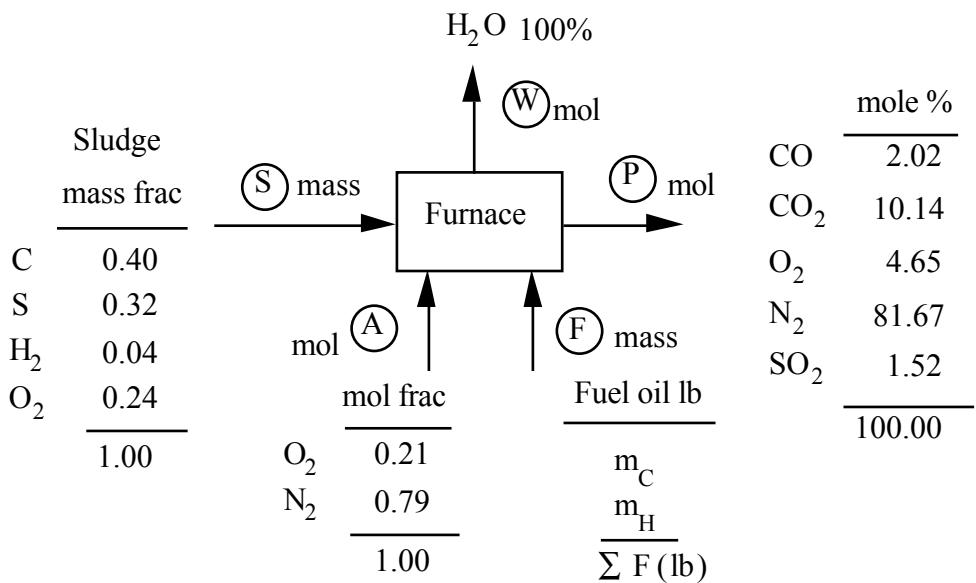
$$\text{air leaked in} = 23.6 \text{ mol}$$

$$\frac{23.6}{100.0} = \boxed{0.236 \text{ mol air / mol exhaust gas}}$$

Solutions Chapter 5

5.5.11

Steps 2, 3, and 4:



Step 5:

Basis: 100 mol P

Steps 6 and 7:

Unknowns: S, W, F (or m_H), A, m_C ⑤ Element Balances: S, C, H, O, N

Element Balances (moles)

$$S: \frac{0.32S}{32} = 1.52 \quad S = 152 \text{ lb}$$

$$2N: A(0.79) = 81.67 \quad A = 103.38 \text{ lb mol (2998.01 lb)}$$

$$C: \frac{S(0.40)}{12} + \frac{m_C}{12} = 10.14 + 2.02 \quad m_C = 85.12 \text{ lb}$$

$$2O: \frac{0.24(152)}{32} + A(0.21) = \frac{W}{2} + 1.52 + 10.14 + 4.65 + \frac{2.02}{2}$$

$$W = 11.04 \text{ lb mol (198.71 lb)}$$

Solutions Chapter 5

$$2H: \frac{0.04(152)}{2.03} + \frac{m_H}{2.03} = W \quad m_H = 16.32 \text{ lb}$$

Check via a total mass balance

$$\begin{array}{lll} 152 + 16.32 + 85.12 + 2998.01 & ? & 198.71 + 3035.56 \\ & = & = \\ 3251.45 & ? & 3234.27 \quad \text{close enough} \\ & = & \end{array}$$

	<u>lb</u>	<u>mass fr</u>
C	85.12	0.84
H	<u>16.32</u>	<u>0.16</u>
	101.44	1.00

$$\boxed{\frac{S}{F} = \frac{152 \text{ lb}}{101.44 \text{ lb}} = 1.50}$$

◀ (B)

5.5.12

Basis: 1 min

$$\begin{aligned} [\text{CaO}]_{\text{theor.}} &= \frac{1000 \text{ gal}}{\text{min}} \left| \frac{\text{ft}^3}{7.48 \text{ gal}} \right| \left| \frac{1.05 \times 62.4 \text{ lb soln.}}{\text{ft}^3} \right| \left| \frac{0.02 \text{ lb H}_2\text{SO}_4}{\text{lb soln.}} \right| \left| \frac{\text{mol H}_2\text{SO}_4}{98 \text{ lb H}_2\text{SO}_4} \right| \left| \frac{\text{mol CaO}}{\text{mol H}_2\text{SO}_4} \right| \\ &\frac{56.1 \text{ lb CaO}}{\text{mol CaO}} = 100.3 \text{ lb CaO/min} \end{aligned}$$

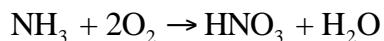
Feed rate of CaO = 1.2 $[\text{CaO}]_{\text{theor.}}$ = 120.4 lb CaO/min

$$\begin{aligned} \text{CaSO}_4 \text{ production rate} &= \frac{100.3 \text{ lb CaO}}{\text{min}} \left| \frac{\text{mol CaO}}{56.1 \text{ lb CaO}} \right| \left| \frac{\text{mol CaSO}_4}{\text{mol CaO}} \right| \left| \frac{136.1 \text{ lb CaSO}_4}{\text{mol CaSO}_4} \right| \left| \frac{\text{ton}}{2000 \text{ lb}} \right| \\ &\times \frac{60 \text{ min}}{\text{hr}} \left| \frac{24 \text{ hr}}{\text{d}} \right| \left| \frac{365 \text{ d}}{\text{yr}} \right| = 63,947 \text{ ton/yr} \end{aligned}$$

Solutions Chapter 5

5.5.13

Basis: 100 mol of product gas



The product gas from such a reactor has the following composition (water free basis):

0.8% NH₃
9.5% HNO₃
3.8% O₂
85.9% N₂

Determine the percent conversion of NH₃ and the percent excess air used.

$$n_{\text{NH}_3}^{\text{out}} = n_{\text{NH}_3}^{\text{in}} + \xi_{\text{NH}_3} (9.5)$$

$$0.8 = n_{\text{NH}_3}^{\text{in}} + (-1)(9.5)$$

$$F = n_{\text{NH}_3}^{\text{in}} = 0.8 + 9.5 = 10.3 \text{ mol}$$

$$\frac{n_{\text{NH}_3}^{\text{out}} - n_{\text{NH}_3}^{\text{in}}}{v} = \xi$$

$$\text{For HNO}_3: \frac{9.5 - 0}{1} = 9.5 =$$

Percent conversion $f = (100\%) \xi / F = 92.2\%$

Calculate the entering oxygen using a N₂ balance:

N₂: 0.79A = 85.9; therefore, A = 108.73 mol

Calculate the theoretical O₂ needed for the reaction

$$(O_2)_{\text{theor}} = 2 \times 10.3 = 20.6 \text{ mol}$$

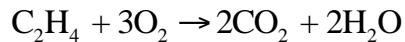
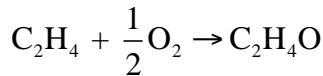
Feed rate of O₂ = 0.21A = 22.83 mol

$$\% \text{ Excess O}_2 = [(22.83 - 20.6) / 20.6] (100) = 10.84\%$$

Solutions Chapter 5

5.5.14

Basis: 100 mol of product gas (20.5%, C₂H₄O; 72.7 N₂; 2.3 O₂; and 4.5%CO₂



Calculate ξ_1 : $\xi_1 = \frac{n_i^{\text{out}} - n_i^{\text{in}}}{v_i}$ Use C₂H₄O: $\xi_1 = \frac{20.5 - 0}{1} = 20.5$

Calculate ξ_2 : Use CO₂: $\xi_2 = \frac{4.5 - 0}{2} = 2.25$

Calculate the entering air using a N₂ balance:

N₂: 0.79A = 72.7; therefore, A = 92.03 mol

Calculate the moles of C₂H₄ entering (F)

$$n_{\text{CH}_4}^{\text{out}} - n_{\text{CH}_4}^{\text{in}} = v_1\xi_1 + v_2\xi_2$$

$$0 - F = -\xi_1 - \xi_2 \text{ hence } F = 22.75$$

O₂ feed rate = 0.21A = 19.33 mol

(O₂)_{theor} = F/2 = 11.375 mol

% Excess O₂ = [(19.33-11.375)/11.375](100) = 70.0%

To get the ethylene feed:

$$\begin{aligned} \frac{22.75 \text{ C}_2\text{H}_4}{20.5 \text{ mol C}_2\text{H}_4\text{O}} &\left| \frac{100,000 \text{ ton C}_2\text{H}_4\text{O}}{\text{yr}} \right| \frac{2000 \text{ lb C}_2\text{H}_4\text{O}}{\text{ton C}_2\text{H}_4\text{O}} \left| \frac{\text{mol C}_2\text{H}_4\text{O}}{44 \text{ lb C}_2\text{H}_4\text{O}} \right. \\ &\times \frac{\text{yr}}{365 \text{ d}} \left| \frac{\text{d}}{24 \text{ h}} \right| \left| \frac{28 \text{ lb C}_2\text{H}_4}{\text{mol C}_2\text{H}_4} \right| = \boxed{16,123 \text{ lb C}_2\text{H}_4/\text{h}} \end{aligned}$$

Solutions Chapter 5

5.5.15

	<u>mole fr</u>		<u>mol fr</u>
CH ₄	0.70		CO ₂ 0.0773
C ₃ H ₈	0.05	Fuel	H ₂ O 0.1235
CO	0.15	F mol	O ₂ x _{O₂}
O ₂	0.05		N ₂ x _{N₂}
N ₂	0.05		
	1.00		1.00
		<u>mol frs</u>	
		O ₂ 0.21	
		N ₂ 0.79	
		1.00	

Unknowns A, F, P, x_{O₂}, x_{N₂}, Pick F = 100 as basis ④

Balances: C, H, O, N (is one redundant ?) plus
 $0.0773 + 0.1235 + x_{O_2} + x_{N_2} = 1$ ⑤

Balances:

$$C: \quad 100(0.70) + 100(0.05)(3) + 100(0.15) = P(0.0773)$$

$$N_2: \quad 100(0.05) + 0.79A = P x_{N_2}$$

$$H_2: \quad 100(0.70)(2) + 100(0.05)4 = P(0.1235) \text{ (redundant with C)}$$

$$O_2: \quad 100(0.15)\frac{1}{2} + 100(.05) + A(0.21) = P \left[(0.0773) + \frac{0.1235}{2} + x_{O_2} \right]$$

$$\Sigma x_i = 0.7992 = x_{O_2} + x_{N_2}$$

Solve C (or H2) balance for P; P = 1294

Solve N₂, O₂ and $\Sigma x_i = 1$ simultaneously for A, x_{O₂}, x_{N₂}

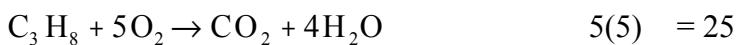
$$A = 1203 \text{ moles} \quad x_{O_2} = 0.0648 \text{ and } x_{N_2} = 0.7344 \text{ (not needed)}$$

Calculation of the required O₂

Required O₂



Solutions Chapter 5



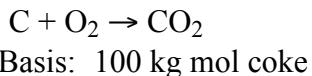
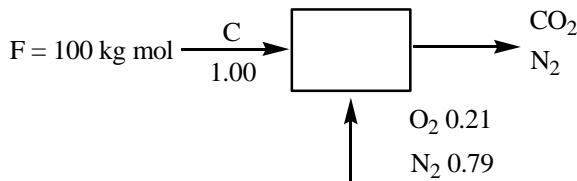
$$\begin{array}{r} \text{O}_2 \text{ present in F} \\ \hline & -5.0 \\ & 167.5 \text{ reqd} \end{array}$$

A(0.21) = 252.54 O₂ in

less $\frac{167.5 \text{ reqd O}_2}{85.04 \text{ xs O}_2}$

$$\frac{85.04}{167.5} (100) = \boxed{51\%}$$

5.5.16



Step 5:

a. O₂ in = 100 kg mol

$$\frac{100 \text{ kg mol C}}{1 \text{ mol C}} \left| \frac{1 \text{ mol O}_2}{21 \text{ mol O}_2} \right| \left| \frac{79 \text{ mol N}_2}{1 \text{ mol C}} \right| = 376 \text{ kg mol N}_2 \quad \text{in}$$

Steps 6 and 7:

Unknowns: moles (n_i) CO₂, O₂, and N₂ in P, and P
Balances: elements C, O, N

Equations: $\sum n_i^P = P$

or add ξ and have C, CO₂, N₂, O₂ species balances

Solutions Chapter 5

Steps 8 and 9:

Element balances

	in	out
C:	100	n_{CO_2}
2O:	100	$n_{CO_2} + n_{O_2}$
2N:	376	n_{N_2}

<u>Component in P</u>	<u>kg mol</u>	<u>mol %</u>
N_2	376	79
O_2	0	0
CO_2	<u>100</u>	<u>21</u>
	476	100

With 50% xs air, x_{O_2} , is 50 mol

The total O_2 in is 150 kg mol

The N_2 in is

$$\frac{150}{0.79} = 564$$

$$\frac{150}{0.21} = 564$$

The N and C balance are the same but the 2O balance is

<u>In</u>	<u>out</u>	<u>reacts</u>
150	-	$n_{O_2} = 50$

<u>Component in P</u>	<u>kg mol</u>	<u>mol %</u>
N_2	564	79
O_2	50	7
CO_2	<u>100</u>	<u>14</u>
	714	100

c. Same 150 mol O_2 enter and 564 mol N_2 exit but O_2 is different

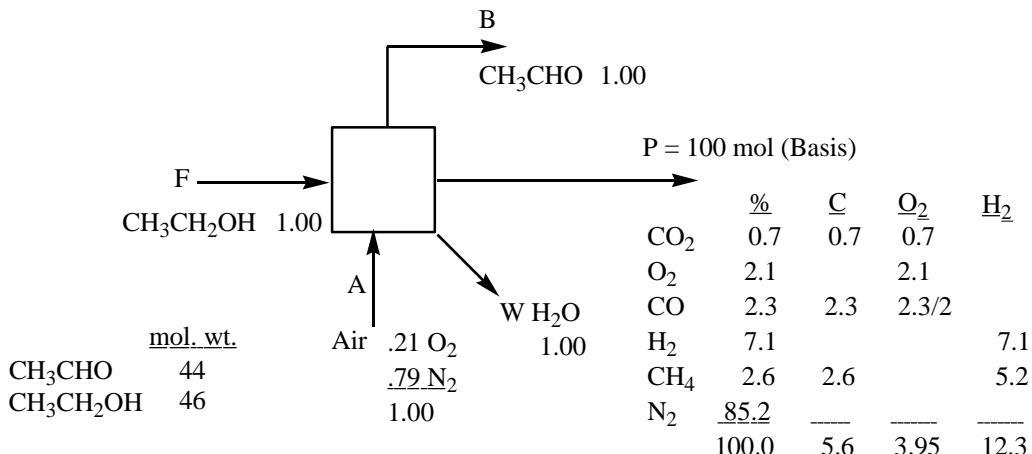
	<u>in</u>	<u>mol CO₂ used</u>	<u>Used CO</u>
Oxygen balance:	150	-	$90 - 5 = 55 \text{ kg mol } O_2 \text{ lb fg}$

Solutions Chapter 5

Component	kg mol	mol%
CO ₂	90	12.51
CO	10	1.39
O ₂	55	7.65
N ₂	564	78.45
Total	719	100.00

5.5.17

Steps 1, 2, 3 and 4:



Step 5: Basis: 100 mol P

Step 6: Unknowns: F, A, B, W

Step 7: Balances: C, O, H, N ok

Steps 8 and 9:

Via algebra

$$2N \text{ balance: } A(0.79) = 85.2 \quad A = 107.85 \text{ mol}$$

$$C \text{ balance: } F(2) = B(2) + 5.6$$

$$2H \text{ balance: } F(3) = B(2) + W(1) + 12.3$$

$$2O \text{ balance: } F\left(\frac{1}{2}\right) + (0.21)A = B\left(\frac{1}{2}\right) + W\left(\frac{1}{2}\right) + 3.95$$

Solutions Chapter 5

Solution: $B = 44.1 \text{ mol}$
 $F = 46.9 \text{ mol}$
 $W = 40.2 \text{ mol}$

$$\frac{44.1 \text{ mol acet.}}{100 \text{ mol P}} \left| \frac{44 \text{ kg acet.}}{1 \text{ kg mol acet.}} \right| \left| \frac{100 \text{ mol P}}{46.9 \text{ mol EtOH}} \right| \left| \frac{1 \text{ kg mol EtOH}}{46 \text{ kg}} \right| = \boxed{0.899} \frac{\text{kg acetaldehyde}}{\text{kg ethanol}}$$

Alternate solution: Use extent of reaction and species balances, but it is more complicated.

5.5.18

Basis: $F = 100 \text{ lb}$ given in Example 10.9

This basis gives $P = 50 \text{ lb}$ moles. Note: If the problem calculations were redone because of the stated additional reactions, the value of $P = 50$ for two significant figures would not change. Similarly, the other values of the moles in P would not change. Thus, the $\text{SO}_2 + \text{CO}_2$ is $0.154 (50) = 7.7 \text{ lb mol}$. The values of the pertinent components (for NO_x use $\text{NO}_{1.5}$) for this problem are

		<u>lb mol</u>	<u>MW</u>	<u>kg</u>	<u>ELU/kg</u>	<u>ELU</u>
$\text{NO}_x:$	$(0.0024)(80.6)$	=	0.193	2.2	4.25	0.22
CO:	$(0.0018)(7.7)$	=	0.090	28	2.52	0.27
$\text{SO}_2:$	$(0.014)(7.7)$	=	0.002	64	0.128	0.09
$\text{CO}_2:$	$(0.986)(7.7)$	=	7.59	48	364	0.10
				Total		38.0

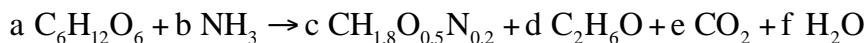
the total lb mol of nitrogen (N) entering is $2(50)(0.806) + 0.001 = 80.6$

Solutions Chapter 5

5.5.19

Assume ammonia and glucose (MW = 180.1) are fed in stoichiometric proportions.

The reaction equation has to be set up and balanced to use the value given of 60% (mole assumed) conversion of glucose.



Pick a basis of 4.6 kg of EtOH (C₂H₆O, MW = 46.07)

$$\frac{4600 \text{ g EtOH}}{46.07 \text{ g EtOH}} \left| \frac{1 \text{ g mol EtOH}}{1 \text{ g mol EtOH}} \right. = 100 \text{ g mol EtOH produced}$$

To balance the chemical reaction equation use element balances. Take a basis of a = 1. Assume 60% conversion of the glucose means that 1 mole of glucose produces 0.6 mol of ethanol, not that one mole of glucose produces 3 mol of ethanol.

$$\begin{array}{ll} \text{C:} & 6 = c + 2d + e \\ \text{H:} & 12 + 3b = 1.8c + 6d + 2f \\ \text{O:} & 6 = 0.5c + d + 2e + f \\ \text{N:} & b = 0.2c \end{array}$$

Specifications 0.60 = d

Results

$$\begin{array}{ll} a = 1 \text{ (the basis)} & d = 0.6 \\ b = 0.8 & e = 0.8 \\ c = 4 & f = 1.8 \end{array}$$

$$\frac{167 \text{ g mol C}_6\text{H}_{12}\text{O}}{1 \text{ g mol C}_6\text{H}_{12}\text{O}} \left| \frac{.08 \text{ g mol NH}_3}{1 \text{ g mol NH}_3} \right. = 133.6 \text{ g mol NH}_3$$

$$\frac{167 \text{ g mol C}_6\text{H}_{12}\text{O}_6}{1 \text{ g mol C}_6\text{H}_{12}\text{O}_6} \left| \frac{180.1 \text{ g mol C}_6\text{H}_{12}\text{O}_6}{1 \text{ g mol C}_6\text{H}_{12}\text{O}_6} \right. = 30,076 \text{ g or } 30.1 \text{ kg C}_6\text{H}_{12}\text{O}_6$$

$$\frac{133.6 \text{ g mol NH}_3}{1 \text{ g mol NH}_3} \left| \frac{17.03 \text{ g NH}_3}{1 \text{ g mol NH}_3} \right. = 2,275 \text{ g or } 2.28 \text{ kg NH}_3$$

Solutions Chapter 6

6.1.1

2 (The two overall balances on A and B sum up to the overall balance on the system)

6.1.2

4 (such as 2 component balances for each unit)

6.1.3

	<u>Components</u>
Unit I involves A, B, C	3
Unit II involves D, E	2
Unit III involves A, B, C, D	<u>4</u>
Number of independent balances	9

If A and B are always combined in the same ratio, then you have to reduce the independent balances by 1 for Unit I and 1 for Unit III, a total of 2.

6.1.4

Six independent equations if all compositions are known. The sum of the components (in moles) would equal the total flow, hence not all of the equations that could be written would be independent, only 2 per subsystem.

Total balances:

Condenser

$$F_2 = F_4 + F_5 \quad (F_3 \text{ does not mix, hence cancels out or can be omitted})$$

Column

$$F_1 + F_5 + F_9 = F_2 + F_8$$

Reboiler

$$F_8 = F_9 + F_7 \quad (F_6 \text{ does not mix, hence cancels out or can be omitted})$$

Component balances:

In addition, (2) component balances could be written for each component for each subsystem cited above. Multiply F_i by the composition x_{ij} .

Solutions Chapter 6

6.1.5

Unknowns: stream flows including F: 6
 Mass fractions (7 plus 3 in F) 10 16

Independent material balances:

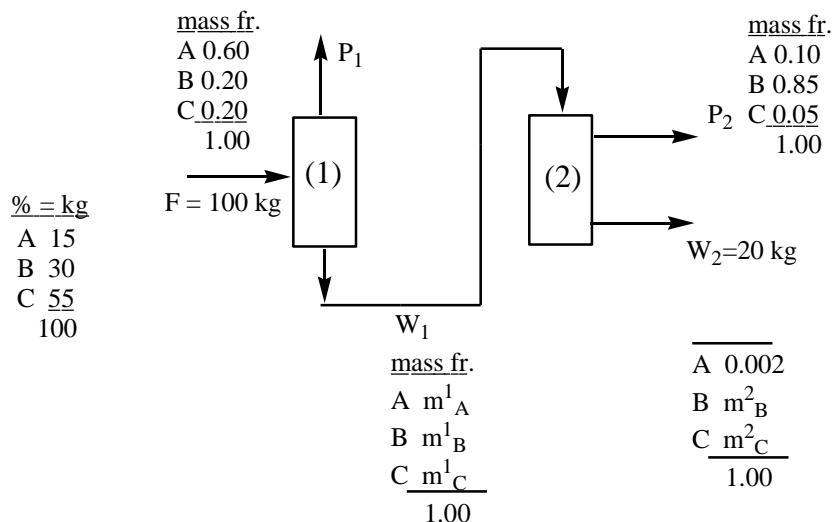
Species in 1 : 3	
2 : 2	
3 : 3	8

Other independent equations:

$\sum \omega_i = 1$ in each stream including F 8 16

6.1.6

Basis: $F = 100 \text{ kg}$ $m = \text{mass fraction}$



(a) SEPARATE ANALYSIS

Column (1) balances

$$\begin{aligned}
 (1) \text{ A: } 0.15(100) &= W_1(m_A^1) + P_1(0.60) \\
 (2) \text{ B: } 0.30(100) &= W_1(m_B^1) + P_1(0.20) \\
 (3) \text{ C: } 0.55(100) &= W_1(m_C^1) + P_1(0.20) \\
 100 &= W_1 + P_1 \\
 (4) \quad m_A^1 + m_B^1 + m_C^1 &= 1
 \end{aligned}
 \quad \left| \quad \begin{array}{l} \text{any 3 are indept. eqns.} \\ \text{4 indept. eqns.} \\ \text{eqns.} \end{array} \right.$$

Unknowns: $W_1, P_1, m_A^1, m_B^1, m_C^1$ 5 unknowns
 $5 - 4 = 1$ degree of freedom

Solutions Chapter 6

Column (2) balances

$$\begin{array}{l}
 (5) A: m_A^1 W_1 = 0.10 P_2 + 0.002 (20) \\
 (6) B: m_B^1 W_1 = 0.85 P_2 + m_B^2 (20) \\
 (7) C: m_C^1 W_1 = 0.05 P_2 + m_C^2 (20) \\
 \quad \quad \quad W_1 = P_2 + 20 \\
 \quad \quad \quad m_A^1 + m_B^1 + m_C^1 = 1 \\
 \quad \quad \quad 0.002 + m_B^2 + m_C^2 = 1
 \end{array}
 \left. \begin{array}{l}
 \text{any 3} \\
 \text{are indept.} \\
 \text{eqns.}
 \end{array} \right\} 5 \text{ indept. eqns.}$$

Unknowns: $W_1, P_2, m_A^1, m_B^1, m_C^1, m_B^2, m_C^2$ > unknowns
 $7 - 5 = 2$ degrees of freedom

JOINT ANALYSIS

Adding the 2 units to make a joint system

	No. of <u>Unknowns</u>	No. of indept. Eqns.	Degrees of freedom
• From the separate calculations start with:	12	9	3
• Delete the 4 common variables W_1, m_A^1, m_B^1, m_C^1 that are treated as unknowns in both subsystems leaving:	8	9	-1
• Delete the equation $m_A^1 + m_B^1 + m_C^1$ that will no longer be independent in the joint system (it appears in both subsystems) once leaving:	8	8	0

ANALYSIS OF OVERALL SYSTEM

System overall balances

$$\begin{array}{l}
 (1) A: 100 (0.15) = P_1 (0.60) + P_2 (0.10) + 20 (0.002) \\
 (2) B: 100 (0.30) = P_1 (0.20) + P_2 (0.85) + 20 (m_B^2) \\
 (3) C: 100 (0.55) = P_1 (0.20) + P_2 (0.05) + 20 (m_C^2) \\
 \quad \quad \quad 0.002 + m_B^2 + m_C^2 = 1
 \end{array}
 \left. \begin{array}{l}
 \text{4 indept.} \\
 \text{eqns.}
 \end{array} \right\} 4 \text{ indept. eqns.}$$

Unknowns: P_1, P_2, m_B^2, m_C^2 4 unknowns
 $4 - 4 = 0$ degrees of freedom as expected

Solutions Chapter 6

6.2.1

POLYMATHE Results

LEQ SOLUTION

[1] $x_1 = 25.071678$
 [2] $x_2 = 9.5018368$
 [3] $x_3 = 15.789356$
 [4] $x_4 = 19.442702$

LEQ REPORT

Coefficients matrix and beta matrix

$$\begin{array}{cccc|c} x_1 & x_2 & x_3 & x_4 & \\ \hline 0.07 & 0.18 & 0.15 & 0.24 & 10.5 \\ 0.04 & 0.24 & 0.1 & 0.65 & 17.5 \\ 0.54 & 0.42 & 0.54 & 0.1 & 28 \\ 0.35 & 0.16 & 0.21 & 0.02 & 14 \end{array}$$

The equations

[1] $.07x_1 + .18x_2 + .15x_3 + .24x_4 = 10.5$
 [2] $.04x_1 + .24x_2 + .10x_3 + .65x_4 = 17.5$
 [3] $.54x_1 + .42x_2 + .54x_3 + .10x_4 = 28$
 [4] $.35x_1 + .16x_2 + .21x_3 + .02x_4 = 14$

LEQ SOLUTION

[1] $x_1 = 25.193509$
 [2] $x_2 = -1.5823851$
 [3] $x_3 = 23.759139$
 [4] $x_4 = 22.30172$

LEQ REPORT

Coefficients matrix and beta matrix

$$\begin{array}{cccc|c} x_1 & x_2 & x_3 & x_4 & \\ \hline 0.07 & 0.18 & 0.15 & 0.24 & 10.395 \\ 0.04 & 0.24 & 0.1 & 0.65 & 17.5 \\ 0.54 & 0.42 & 0.54 & 0.1 & 28 \\ 0.35 & 0.16 & 0.21 & 0.02 & 14 \end{array}$$

The equations

[1] $.07x_1 + .18x_2 + .15x_3 + .24x_4 = 10.395$
 [2] $.04x_1 + .24x_2 + .10x_3 + .65x_4 = 17.5$
 [3] $.54x_1 + .42x_2 + .54x_3 + .10x_4 = 28$
 [4] $.35x_1 + .16x_2 + .21x_3 + .02x_4 = 14$

LEQ SOLUTION

[1] $x_1 = 24.968193$
 [2] $x_2 = 15.47106$
 [3] $x_3 = 11.587223$
 [4] $x_4 = 17.622301$

LEQ REPORT

Coefficients matrix and beta matrix

$$\begin{array}{cccc|c} x_1 & x_2 & x_3 & x_4 & \\ \hline 0.07 & 0.18 & 0.15 & 0.24 & 10.5 \\ 0.04 & 0.24 & 0.1 & 0.65 & 17.325 \\ 0.54 & 0.42 & 0.54 & 0.1 & 28 \\ 0.35 & 0.16 & 0.21 & 0.02 & 14 \end{array}$$

The equations

[1] $.07x_1 + .18x_2 + .15x_3 + .24x_4 = 10.5$
 [2] $.04x_1 + .24x_2 + .10x_3 + .65x_4 = 17.325$
 [3] $.54x_1 + .42x_2 + .54x_3 + .10x_4 = 28$
 [4] $.35x_1 + .16x_2 + .21x_3 + .02x_4 = 14$

LEQ SOLUTION

[1] $x_1 = 25.745274$
 [2] $x_2 = 20.920348$
 [3] $x_3 = 6.2323269$
 [4] $x_4 = 16.655497$

LEQ REPORT

Coefficients matrix and beta matrix

$$\begin{array}{cccc|c} x_1 & x_2 & x_3 & x_4 & \\ \hline 0.07 & 0.18 & 0.15 & 0.24 & 10.5 \\ 0.04 & 0.24 & 0.1 & 0.65 & 17.5 \\ 0.54 & 0.42 & 0.54 & 0.1 & 27.72 \\ 0.35 & 0.16 & 0.21 & 0.02 & 14 \end{array}$$

The equations

[1] $.07x_1 + .18x_2 + .15x_3 + .24x_4 = 10.5$
 [2] $.04x_1 + .24x_2 + .10x_3 + .65x_4 = 17.5$
 [3] $.54x_1 + .42x_2 + .54x_3 + .10x_4 = 27.72$
 [4] $.35x_1 + .16x_2 + .21x_3 + .02x_4 = 14$

LEQ SOLUTION

[1] $x_1 = 24.129021$
 [2] $x_2 = 3.1033062$
 [3] $x_3 = 21.42084$
 [4] $x_4 = 20.996864$

LEQ REPORT

Coefficients matrix and beta matrix

$$\begin{array}{cccc|c} x_1 & x_2 & x_3 & x_4 & \\ \hline 0.07 & 0.18 & 0.15 & 0.24 & 10.5 \\ 0.04 & 0.24 & 0.1 & 0.65 & 17.5 \\ 0.54 & 0.42 & 0.54 & 0.1 & 28 \\ 0.35 & 0.16 & 0.21 & 0.02 & 13.86 \end{array}$$

The equations

[1] $.07x_1 + .18x_2 + .15x_3 + .24x_4 = 10.5$
 [2] $.04x_1 + .24x_2 + .10x_3 + .65x_4 = 17.5$
 [3] $.54x_1 + .42x_2 + .54x_3 + .10x_4 = 28$
 [4] $.35x_1 + .16x_2 + .21x_3 + .02x_4 = 13.86$

The results show that the system of equations is very sensitive to small perturbations in the coefficients (measurements).

Solutions Chapter 6

6.2.2

Basis: 1 hr (1000 kg)

a. Overall balances:

$$\text{Total: } 1000 = W + D$$

$$\text{Salt: } 1000 (0.0345) = 0 + 0.069D$$

$$W = 500 \text{ kg}$$

$$D = 500 \text{ kg}$$

b. Salt balance on the freezer:

$$1000 (0.0345) = 0 + 0.048B$$

$$B = 718.75 \text{ kg}$$

Total balance on the freezer:

$$1000 = A + B$$

$$A = 281.25 \text{ kg}$$

Total balance around filter:

$$B = 718.75 = C + D$$

$$C = 218.75 \text{ kg}$$

6.2.3

Basis: 220g IgG from the reactor

$$\text{Fraction recovered} = \frac{140}{220} = 0.64$$

Solutions Chapter 6

6.2.4

Two subsystems exist, hence 4 component balances can be written. No reaction occurs and the process is assumed to be in the steady state. Steps are omitted here. The balances are

System : Splitter

$$\begin{aligned} \text{Total: } R &= E + P \\ \text{Fiber: } 2.34 &= x^E + x^P \\ \text{Water: } 7452 &= 4161 + 3291 \end{aligned}$$

System : Stock Chest

$$\begin{aligned} \text{Total: } P + N &= L \\ \text{Fiber: } x^P + x^N &= 103.26 \\ \text{Water: } 3291 + 18 &= 3309 \end{aligned}$$

$$\text{Also } N(0.15) = 18 \quad N = 120$$

$$0.85 (N) = x^N = 0.85 (120) \quad (\text{b})$$

Overall balances

$$\begin{aligned} \text{Total: } R + N &= E + L \\ \text{Fiber: } 2.34 + x^N &= x^E + 103.26 \quad (\text{c}) \\ \text{Water: } 7452 + 18 &= 4161 + 3309 \end{aligned}$$

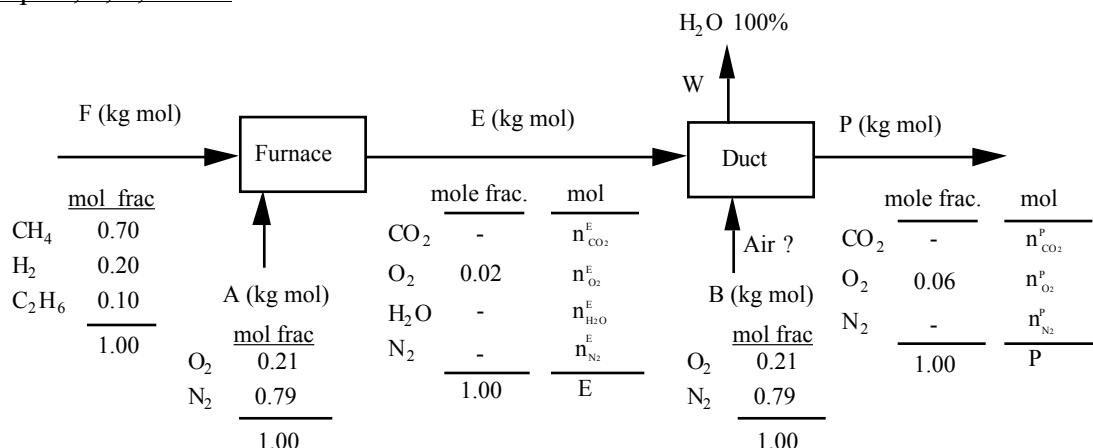
Substitute (b) into (c), solve (c) for x^E , and then solve (a) for x^P .

$x^N = 102$	$x^P = 1.26$	$x^E = 1.08$	all in kg
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6.2.5

Step 5: Basis: 100 kg mol = F

Steps 1, 2, 3, and 4:



Assume an air leak occurs first and use material balances to calculate the amount. This is a steady state flow process without reaction.

Solutions Chapter 6

Overall system

Step 6: Unknowns are: A, B, W, P, x_{N_2} (or n_{N_2}), x_{CO_2} (or n_{CO_2})

Step 7: Balances are: C, H, O, N, $\sum x_i^P = 1$ (or $\sum n_i^P = P$)

Steps 8 and 9:

	In		Out
C(kg mol):	$0.70(100) + 0.10(100)2$	=	n_{CO_2}
	$n_{CO_2} = 90 \text{ kg mol}$		
H (kg mol):	$0.70(100)(4) + 0.20(100)(2)$ + $0.10(100)(6)$	=	W (2)
	$W = 190 \text{ kg mol}$		
2O (kg mol):	$0.21A + 0.21B$	=	$\frac{190(1.00)}{2} + 90 + 0.06P$
2N (kg mol):	$0.79A + 0.79B$	=	$n_{N_2}^P$
	$90 + 0.06P + n_{N_2}^P$	=	P

A balance about the furnace or about the duct is needed; or these two alone would have been sufficient, omitting the overall balance.

System: Furnace (or Duct)

Step 6: Unknowns: A, $n_{CO_2}^E$, $n_{O_2}^E$, $n_{H_2O}^E$, $n_{N_2}^E$

Step 7: Balances: C, H, O, N₂, $\sum n_i^E = E$

Steps 8 and 9:

$$\begin{aligned} C \text{ (kg mol): } & 0.70(100) + 0.10(100)(2) = n_{CO_2}^E \\ & n_{CO_2}^E = 90 \text{ kg mol} \end{aligned}$$

$$\begin{aligned} H \text{ (kg mol): } & 0.70(100)(4) + 0.20(100)(2) + 0.10(100)(6) = n_{H_2O}^E \\ & n_{H_2O}^E = 190 \end{aligned}$$

$$2O \text{ (kg mol): } 0.21A = n_{O_2}^E + 90 + \frac{190}{2}$$

Solutions Chapter 6

$$2N \text{ (kg mol)}: 0.79A = n_{N_2}^E$$

$$90 + 190 + n_{O_2}^E + n_{N_2}^E = E$$

$$0.02 = n_{O_2}^E / E$$

<u>Solution:</u>	<u>kg mol in E</u>	<u>kg mol</u>
$n_{CO_2}^E$	90	A
$n_{H_2O}^E$	190	E
$n_{O_2}^E$	21.5	
$n_{N_2}^E$	<u>776</u>	
	1077.5	

From the overall N₂ balance: $0.79(982) + 0.79B = n_{N_2}^P$ (1)

O₂ balance: $0.21(982) + 0.21B = 185 + 0.06P$ (2)

(1) $22.2 + 0.21B = 0.06P$ $B = 207 \text{ kg mol}$

(3) $90 + (0.79)(982) + 0.79B = 0.94P$ $P = 1095 \text{ kg mol}$

It is an air leak.

207 kg mol / 100 kg mol F

Solutions Chapter 6

6.2.6

Steps: 1,2,3, and 4: This is a steady state process with no reaction taking place. All the compositions are known except for stream C. We can pick the overall system first to get D, and then make balances on the first (or second) units to get C and its composition.

Step 5: Basis: $F = 290 \text{ kg}$ (equivalent to 1 second)

Step 6: Unknowns: A, B, C, D and E and the composition of C

Step 7: Balances: NaCl, HCl, H₂SO₄, H₂O, inert solid

Step 8: For the overall system there are 4 unknowns (C is excluded) and 5 species balances:

Overall balances (kg)

	In		Out
NaCl:	A(0.040)	=	290(0.0138)
HCl:	A(0.050)	=	290(0.0255)+D(0.020)+E(0.015)
H ₂ SO ₄ :	A(0.040)	=	290(0.0221)+D(0.020)+E(0.015)
H ₂ O:	A(0.870)+B(0.910)	=	290(0.9232)+D(0.960)+E(0.970)
Inerts:	B(0.09)	=	290(0.0155)
Totals:	A + B	=	D + E + 290

Steps 6 and 7:

Two of the equations are not independent: HCl and H₂SO₄.

$$\text{HCl: } D(0.020) + E(0.015) = 7.40 - 5.00 = 2.40$$

$$\text{H}_2\text{SO}_4: D(0.020) + E(0.015) = 6.41 - 4.00 = 2.41$$

Thus, overall the degrees of freedom are 0.

Steps 8 and 9:

The solution of the equations is (in kg/s)

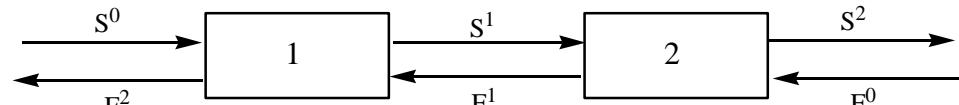
$$[A = 100], [B = 50], [D = 60] \text{ and } [E = 80]$$

from which $[C = 150]$ via a total balance about the first unit.

Solutions Chapter 6

6.2.7

Notation: Subscripts Benzene = bz, Xylene = xy, Solids = s
 W = mass fraction, F^i = liquid stream, S^i = solids stream

$\omega_{\text{bz}}^{S^0} = 1.0$ $\omega_{\text{xy}}^{S^0} = 0$ $\omega_s^{S^0} = 0$ $\frac{\omega_s^{S^0}}{1.0}$	$\omega_{\text{bz}}^{S^1} = (1 - \omega_{\text{xy}}^{S^1})$ $\omega_{\text{xy}}^{S^1}$ $\omega_s^{S^1} = 0$ $\frac{\omega_s^{S^1}}{1.0}$	$\omega_{\text{bz}}^{S^2} = (1 - \omega_{\text{xy}}^{S^2})$ $\omega_{\text{xy}}^{S^2}$ $\omega_s^{S^2} = 0$ $\frac{\omega_s^{S^2}}{1.0}$
		
$\omega_{\text{bz}}^{F^2} = (1 - \omega_{\text{xy}}^{F^2})$ $\omega_{\text{xy}}^{F^2}$ $\omega_s^{F^2} = 0.9$ $\frac{\omega_s^{F^2}}{1.0}$	$\omega_{\text{bz}}^{F^1} = (1 - \omega_{\text{xy}}^{F^1})$ $\omega_{\text{xy}}^{F^1}$ $\omega_s^{F^1} = 0.9$ $\frac{\omega_s^{F^1}}{1.0}$	$\omega_{\text{bz}}^{F^0} = 0$ $\omega_{\text{xy}}^{F^0} = 0.1$ $\omega_s^{F^0} = 0.9$ $\frac{\omega_s^{F^0}}{1.0}$

Step 5: Basis is 1 hr ($F^0 = 2000$ kg and $S^0 = 1000$ kg)

Steps 6 and 7:

Unknowns:

Unit 1: $\omega_{\text{xy}}^{F^2}, \omega_{\text{xy}}^{S^1}, \omega_{\text{xy}}^{F^1}, S^1, F^1, F^2$	$\left. \right\} \text{Net} = 8$
Unit 2: $\omega_{\text{xy}}^{S^1}, \omega_{\text{xy}}^{F^1}, \omega_{\text{xy}}^{S^2}, S^1, F^1, S^2$	

Material Balances:

Unit 1: bz, xy, s		
Unit 2: bz, xy, s		

Additional Equations: $\omega_{\text{xy}}^{F^2} = \omega_{\text{xy}}^{S^1}$ and $\omega_{\text{xy}}^{F^1} = \frac{S^2}{F^1}$ (the related equations for benzene are redundant). Total equations = 8.

The solution is simplified if two balances are made first (not an essential step):

All material balances are in kg.

Solids balance on Unit 2 and also Unit 1:

$$\begin{array}{ll} 2000 (0.9) = F^1 (0.9) & F^1 = 2000 \\ 2000 (0.9) = F^2 (0.9) & F^2 = 2000 \end{array}$$

Solutions Chapter 6

Total balance on Unit 1 and also Unit 2:

$$\begin{aligned} 2000 + S^1 &= 2000 + S^2 & S^1 &= S^2 \\ 1000 + 2000 &= 2000 + S^1 & S^1 &= 1000 \\ && S^2 &= 1000 \end{aligned}$$

The other balances are

Unit 2:

$$\begin{aligned} \text{Benzene: } 1000(1 - \omega_{xy}^{S^1}) &= 2000(1 - \omega_{xy}^{F^1}) + 1000(1 - \omega_{xy}^{S^2}) \\ \text{Xylene: } 2000(0.1) + 1000\omega_{xy}^{S^1} &= 2000 \frac{F^1}{xy} + 1000 \frac{S^2}{xy} \\ 10\omega_{xy}^{F^1} &= \frac{S^2}{xy} \end{aligned}$$

Unit 1:

$$\begin{aligned} \text{Benzene: } 1.0(1000) + 2000(1 - \omega_{xy}^{F^1}) &= 2000(1 - \omega_{xy}^{F^2}) + 1000(1 - \omega_{xy}^{S^1}) \\ \text{Xylene: } 0 + 2000\omega_{xy}^{F^1} &= 2000\omega_{xy}^{F^2} + 1000(\omega_{xy}^{S^1}) \\ 10\omega_{xy}^{F^2} &= \frac{S^1}{xy} \end{aligned}$$

Solve the equations to get the compositions of the streams:

Stream	Component wt fr	Stream	Component wt fr
S^0	Bz 1.0 Xy 0.0	F^0	Bz 0.9 Xy 0.1
S^1	Bz 0.97 Xy 0.03	F^1	Bz 0.082 Xy 0.018
S^2	Bz 0.82 Xy 0.18	F^2	Bz 0.097 Xy 0.003

b) Xylene in Feed = $2000 \times 0.1 = 200 \text{ kg}$

Xylene in Product = $1000 \times 0.18 = 180 \text{ kg}$

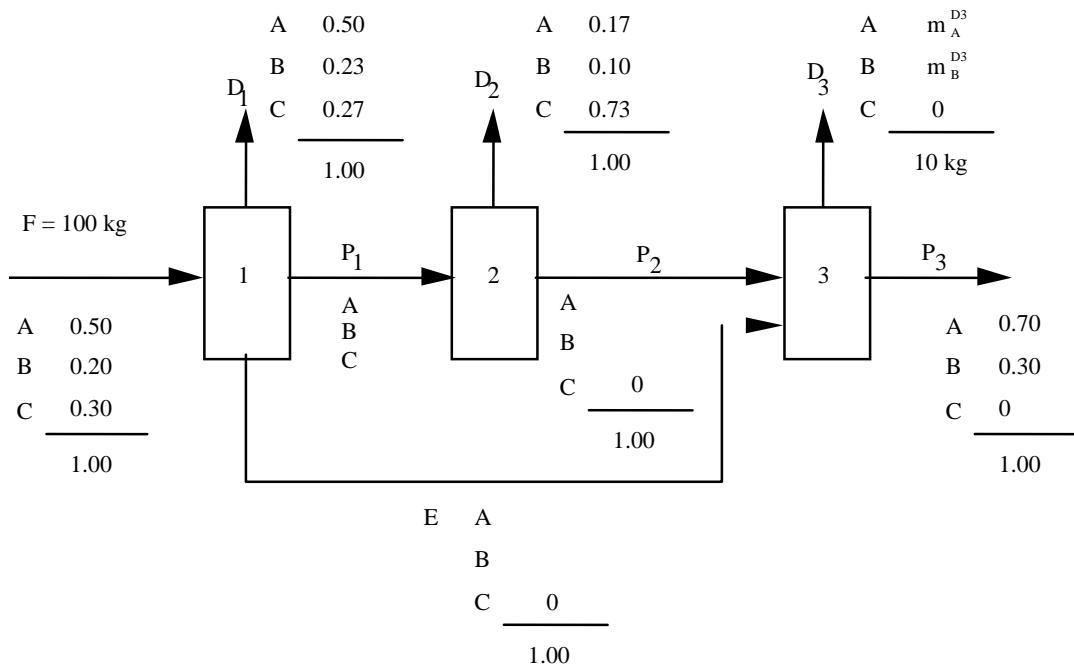
$$\boxed{\% \text{ Recovery}} = \frac{180}{200} \times 100 = \boxed{90\%}$$

Solutions Chapter 6

6.2.8

Step 5: Basis: $F = 100 \text{ kg}$ and $D_3 = 10 \text{ kg}$

Steps 2, 3, and 4:



Additional information: $P_3 = 3D_3 = 30 \text{ kg}$
 $P_2 = D_2$

$$m_A^{P_2} = 4m_B^{P_2}$$

Begin with overall balances.

Steps 6 and 7:

Unknowns 4: $D_1, D_2, m_A^{D_3}, m_B^{D_3}$
 Balances (3) : A, B, C (plus total)
 Implicit equation (1): $m_A^{D_3} + m_B^{D_3} = 10 \text{ kg}$

$\left. \right\} \text{Degrees of freedom} = 0$

Steps 8 and 9:

Overall balances

$$\text{Total : } 100 = D_1 + D_2 + 10 + 30 \quad \text{or } 60 = D_1 + D_2$$

Solutions Chapter 6

$$C: \quad 100 (.30) = 0.27D_1 + 0.73 D_2 + 0$$

Solve these two equations to get $D_1 = 30$ and $D_2 = 30$

Get $m_A^{D_3}$ and $m_B^{D_3}$ from A balance and $m_A^{D_3} + m_B^{D_3} = 1$

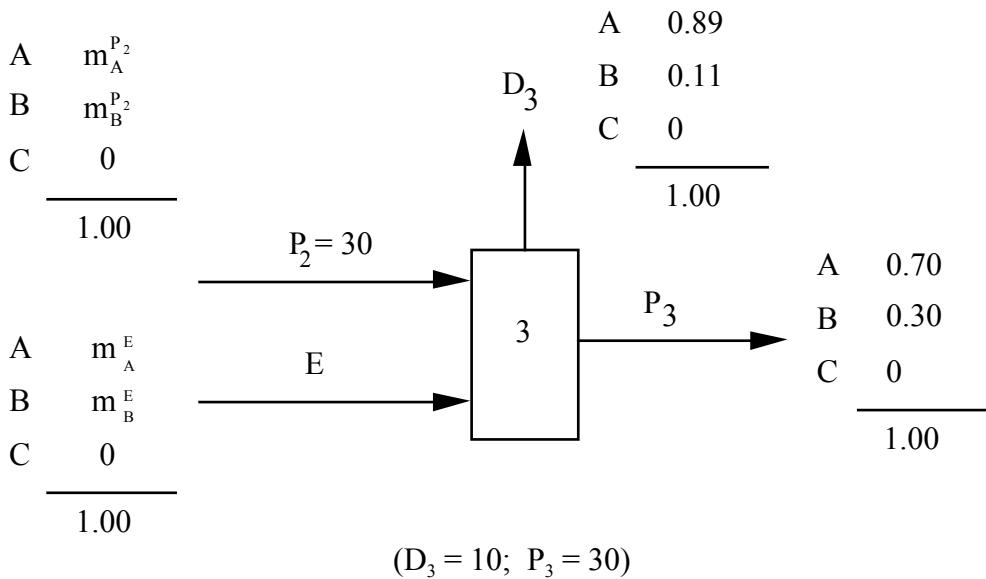
$$A: \quad 100(.50) = 30(.50) + 30(.17) + 10m_A^{D_3} + 30 (.70) \text{ so, } m_A^{D_3} = 0.89$$

$$m_A^{D_3} + m_B^{D_3} = 1 \text{ so } m_B^{D_3} = 0.11$$

Step 10:

Note - Can check using the B balance (not independent)

Balances on Unit No. 3



$$(D_3 = 10; P_3 = 30)$$

Steps 6 and 7:

Unknowns (5): $E, m_A^{P_2}, m_B^{P_2}, m_A^E, m_B^E$

Balances (2): A, B

Implicit equations (2): $m_A^{P_2} + m_B^{P_2} = 30, m_A^E + m_B^E = E$

Other equations: $m_A^{P_2} = 4m_B^{P_2}$

Steps 8 and 9:

$$\text{Total: } 30 + E = D_3 + P_3 = 10 + 30 = 40 \quad \text{so} \quad E = 10 \text{ kg}$$

One component balance:

Solutions Chapter 6

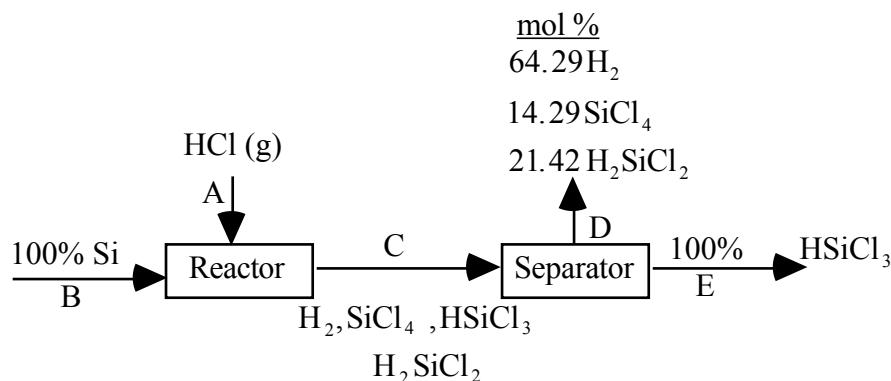
$$\left. \begin{array}{l} A: 30m_A^{P_2} + 10m_A^E = 10(.89) + 30(.70) = 29.9 \\ B: 30m_B^{P_2} + 10m_B^E = 10(.11) + 30(.30) = 10.1 \end{array} \right\} \text{not independent equations}$$

$$\left. \begin{array}{l} \sum m_i^{P_2} = m_A^{P_2} + m_B^{P_2} = 1 \\ m_A^{P_2} = 4m_B^{P_2} \end{array} \right\} \quad \begin{array}{l} m_A^{P_2} = 0.80 \\ m_B^{P_2} = 0.20 \end{array} \quad \text{so that} \\ 30 (.80) + 10 m_A^E = 29.9 \quad \text{so that } m_A^E = 0.59 \quad \boxed{\text{or } 59\%}$$

$$m_A^E + m_B^E = 1 \quad m_B^E = 0.41 \quad \boxed{\text{or } 41\%}$$

6.2.9

Steps 1, 2, 3 and 4:



Step 5: Basis: 100 kg B

$$\frac{100 \text{ kg Si}}{28.09 \text{ kg Si}} \left| \frac{1 \text{ kg mol Si}}{1 \text{ kg mol Si}} \right. = 3.560 \text{ kg mol Si}$$

Steps 6 and 7: Unknowns: A, D, E Balances: H, Cl, Si

Steps 8 and 9: Balances to be solved:

System: overall process

Si overall mole balance

$$\text{kg mol Si} = 3.560$$

Solutions Chapter 6

$$= D \frac{\text{kg mol gas}}{\text{kg mol gas}} \left[\frac{0.1429 \text{ kg mol SiCl}_4}{\text{kg mol gas}} \right] \left[\frac{1 \text{ kg mol Si}}{\text{kg mol SiCl}_4} \right] + \frac{0.2142 \text{ kg mol H}_2\text{SiCl}_2}{\text{kg mol gas}} \left[\frac{1 \text{ kg mol Si}}{\text{kg mol H}_2\text{SiCl}_2} \right]$$

$$+ \frac{E \text{ kg mol HSiCl}_3}{\text{kg mol HSiCl}_3} \left[\frac{1 \text{ kg mol Si}}{\text{kg mol HSiCl}_3} \right] = 0.3571D + E$$

Cl overall mol balance

$$\frac{A \text{ kg mol HCl}}{\text{kg mol HCl}} \left[\frac{1 \text{ kg mol Cl}}{\text{kg mol HCl}} \right] = D \frac{\text{kg mol gas}}{\text{kg mol gas}} \left[\frac{0.1429 \text{ kg mol SiCl}_4}{\text{kg mol gas}} \right] \left[\frac{4 \text{ kg mol Cl}}{\text{kg mol SiCl}_4} \right]$$

$$+ \frac{0.2142 \text{ kg mol H}_2\text{SiCl}_2}{\text{kg mol gas}} \left[\frac{2 \text{ kg mol Cl}}{\text{kg mol H}_2\text{SiCl}_2} \right] + \frac{E \text{ kg mol HSiCl}_3}{\text{kg mol HSiCl}_3} \left[\frac{3 \text{ kg mol Cl}}{\text{kg mol HSiCl}_3} \right]$$

$$A = D + 3E$$

H overall mol balance

$$\frac{A \text{ kg mol HCl}}{\text{kg mol HCl}} \left[\frac{1 \text{ kg mol H}}{\text{kg mol HCl}} \right] = D \frac{\text{kg mol gas}}{\text{kg mol gas}} \left[\frac{0.6429 \text{ kg mol H}_2}{\text{kg mol gas}} \right] \left[\frac{2 \text{ kg mol H}}{\text{kg mol H}_2} \right]$$

$$+ \frac{0.2142 \text{ kg mol H}_2\text{SiCl}_2}{\text{kg mol gas}} \left[\frac{2 \text{ kg mol H}}{\text{kg mol H}_2\text{SiCl}_2} \right] + \frac{E \text{ kg mol HSiCl}_3}{\text{kg mol HSiCl}_3} \left[\frac{1 \text{ kg mol H}}{\text{kg mol HSiCl}_3} \right]$$

$$A = 1.71421D + E$$

$$\text{Solution: } 3.560 = 0.3571 1D + E \quad \textcircled{1}$$

$$A = D + 3E \quad \textcircled{2}$$

$$A = 1.7142D + E \quad \textcircled{3}$$

$$\textcircled{2} \textcircled{3} \quad 2E = 0.7142 1D$$

$$E = 0.3571 1D \quad \textcircled{4}$$

$$\textcircled{1} \textcircled{4} \rightarrow 3.56 = 0.3571D + 0.3571 D$$

Solutions Chapter 6

$$D = 4.98$$

$$E = 1.78$$

$$A = 10.32$$

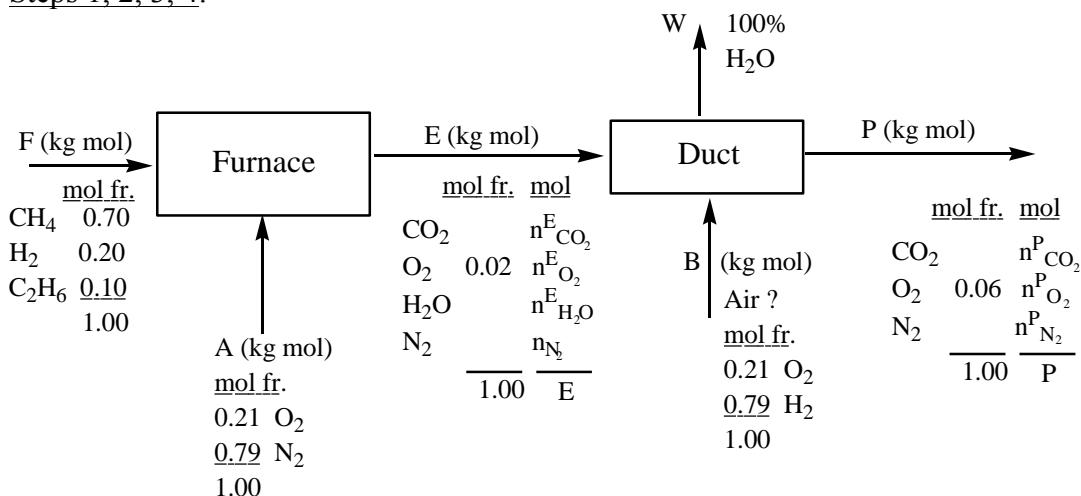
	<u>MW</u>
H	1.01
Si	28.09
Cl ₃	<u>106.35</u>
	135.45 kg/mol

$$\frac{135.45 \text{ kg HSiCl}_3}{\text{kg mol HSiCl}_3} \left| \frac{1.78 \text{ kg mol}}{\text{mol}} \right| = \boxed{241 \text{ kg HSiCl}_3}$$

6.2.10

Step 5: Basis: 100 kg mol = F

Steps 1, 2, 3, 4:



Assume first an air leak occurs and use material balances to calculate the amount. This is a steady state flow process without reaction.

Overall system

Step 6: Unknowns are: A, B, W, P, x_{N₂} (or n_{N₂}), x_{CO₂} (or n_{CO₂})

Solutions Chapter 6

Step 7: Balances are: C, H, O, N, $\sum x_i^P = 1$ (or $\sum n_i^P = P$)

Step 8:

	<u>In</u>	<u>Out</u>
C (kg mol):	$0.70(100) + 0.10(100)2$	$= n_{CO_2}$
	$n_{CO_2} = 90 \text{ kg mol}$	
H (kg mol):	$0.70(100)(4) + 0.20(100)(2) + 0.10(100)(6) = W(2)$	
	$W = 190 \text{ kg mol}$	
2O (kg mol):	$0.21A + 0.21 B$	$= \frac{190(1.00)}{2} + 90 + 0.06P$
2N (kg mol):	$0.79A + 0.79 B$	$= n_{N_2}^P$
	$90 + 0.06P + n_{N_2}^P$	$= P$

A balance about the furnace or about the duct is needed, or those two alone would have been sufficient, omitting the overall balance.

System: Duct

Step 6: Unknowns: A, E, $n_{CO_2}^E$, $n_{O_2}^E$, $n_{H_2O}^E$

Step 7: Balances: C, H, O, N₂, $\sum n_i^E = E$

Steps 8 and 9:

C (kg mol):	$0.70(100) + 0.10(100) (2) = n_{CO_2}^E$
	$n_{CO_2}^E = 90 \text{ kg mol}$
H (kg mol):	$0.70(100)(4) + 0.20 (100) (2) + 0.10(100) (6) = n_{H_2O}^E$
	$n_{H_2O}^E = 190$
2O (kg mol):	$0.21A = n_{O_2}^E + 90 + \frac{190}{2}$
2N (kg mol):	$0.79A = n_{N_2}^E$
	$90 + 190 + n_{O_2}^E + n_{N_2}^E = E$
	$0.02 = \frac{n_{O_2}^E}{E}$

Solution

	<u>kg mol in E</u>		<u>kg mol</u>
$n_{CO_2}^E$	90	A	982
$n_{H_2O}^E$	190	E	1077
$n_{O_2}^E$	21.5		
$n_{N_2}^E$	<u>776</u>		

Solutions Chapter 6

1077.5

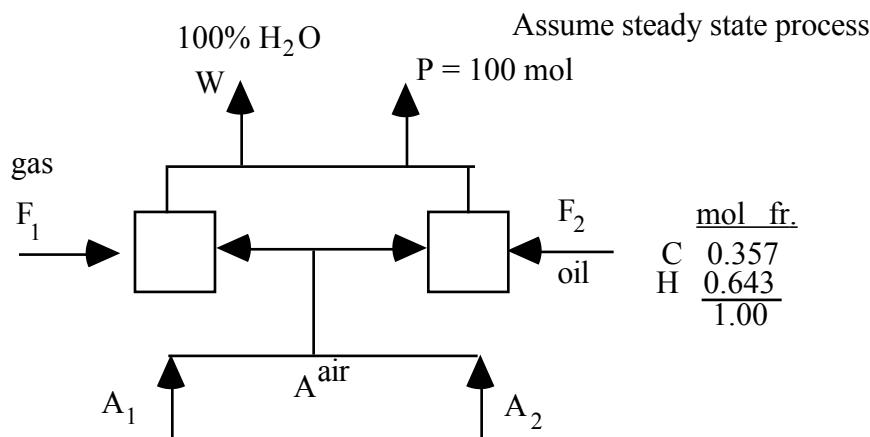
From the overall 2N balance $0.79(982) + 0.79B = n_{N_2}^P$ (1)

2O balance $0.21(982) + 0.21B = 185 + 0.06P$ (2)

(1') $22.2 + 0.21B = 0.06P$

(3) $90 + (0.79)(982) + 0.79B = 0.94P \quad \left. \begin{array}{l} B = 207 \text{ kg mol} \\ P = 1095 \text{ kg mol} \end{array} \right\} \boxed{207} \text{ kg mol / 100 kg mol F}$

6.2.11



Basis: 100 mol natural gas

Comp.	mol=%atoms C	atoms O	atoms H
CH ₄	96	96	--
C ₂ H ₂	2	4	--
CO ₂	2	2	4
Total	100	102	4
			388

Basis: 100 mol oil

Comp.	atoms C	atoms H
(CH _{1.8}) _n	100	180

Basis: 100 mol flue gas (dry)

Solutions Chapter 6

Comp. mol%	mol C	mol O	atoms H	mol N ₂
CO ₂	10.0	10.00	20.00	--
CO	0.63	0.63	0.63	--
O ₂	4.55	--	9.10	--
N ₂	<u>84.82</u>	--	--	<u>84.82</u>
Total	100.00	10.63	29.73	84.82

Note: If have separate air streams, we have 5 unknowns and can't solve.

Basis: 100 mol natural gas (or use 100 mol dry gas product.)

Let F₂ = mol oil

F₁ or P = mol dry flue gas

A = mol air to natural gas fed boiler plus oil fed boiler

W = mol water associated with the dry flue gas

Four balances: In = Out

C balance

$$102 + F_2 = 0.1063 P \quad (1)$$

N₂ balance

$$0.79A = 0.8482 P \quad (2)$$

H balance

$$388 + 1.80 F_2 = 2 W \quad (3)$$

O balance

$$4 + 0.42A = 0.2973P + W \quad (4)$$

$$P = 1729 \text{ mol dry flue gas}$$

$$W = 268 \text{ mol H}_2\text{O}$$

$$F_2 = 82 \text{ mol oil and } 1 \text{ mol C} = 1 \text{ mol oil so}$$

$$\text{C in oil} = F_2 = 82 \text{ mol}$$

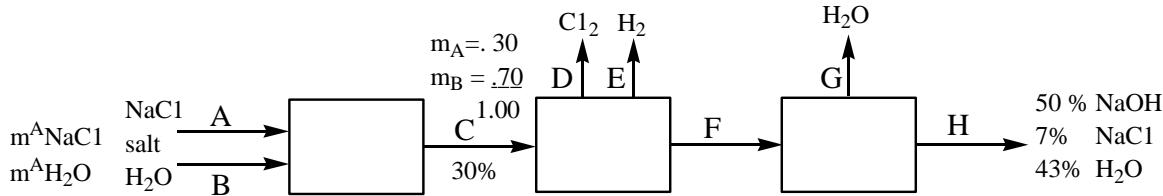
Solutions Chapter 6

$$\text{Total C} = 102 + 82 = 184 \text{ mol}$$

$$\% \text{ C burned from oil} = \frac{(0.82)(100)}{184} = \boxed{44.5\%}$$

6.2.12

Steady-state, reaction take place



Overall balances

Steps 6 and 7:

5 unknowns: A, B, D, E, G

4 balances: Na, Cl, H, O

other equations: A/B = 30/70

Steps 8 and 9:

(a) Percent conversion of salt to sodium hydroxide.

Basis: 1 lb product = H

1b mol of NaOH:

$$\frac{1 \text{ lb}}{\text{lb}} \left| \frac{0.5 \text{ lb NaOH}}{\text{lb}} \right| \left| \frac{\text{lb mol NaOH}}{40 \text{ lb NaOH}} \right| = 1.25 \times 10^{-2} \text{ lb mol NaOH}$$

1b mol NaCl:

$$\frac{1 \text{ lb}}{\text{lb}} \left| \frac{0.07 \text{ lb NaCl}}{\text{lb}} \right| \left| \frac{\text{lb mol NaCl}}{58.45 \text{ lb NaCl}} \right| = 1.20 \times 10^{-3} \text{ lb mol NaCl}$$

$$\text{Conversion} = \frac{1.25 \times 10^{-2}}{1.25 \times 10^{-2} + 1.20 \times 10^{-3}} (100) = \boxed{91.2\%}$$

Solutions Chapter 6

- (b) How much chlorine gas is produced per lb of product?

$$\frac{1.25 \times 10^{-2} \text{ lb mol NaOH}}{\text{lb mol NaOH}} \left| \frac{0.5 \text{ lb mol Cl}_2}{\text{lb mol NaOH}} \right| \left| \frac{70.9 \text{ lb Cl}_2}{\text{lb mol Cl}_2} \right| = \boxed{0.44 \text{ lb Cl}_2/\text{lb product}}$$

$$\begin{aligned} \text{(c)} \quad A &= (1.25 \times 10^{-2} \text{ lb mol} + 1.20 \times 10^{-3} \text{ lb mol}) \left(\frac{58.45 \text{ lb}}{\text{lb mol}} \right) \\ &= 0.80 \text{ lb} \end{aligned}$$

Using salt as a tie component:

$$C = \frac{A}{0.30} = \frac{1}{0.30} \cdot 0.8 \text{ lb} = 2.67 \text{ lb}$$

$$B = C - A = 2.67 - 0.8 = 1.87 \text{ lb}$$

Balance on oxygen:

$$G = \left(\frac{1.87 \text{ lb}}{18 \text{ lb}} \left| \frac{\text{mol}}{\text{lb}} \right. - \frac{0.43 \text{ lb}}{18 \text{ lb}} \left| \frac{\text{mol}}{\text{lb}} \right. - \frac{0.50 \text{ lb}}{40 \text{ lb}} \left| \frac{\text{mol}}{\text{lb}} \right. \right) \cdot \left(\frac{18 \text{ lb}}{\text{mol}} \right) = \boxed{1.22 \text{ lb}}$$

6.2.13

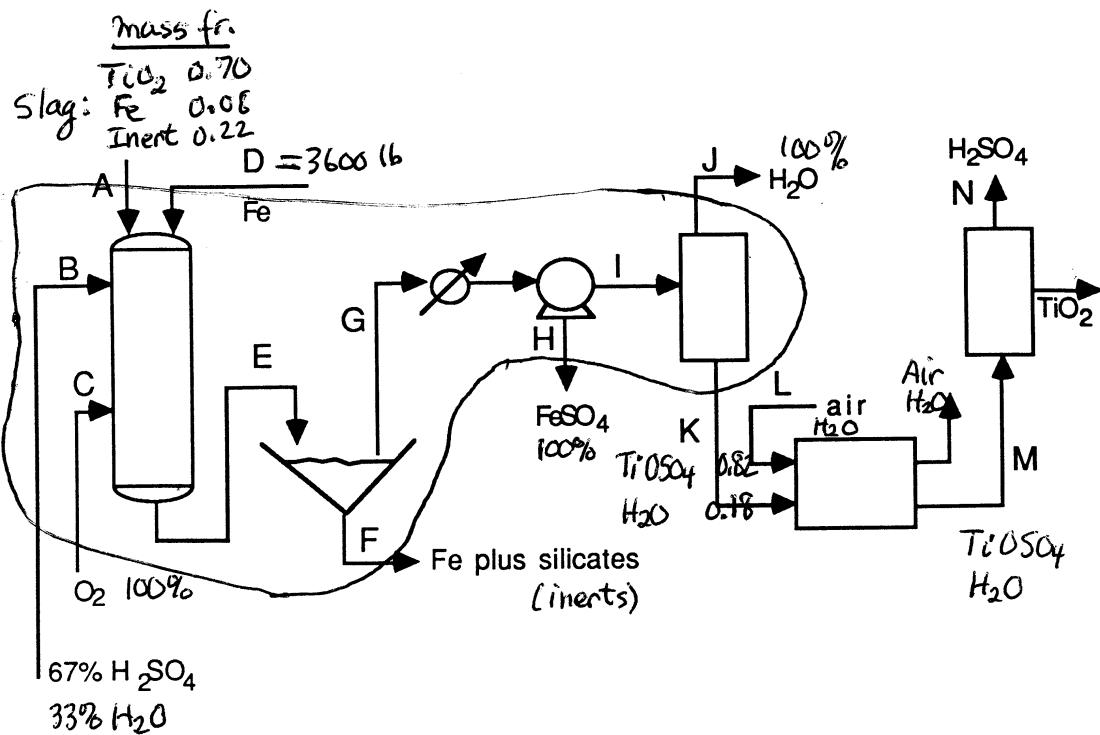
Step 5: Basis = 100 lb A

Steps 2, 3, and 4:

$$\text{Fe added: } 36(100) = 3600 \text{ lb}$$

$$\begin{array}{ll} \text{MW TiO}_2 = 79.9 \text{ lb/lb mol} & \text{MW H}_2\text{SO}_4 = 98.1 \text{ lb/lb mol} \\ \text{MW Fe} = 55.8 \text{ lb/lb mol} & \text{MW TiOSO}_4 = 159.7 \text{ lb/lb mol} \end{array}$$

Solutions Chapter 6



For Part (a), the system boundary has been drawn on a light solid line.

Steps 6 and 7:

Unknowns (9): B, C, J, K, H, F, $\xi_1, \xi_2, m_{\text{Fe}}^F$

Species balances (7): $\text{TiO}_2, \text{Fe}, \text{H}_2\text{SO}_4, \text{H}_2\text{O}, \text{TiOSO}_4, \text{O}_2$, inert

Other equations (2): Reactions 1 and 2 are complete

Degrees of freedom = 0

Steps 8 and 9

a. lb H_2O removed in evaporator (J):

Mol TiO_2 in slag:

$$\frac{(0.70)(100 \text{ lb})}{79.9 \text{ lb}} \left| \frac{\text{lb mol}}{\text{lb mol}} \right. = 0.876 \text{ lb mol}$$

Mol Fe in Slag:

$$\frac{(0.80)(100 \text{ lb})}{58.8 \text{ lb}} \left| \frac{\text{lb mol}}{\text{lb mol}} \right. = 0.143 \text{ lb mol}$$

Amount of H_2SO_4 based on theoretical requirements of Equations (1) and (2)

$$0.876 + 0.143 = 1.02 \text{ lb mol } \text{H}_2\text{SO}_4$$

Solutions Chapter 6

$$\frac{1.02 \text{ lb mol H}_2\text{SO}_4}{\text{lb mol}} \left| \frac{98.1 \text{ lb}}{\text{lb mol}} \right. = 100 \text{ lb H}_2\text{SO}_4$$

$$B = \frac{100 \text{ lb}}{0.67} = 149.2 \text{ lb} \quad \text{Water in stream B} = 49.2 \text{ lb}$$

$$\text{O}_2 \text{ in: } \frac{0.143 \text{ lb mol Fe}}{\text{1 lb mol Fe}} \left| \frac{0.5 \text{ lb mol O}_2}{\text{1 lb mol Fe}} \right| \left| \frac{32 \text{ lb O}_2}{\text{1 lb mol O}_2} \right. = 2.29 \text{ lb O}_2 = C (0.0715 \text{ lb mol})$$

$$\text{Using TiO}_2: \quad \xi_1 = \frac{0 - 0.876}{(-1)} = 0.876 \text{ moles reacting}$$

$$\text{Using O}_2: \quad \xi_2 = \frac{0 - 0.0715}{(0.5)} = 0.143 \text{ moles reacting}$$

TiOSO_4 in stream K

$$n_{\text{TiOSO}_4}^K = 0 + (1)(0.876) = 0.876 \text{ lb mol TiOSO}_4$$

$$K = \frac{0.876 \text{ lb mol}}{\text{1 lb mol}} \left| \frac{159.7 \text{ lb}}{0.82} \right. = 170.6 \text{ lb}$$

$$\text{H}_2\text{O in K} = 170.6 (0.18) = 30.7 \text{ lb}$$

Water formed in the reactions (use ξ_1 and ξ_2):

$$n_{\text{H}_2\text{O}}^{\text{out,rxn}} = (1)(0.876) + (1)(0.143) = 1.019 \text{ lb mol (or 8.36 lb H}_2\text{O)}$$

Water exiting from the evaporator J (lb):

$$49.2 + 18.36 - 30.7 = \boxed{36.9 \text{ lb}}$$

b. Exit H_2O from dryer:

$$\text{inlet air} = \frac{18 \text{ lb mol}}{\text{lb mol}} \left| \frac{29 \text{ lb}}{\text{lb mol}} \right. = 522 \text{ lb dry air}$$

$$\text{inlet water} = \frac{0.036 \text{ mol H}_2\text{O}}{\text{mol air}} \left| \frac{18 \text{ mol air}}{\text{lb mol}} \right| \left| \frac{18 \text{ lb}}{\text{lb mol}} \right. = 11.7 \text{ lb H}_2\text{O}$$

$$\text{water added to air} = (0.18) 170.9 \text{ lb} - (0.876 \text{ lb mol}) \frac{18 \text{ lb}}{\text{lb mol}} = 15.0 \text{ lb}$$

Solutions Chapter 6

$$\text{Humidity} = (15.0 \text{ lb H}_2\text{O} + 11.7 \text{ lb H}_2\text{O})/522 \text{ lb air}$$

$$= \boxed{0.051 \text{ lb H}_2\text{O/lb air}}$$

- c. The pounds of TiO_2 produced (P):

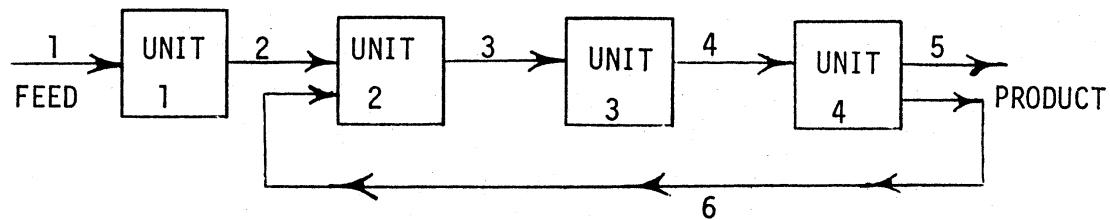
By reaction (3), 0.876 lb mol of TiOSO_4 goes to TiO_2 .

$$(0.876) (79.9) = \boxed{70 \text{ lb}} \text{ TiO}_2$$

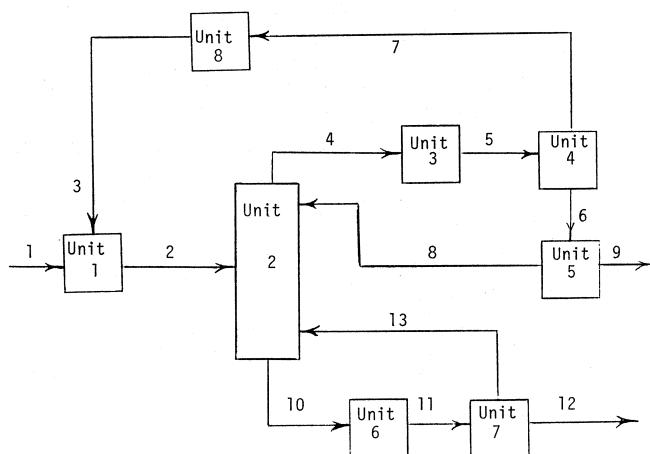
6.3.1

- a. 1; b. 3; c. 0; d. 7

a.

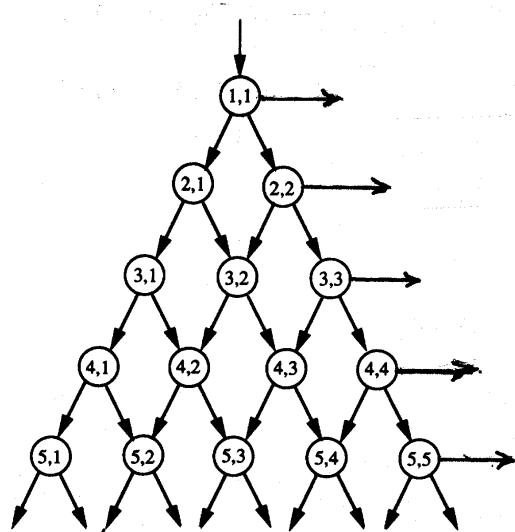


b.

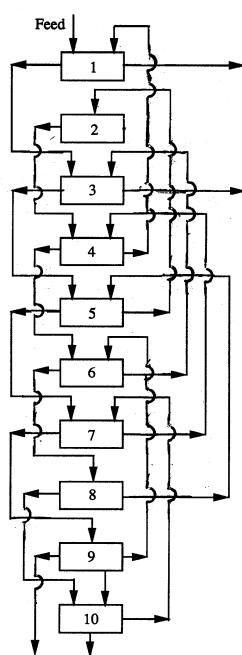


Solutions Chapter 6

c.



d.



Solutions Chapter 6

6.3.2

Step 5: Basis: 60 kg W

Pick the overall system

Steps 6 and 7:

Unknowns: F, P

Balances: A, B

Steps 8 and 9:

$$\begin{aligned} \text{Total } F &= 60 + P \\ B: 0.80F &= 0 + 0.95P \end{aligned} \quad \left. \begin{array}{l} F = 380 \text{ kg} \\ P = 320 \text{ kg} \end{array} \right\}$$

Pick mixing point as the system

Steps 6 and 7:

Unknowns: G, R

Balances: A, B (or total as alternate)

Steps 8 and 9:

$$\begin{aligned} \text{Total: } 380 + R &= G \\ B: 0.80(380) + R(0) &= 0.60G \end{aligned} \quad \left. \begin{array}{l} R = 126.7 \end{array} \right\}$$

$$\frac{R}{F} = \frac{125.7}{380} = \boxed{0.33} \text{ kg R/kg F}$$

6.3.3

Basis: 100 kg of fresh feed

Overall balance around junction

$$100 + R = F$$

KC1 balance around mixing point

Solutions Chapter 6

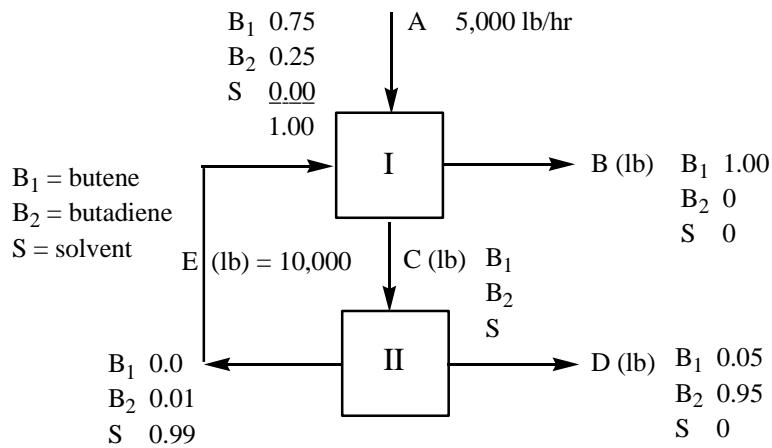
$$20 + 0.6 R = 0.4 F = 0.4 (100 + R)$$

$$20 + 0.6 R = 40 + 0.4 R$$

$$R = \boxed{100 \text{ kg } R / 100 \text{ kg fresh feed}}$$

6.3.4

Steps 2, 3, and 4:



Step 5: Basic: 1 hr ($A = 5000$ lb)

Select whole process as the system.

Steps 6 and 7:

Unknowns: B, D

Balances: Total, B_1 , B_2 , S (not all independent)

Steps 8 and 9:

Total balance: $5000 = B + D$

B_1 balance: $5000 (0.75) = B(1) + D(0.05)$

$$D = 1316 \text{ lb} \quad B = 3684$$

Apparently the calculated values are not correct. (The value for C can be obtained from balances on Unit I or II).

Solutions Chapter 6

6.3.5

Basis: 1 hour

An overall balance shows that R_{out} from the adsorber must equal R_{in} to the adsorber if a steady state exists. Let $R_i = R$.

Adsorber balance of U (units are U):

$$\frac{600 \text{ mL}}{1 \text{ mL}} \left| \frac{1.37U}{1 \text{ mL}} + \frac{R \text{ mL}}{1 \text{ mL}} \right| \frac{5.2U}{1 \text{ mL}} = \frac{600 \text{ mL}}{1 \text{ mL}} \left| \frac{0.08U}{1 \text{ mL}} + \frac{R \text{ mL}}{1 \text{ mL}} \right| \frac{19.3U}{1 \text{ mL}}$$

$$600(1.37-0.08) = R(19.3-5.2)$$

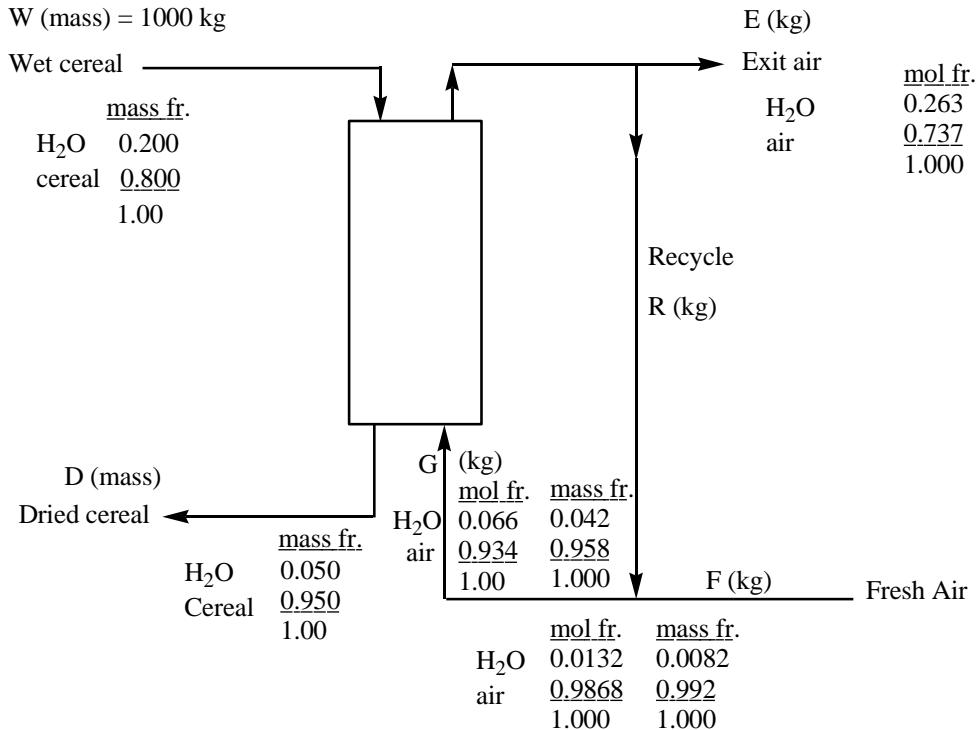
$$R = 55 \text{ mL/hr}$$

6.3.6

Step 5: Basis: $1000 \text{ kg} = W = 1 \text{ hour}$

Steps 1-4: Revised compositions are in mass fractions.

Note: compositions identical



Solutions Chapter 6

Conversion of mole fractions to mass fractions is not required, but since both mass fractions and mol fractions are listed as data, convert all to mass fractions (can't convert cereal to mol) to avoid confusion in making the balances.

Fresh air, Basis 100 mol

	<u>mol</u>	<u>MW</u>	<u>mass(kg)</u>	<u>mass fr.</u>		<u>mol</u>	<u>MW</u>	<u>mass</u>	<u>mass fr.</u>
air	98.68	29	2861.7	0.992		0.737	29	21.37	0.819
H ₂ O	1.32	18	23.76	0.0082		0.263	18	4.73	0.181
	100.00		2885.48	1.000		1.00		26.11	1.000

Air entering drier, basis 1.00 mol

	<u>mol</u>	<u>MW</u>	<u>mass</u>	<u>mass fr.</u>
air	0.934	29	27.09	0.958
H ₂ O	0.066	18	1.19	0.042
			28.27	1.000

Overall balances (unknowns D, E, F; balances H₂O, cereal, air)

Total: can be made in mass: $1000 + F = E + D$

in

$$\text{cereal (dry)}: 1000 (0.80) + F (0) = E (0) + D (0.950) \quad D = 842 \text{ kg}$$

$$\text{H}_2\text{O}: 1000 (0.20) + F (0.0082) = E (0.181) + D (0.050)$$

$$\text{air: } 1000 (0) + F (0.992) = E (0.819) + D (0)$$

3 are independent eqns. check by 4th eqn.

a. $D = 842 \text{ kg}$

$F = 748 \text{ kg/hr}$

$E = 906 \text{ kg}$

Balance on mixing point (to get R)

Total: $R + F = G$

air : $R (0.819) + F (0.992) = G (0.958)$

$\text{H}_2\text{O}: R (0.181) + F (0.0082) = G (0.042)$

2 equations are independent, check via 3d equation

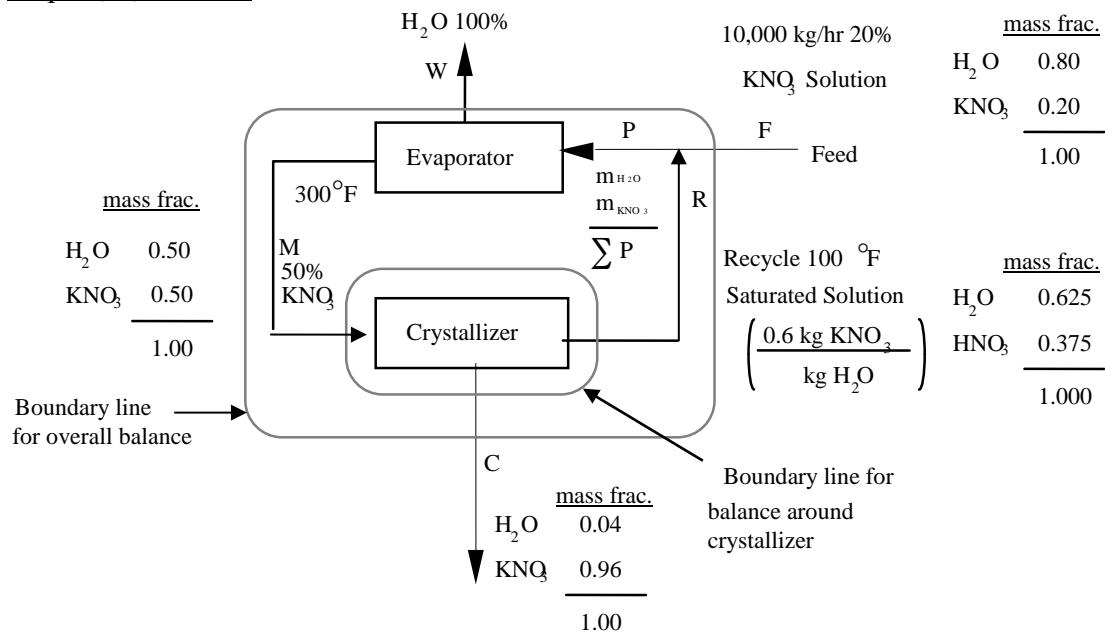
b.

$R = 183 \text{ kg/hr}$

Solutions Chapter 6

6.3.7

Steps 1, 2, 3 and 4:



Step 5: Basis: 1 hr = 10,000 kg KNO₃ solution

Step 4 cont'd:

Compute the weight fraction composition of R. On the basis of 1 kg of water, the saturated recycle steam contains (1.0 kg of H₂O + 0.6 kg of KNO₃) = 1.6 kg total. The recycle steam composition is

$$\frac{0.6 \text{ kg KNO}_3}{1 \text{ kg H}_2\text{O}} \left| \frac{1 \text{ kg H}_2\text{O}}{1.6 \text{ kg solution}} \right. = 0.375 \text{ kg KNO}_3 / \text{kg solution}$$

or 37.5% KNO₃ and 62.5% H₂O (which has been added to the figure).

Analysis of complete process (6 streams):

Unknowns: W, M, C, R, m_{H₂O}^P, m_{KNO₃}^P = 6

Balances: (2 units + 1 mix point) × 2 components = 6

Solutions Chapter 6

Other compositions are (in %)

	<u>M</u>	<u>F</u>	<u>W</u>	<u>C</u>	<u>R</u>
H ₂ O	50	80	100	4	62.5
KNO ₃	50	20	0	96	37.5

Start with overall balances as substitute for unit balances

Steps 6 and 7: Unknowns: W, C,

Balances: 2 components

Overall balance to calculate C: Total: 10,000 = W + C

$$\text{KNO}_3: 10,000 (0.20) = W (0) + C (0.96)$$

$$\frac{10,000 \text{ kg F}}{1 \text{ hr}} \left| \frac{0.20 \text{ kg KNO}_3}{1 \text{ kg F}} \right| \left| \frac{1 \text{ kg crystals}}{0.96 \text{ kg KNO}_3} \right| = 2083 \text{ kg / hr crystals} = C$$

$$W = 10,000 - 2083 = 7917 \text{ kg}$$

To determine the recycle stream R, we need to make a balance that involves the stream R. Either (a) a balance around the evaporator or (b) a balance around the crystallizer will do. The latter is easier since only three rather than four (unknown) streams are involved.

Total balances on crystallizer:

$$M = C + R$$

$$M = 2083 + R \quad @$$

Component (KNO₃) balance on crystallizer:

$$M\omega_M = C\omega_C + R\omega_R$$

$$0.5M = 0.96C + R (0.375) \quad @$$

Solving equations @ and @ we obtain

$$0.5 (2083 + R) = 0.375R + 2000$$

$$R = 7670 \text{ kg/hr}$$

Solutions Chapter 6

6.3.8

Single pass conversion is: $f_{sp} = \frac{-v_{LR}\xi}{n_{LR}^{reactor\ feed}}$

- a. Single pass conversion based on H₂ as the limiting reactant:

$$\xi = \frac{1.979 - 3.96}{-2} = 0.99$$

$$\xi^{\max} = \frac{0 - 3.96}{-2} = 1.98$$

$$SP\ conversion = \frac{-(-2)(0.99)}{3.96} = \boxed{0.50}$$

Use Eq. (12.1) and Eq. 12.2 with H₂ the limiting reactant

b. $0.99 = \frac{-v_{LR}\xi}{n_{LR}^{fresh\ feed}} = \frac{-(-2)}{1.98} \xi \quad \xi = 0.980$

$$f_{sp} = \frac{-(-2)(0.98)}{1.989} = 0.986$$

- c. Overall conversion of H₂

$$f_{overall\ of\ H_2} = \frac{-(-2)(0.99)}{1.98} = \boxed{1.0}$$

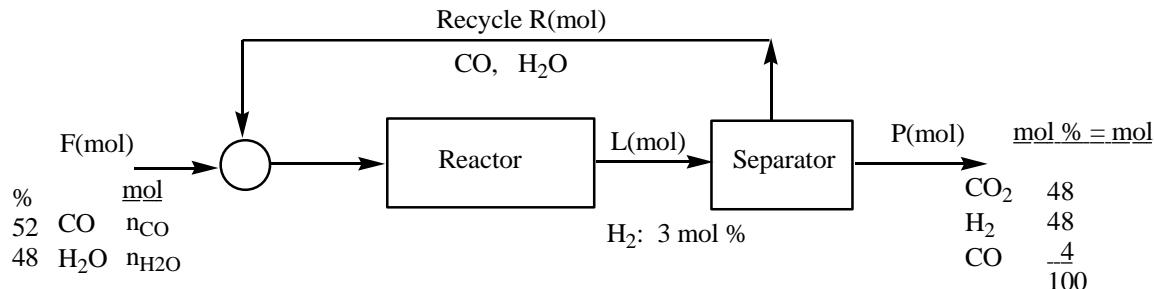
- d. Overall conversion of CO

$$f_{overall\ of\ CO} = \frac{-(-1)(.99)}{1} = \boxed{0.99}$$

Solutions Chapter 6

6.3.9

Steps 2, 3, and 4:



Step 5: Basis: $P = 100 \text{ mol}$

Pick the overall process as the system.

Step 6: Unknowns: $n_{\text{CO}}^F, n_{\text{H}_2\text{O}}^F$

Step 7: Balances: C, H, O

Steps 8 and 9: Element balances

$$\begin{aligned} \text{C (mol): } n_{\text{CO}} &= 48 + 4 = 52 \\ \text{H (mol): } n_{\text{H}_2\text{O}}(2) &= 48(2) \quad n_{\text{H}_2\text{O}} = 48 \end{aligned} \quad \left. \right\} \text{total 100}$$

Step 10: O (mol): $n_{\text{H}_2\text{O}}(1) + n_{\text{CO}}(1) = 48(2) + 4$ check is ok.

a. Composition of fresh feed $40\% \text{ H}_2\text{O}$ and $52\% \text{ CO}$

Alternate solution: Use extent of reaction

$$\text{Based on } \text{CO}_2: \xi = \frac{48 - 0}{1} = 48$$

$$\text{Then } \begin{aligned} n_{\text{CO}}^F &= 4 + \xi = 4 + 48 = 52 \text{ mol} \\ n_{\text{H}_2\text{O}}^F &= 0 + \xi = 48 \text{ mol} \end{aligned}$$

To get the recycle, make a balance about the separator (no reaction occurs)

Solutions Chapter 6

$$\begin{aligned} \text{H}_2 \text{ balance (mol)}: & L(0.03) = 48 \\ \text{Total (mol)}: & L=100 + R \end{aligned} \quad \left. \begin{array}{l} L=1600 \text{ mol} \\ R=1500 \text{ mol} \end{array} \right\}$$

b.

$$\frac{1500 \text{ mol } R}{48 \text{ mol H}_2} = \boxed{31.3}$$

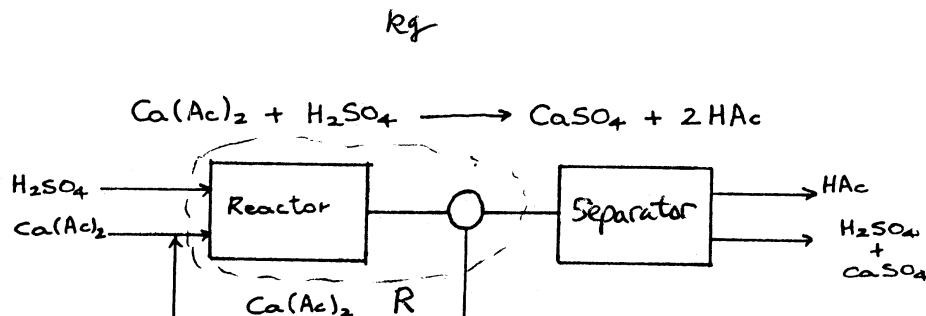
6.3.10

Steps 2, 3, and 4:

$$\text{MW Ca(Ac)}_2 = 158.1 \quad \text{MW HAc} = 60$$

$$\frac{100 \text{ kg Ca(Ac)}_2}{158.1 \text{ kg Ca(Ac)}_2} \left| \frac{1 \text{ kg mol Ca(Ac)}_2}{1 \text{ kg mol Ca(Ac)}_2} \right. = 0.633 \text{ kg mol Ca(Ac)}_2$$

Step 5: Basis: 1000 kg of Ca(Ac)₂ feed



Inspection of the diagram shows that the overall conversion of Ca(Ac)₂ is 100% (none leaves the process). Thus, $f_{OA} = 1$. You are given $f_{SP} = 0.90$. Then

a.

$$\frac{f_{SP}}{f_{OA}} = \frac{0.90}{1} = \frac{6.33}{6.33 + R} \quad \boxed{\begin{array}{l} R = 0.703 \text{ kg mol} \\ \text{or } 111 \text{ kg} \end{array}}$$

b. The single pass conversion for Ca(AC)₂ is 0.90.

$$0.90 = \frac{-v_{LR}\xi}{n_{LR}^{\text{feed}}} = \frac{-(-1)\xi}{6.33} \quad \xi = 5.697$$

Overall HAc balance:

$$\frac{6.33 \text{ kg mol Ca(Ac)}_2}{1 \text{ kg mol Ca(Ac)}_2} \left| \frac{2 \text{ kg mol HAc}}{1 \text{ kg mol Ca(Ac)}_2} \right. = 12.66 \text{ kg mol HAc or } \boxed{760 \text{ kg}}$$

Solutions Chapter 6

6.3.11

Steps 2, 3, 4:

$$\begin{array}{ll} \text{MW C}_2\text{H}_2 = 26.02 & \text{MW C}_2\text{H}_2\text{Br}_4 = 346 \\ \text{MW Zn} = 65.37 & \end{array}$$

a. C₂H₅ produced per hour

Step 5: Basis: 1 hr = 1000 kg C₂H₂Br₄ (2.890 kg mol)

Make overall balances:

Get the extent of reaction using C₂H₂Br₄

$$\begin{array}{l} n_{\text{out}} - n_{\text{in}} = v\xi \\ 0 - 2.890 = (-1)(\xi) \quad \xi = 2.890 \text{ reacting moles} \end{array}$$

C₂H₂ balance: n_{C₂H₂} = 0 + (1)(2.890) = 2.890 kg mol

$$2.890 (26.02) = \boxed{75.2 \text{ kg}}$$

ZnBr₂ balance: n_{ZnBr₂} = 0 + 2(2.890) = 5.78 kg mol

Alternate solution

$$\frac{100 \text{ kg C}_2\text{H}_2\text{Br}_4}{1} \left| \frac{1 \text{ kg mol C}_2\text{H}_2\text{Br}_4}{346 \text{ kg C}_2\text{H}_2\text{Br}_4} \right| \frac{1 \text{ kg mol C}_2\text{H}_2}{1 \text{ kg mol C}_2\text{H}_2\text{Br}_4} \left| \frac{26 \text{ kg C}_2\text{H}_2}{1 \text{ kg mol C}_2\text{H}_2} \right| = 75.2$$

b. Recycle

Make balance on the mixing point. First, get the feed of C₂H₂Br₄ to the reactor

$$0.80 = \frac{-v\xi}{n_{\text{LR}}^{\text{feed}}} = \frac{-(1)(2.896)}{n_{\text{LR}}^{\text{feed}}} \quad n_{\text{LR}}^{\text{feed}} = 3.61 \text{ kg mol}$$

C₂H₂Br₄ balance: 2.890 + R = 3.61 R = 0.72 kg mol

$$0.72 (346) = \boxed{249 \text{ kg}}$$

Alternate solution (in kg). Balance over separator.

$$\begin{array}{l} (1000 \text{ kg} + R)(0.20) = R \\ R = 250 \text{ kg} \end{array}$$

Solutions Chapter 6

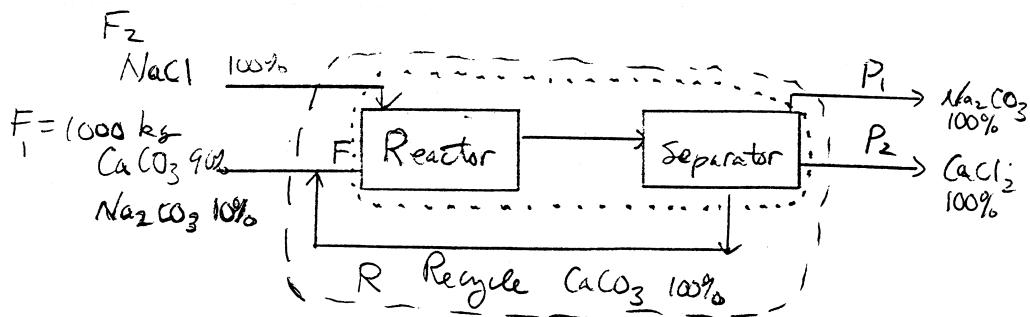
c. Feed rate required for 20% excess Zn in reactor:

$$\frac{1000 \text{ kg C}_2\text{H}_2\text{Br}_4}{1} \left| \frac{1 \text{ kg mol C}_2\text{H}_2\text{Br}_4}{346 \text{ kg C}_2\text{H}_2\text{Br}_4} \right| \frac{2 \text{ kg mol Zn}}{1 \text{ mol C}_2\text{H}_2\text{Br}_4} \left| \frac{65.37 \text{ kg Zn}}{1 \text{ kg mol Zn}} \right| \frac{1.2 \text{ kg Zn in feed}}{1 \text{ kg Zn required}} = [454 \text{ kg}]$$

d. Mole ratio of ZnBr_2 to C_2H_2 in final products:

$$\frac{5.78}{2.89} = [2] \quad 2:1 \text{ (as per reaction)}$$

6.3.12



Step 5: Basis: $100 \text{ kg F}_1 \equiv 1 \text{ hr}$

Overall balance

Step 6 and 7:

Unknowns: F_2, P_1, P_2

Element balances: Ca, Na, Cl, CO_3 (enough, not all independent)

CO_3 balance:

$$\frac{900 \text{ kg CaCO}_3}{100 \text{ kg CaCO}_3} \left| \frac{1 \text{ kg mol CaCO}_3}{100 \text{ kg CaCO}_3} \right| \frac{1 \text{ kg mol CO}_3}{1 \text{ kg mol CaCO}_3} = 9.00 \text{ kg mol CO}_3$$

$$\frac{100 \text{ kg Na}_2\text{CO}_3}{106 \text{ kg Na}_2\text{CO}_3} \left| \frac{1 \text{ kg mol Na}_2\text{CO}_3}{106 \text{ kg Na}_2\text{CO}_3} \right| \frac{1 \text{ kg mol CO}_3}{1 \text{ kg mol Na}_2\text{CO}_3} = \frac{0.94 \text{ kg mol CO}_3}{9.94 \text{ kg mol CO}_3}$$

a.

$$\frac{0.94 \text{ kg mol CO}_3}{1 \text{ kg CO}_3} \left| \frac{1 \text{ kg mol Na}_2\text{CO}_3}{1 \text{ kg CO}_3} \right| \frac{106 \text{ kg Na}_2\text{CO}_3}{1 \text{ kg mol Na}_2\text{CO}_3} = [1054 \text{ kg Na}_2\text{CO}_3]$$

Solutions Chapter 6

Species balance about the reactor plus the separator on CaCO_3 :

$$\underbrace{[1000(0.90) + R]}_{\text{UNREACTED}} \xrightarrow{\text{IN}} (.24) = \xrightarrow{\text{OUT}} R$$

$$R = 284 \text{ kg}$$

Alternate solution:

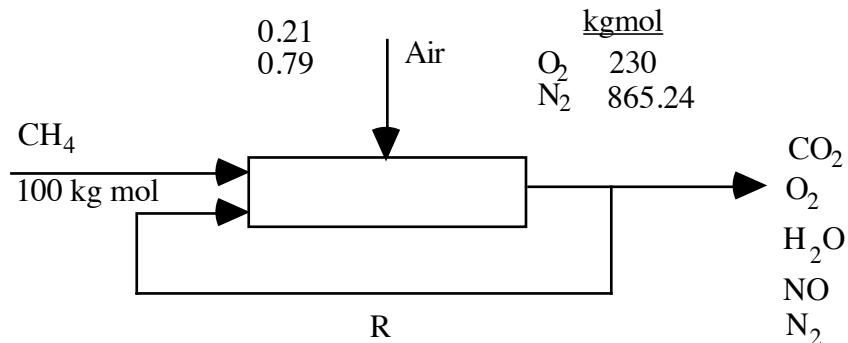
Use the extent of reaction to get the same results.

6.3.13

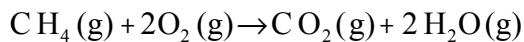
This is steady state process with reaction and recycle. Pick the overall process as the system.

Step 5: Basis: 100 kg mol CH_4

Steps 1, 2, 3, and 4: The system is as shown in the diagram with recycle added.



Calculate the moles of each component entering.



Calculation of the required O_2 and accompanying N_2 in moles

$$\text{req'd O}_2 \quad 100(2) = 200$$

$$\text{xs} \quad 200 (0.15) = \underline{30}$$

$$\text{Total O}_2 \quad 230$$

Solutions Chapter 6

$$N_2 \text{ in } \left(\frac{230}{\begin{array}{|c} .79 \\ .21 \end{array}} \right) = 865.24$$

The exit concentrations (via stoichiometry) are

	<u>Mol</u>
CO ₂	100
O ₂	30
H ₂ O	200
NO	415×10^{-6}
N ₂	<u>865.24</u>
	1195.24

Next, consider adding recycle as shown in the diagram. Recycle is not involved in the overall balance, hence the concentration of NO will not be affected because the extent of reaction with and without recycle remains the same. The recycle does reduce the combustion temperature, which in turn will reduce the exit concentration of NO.

6.3.14

Basis: 1 hr = 1 L = F all concentrations are g/L.

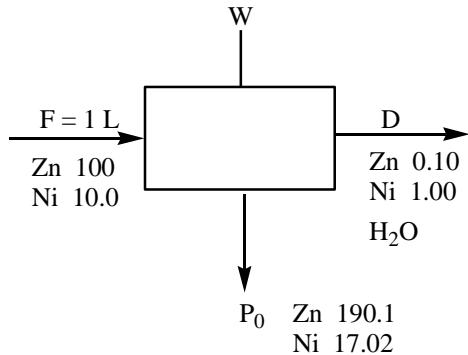


Figure P12.9

Pick the overall process as the system.

Steps 6 and 7:

Balances: 3 H₂O, Zn, Ni

Unknowns: 3 W, D, P (all in L)

Solutions Chapter 6

Steps 8 and 9:

$$\text{Zn: } 100(1) + 0 = \frac{D(L)}{L} \left| \frac{0.10\text{g}}{L} + P_0(190.1\text{g/L}) \right.$$

$$\text{Ni: } 10(1) + 0 = D(1.00) + P_0(17.02)$$

$$\text{Solve to get } P_0 = 0.525L \quad D = 1.056L$$

Pick Unit 3 as the system:

Steps 6 and 7:

Balances:	2	Zn, Ni
Unknowns:	2	R_{32}, P_2 (all in L)

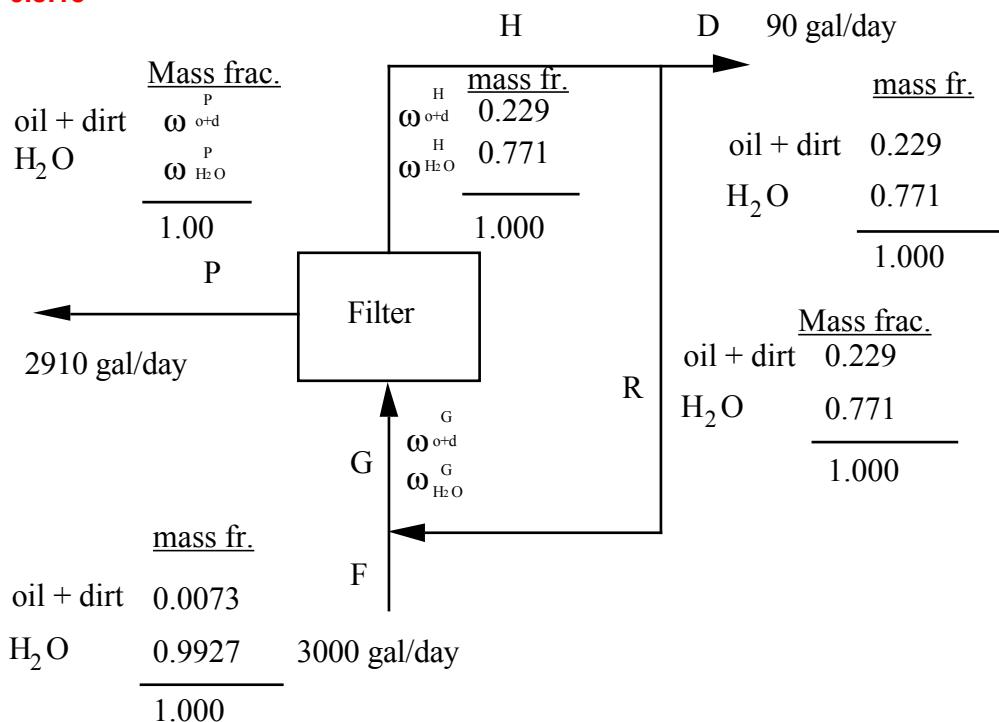
Steps 8 and 9:

$$\text{Zn: } P_2(3.50) + 0 = 0.10(1.056) + R_{32}(4.35)$$

$$\text{Ni: } P_2(2.19) + 0 = 1.00(1.056) + R_{32}(2.36)$$

$$\text{Solve to get } \boxed{R_{32} = 2.75\text{L/hr}}$$

6.3.15



Solutions Chapter 6

Pick the total process as the system

Step 5: Basis: 1 day (equivalent to D = 90 gal, F = 3000 gal, P = 2910 gal)

Steps 6 and 7:

Unknowns: ω_{o+d}^P , $\frac{P}{H_2O}$

Balances: oil + dirt, H_2O

Steps 8 and 9:

	In	Out
Overall oil + dirt balance:	$3,000(0.0073) = 2,910(\omega_{o+d}^P) + 90(0.229)$	

$$\omega_{o+d}^P = \frac{21.9 - 20.61}{2,910} = \boxed{4.43 \times 10^{-4}} \quad (a)$$

To solve for R, make balances on the mixing point, the filter, and the splitter. Not all of the balances are independent:

	Total	oil + dirt
<u>Splitter:</u>	$H = 90 + R$	$0.229H = 0.229(90) + 0.229(R)$
<u>Filter:</u>	$G = 2910 + H$	$\omega_{o+d}^G G = 2910 (4.43 \times 10^{-4}) + H(0.229)$
<u>Mixing point:</u>	$3000 + R = G$	$0.0073 (3000) + 0.229R = \omega_{o+d}^G G$

Unknowns: H, R, G, ω_{o+d}^G

Balances: 6 (4 independent)

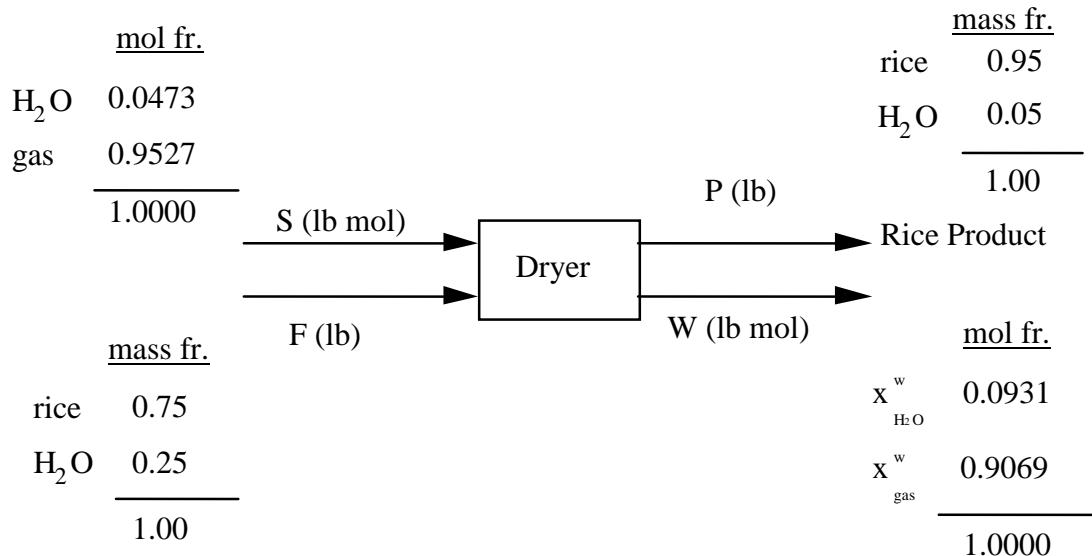
Steps 8 and 9:

The solution is $R = 57.2 \text{ gal/day}$ $\omega_{o+d}^G = 0.01145$

Solutions Chapter 6

6.3.16

Start with the overall system



Steps 1, 2, 3 and 4: In the diagram use mol and mass percent for compositions and mol and mass for flow as specified.

Step 5: Basis $P = 100 \text{ lb}$

Step 6: Unknowns: F, S, W

Step 7: Can make total and 3 component balances: rice, H₂O, dry gas (G)

Steps 8 and 9:

$$\text{lb} \quad \text{Rice:} \quad F(0.75) = P(0.95) = 100(0.95)$$

$$\text{lb mol} \quad \text{Dry gas:} \quad S(0.9527) = W(0.9069)$$

$$\text{lb mol H}_2\text{O} \quad \text{H}_2\text{O:} \quad S(0.0473) + \frac{F(0.25)}{18.02} = W(0.0931) + \frac{P(0.05)}{18.02}$$

$$F = 126.67 \text{ lb}$$

$$S = 27.35 \text{ lb mol}$$

$$W = 28.75 \text{ lb mol}$$

Solutions Chapter 6

Make balances on the mixing point (easiest)

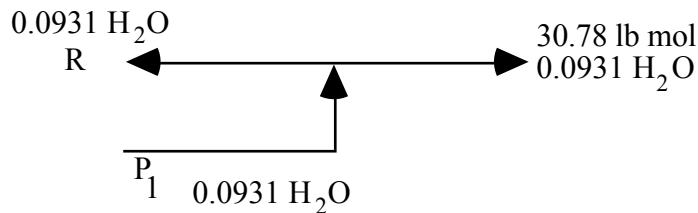
$$\text{lb mol gas: } (27.35)(0.9527) + R (0.9069) = F_1 x_{DG}^{F_1}$$

$$x_{H_2O}^{F_1} = 0.0520$$

$$\text{lb mol H}_2\text{O: } (27.35)(0.0473) + R (0.0931) = F_1 x_{H_2O}^{F_1}$$

$$\text{lb mol total: } 27.35 + R = F_1 \quad x_{DG}^{F_1} + x_{H_2O}^{F_1} = 1$$

$$R = 3.12 \text{ lb mol / 100 lb P}$$



or, make balances on separation point

$$\text{H}_2\text{O: } P_1 (0.0931) = R (0.0931) + 30.768 (0.0931)$$

total

(or G): (only 1 independent equation)

$$0.0473 S + 0.0931 R = F_1 (0.052)$$

$$27.35 + R = F_1$$

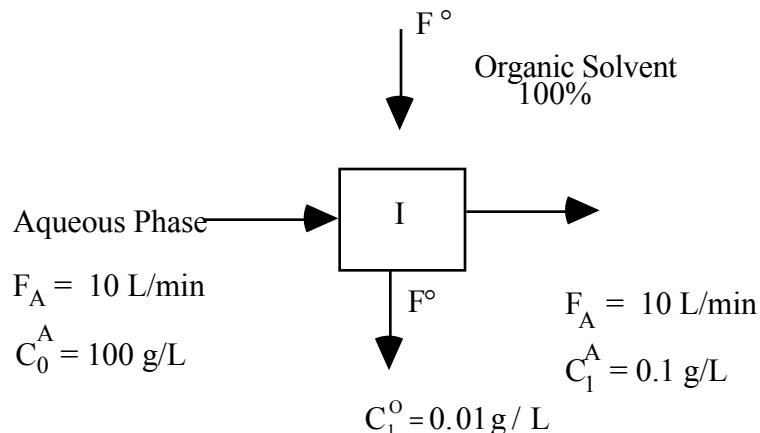
$$1.385 + 0.0931 R = 0.052 (27.35 + R) = 1.523 + 0.052R$$

$$0.041 R = 0.138$$

$R = 3.37 \text{ lb mol}$

Solutions Chapter 6

6.3.17

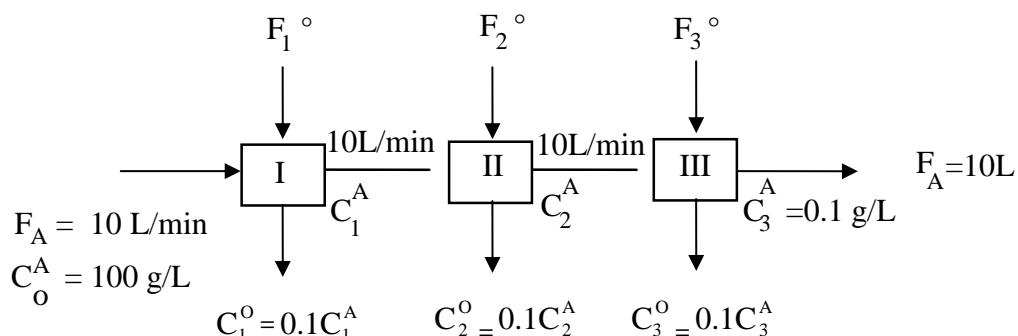


Fermentation product balance:

$$100 \frac{\text{g}}{\text{L}} \left| \frac{10 \text{ L/min}}{\text{L}} \right. = F^\circ(0.01) + \frac{10 \text{ L/min}}{\text{L}} \left| \frac{0.1 \text{ g/L}}{\text{L}} \right.$$

$$F^\circ = \frac{1000 - 1}{0.01} \boxed{= 99,900 \text{ L/min}}$$

B:



Fermentation

balance:

$$\text{Assuming } F_1^\circ = F_2^\circ = F_3^\circ = F^\circ/3$$

$$\text{I: } \frac{100 \frac{\text{g}}{\text{L}} \left| \frac{10 \text{ L/min}}{\text{min}} \right.}{\text{L}} = C_1^A \cdot 10 \text{ L/min} + \frac{F^\circ}{3} \times 0.1 C_1^A \quad (1)$$

$$\text{II: } \frac{C_1^A \frac{\text{g}}{\text{L}} \left| \frac{10 \text{ L/min}}{\text{min}} \right.}{\text{L}} = C_2^A \cdot 10 \text{ L/min} + \frac{F^\circ}{3} \times 0.1 C_2^A \quad (2)$$

Solutions Chapter 6

$$\text{III: } \frac{C_2^A \frac{\text{g}}{\text{L}}}{\left| \frac{10 \frac{\text{L}}{\text{min}}}{C_3^A \cdot 10 \frac{\text{L}}{\text{min}} + \frac{F^\circ}{3} \times 0.1 C_3^A (3)} \right|} = C_3^A \cdot 10 \frac{\text{L}}{\text{min}} + \frac{F^\circ}{3} \times 0.1 C_3^A (3)$$

Solving (1), (2) and (3) Simultaneously

$$C_1^A = 10.0 \frac{\text{g}}{\text{L}} \quad C_2^A = 1.0 \frac{\text{g}}{\text{L}} \quad C_3^A = 0.1 \frac{\text{g}}{\text{L}}$$

$$F = 2702 \frac{\text{L}}{\text{min}}$$

C:

Fermentation Product Balance:

$$\text{I: } \frac{100 \frac{\text{g}}{\text{L}}}{\left| \frac{10 \frac{\text{L}}{\text{min}}}{0.1 C_2^A \cdot F^\circ + 0.1 C_1^A \cdot 10} \right|} + 0.1 C_2^A \cdot F^\circ = 0.1 C_1^A \cdot F^\circ + C_1^A \cdot 10$$

$$\text{II: } C_1^A \cdot 10 + 0.1(0.1)F^\circ = 0.1C_2^A \cdot F^\circ + C_2^A \cdot 10$$

$$\text{III: } C_2^A \cdot 10 + 0 = 0.1(0.1) \cdot F^\circ + 0.1(10)$$

Solving (1), (2) and (3) Simultaneously

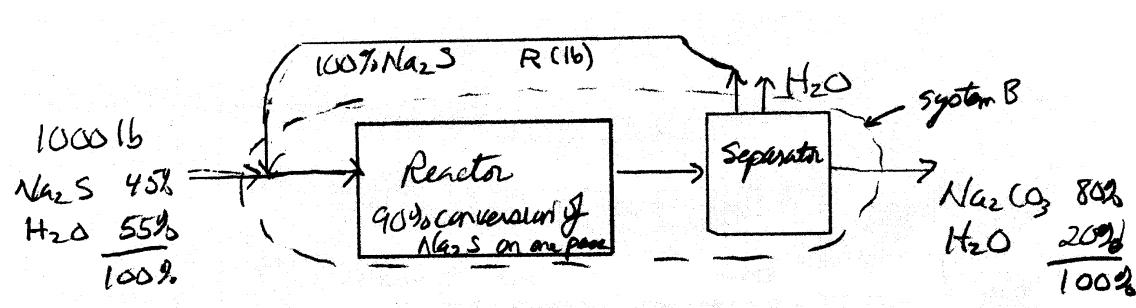
$$C_1^A = 10.36 \frac{\text{g}}{\text{L}} \quad C_2^A = 1.06 \frac{\text{g}}{\text{L}} \quad C_3^A = 0.10 \frac{\text{g}}{\text{L}}$$

$$F = 960 \frac{\text{L}}{\text{min}}$$

This one is the least

6.3.18

Steps 1, 2, 3, and 4:



Mol. Wt: Na₂S, 78; CaCO₃, 100; Na₂CO₃, 106; CaS, 72

Step 5: Basis 1 hr

Solutions Chapter 6

Steps 6, 7, 8, and 9:

System: Overall (System A)

$$\begin{aligned}
 \text{Na Balance: } & \frac{(1000)(0.45)\text{lb Na}_2\text{S}}{78 \text{ lb Na}_2\text{S}} \left| \frac{1 \text{ lb mol Na}_2\text{S}}{1 \text{ lb mol Na}_2\text{S}} \right| \frac{2 \text{ lb mol Na}}{1 \text{ lb mol Na}_2\text{S}} \\
 & = \frac{m_{\text{Na}_2\text{CO}_3} \text{ lb}}{106 \text{ lb Na}_2\text{CO}_3} \left| \frac{1 \text{ lb mol Na}_2\text{CO}_3}{1 \text{ lb mol Na}_2\text{CO}_3} \right| \frac{2 \text{ lb mol Na}}{1 \text{ lb mol Na}_2\text{CO}_3} \left| \frac{100 \text{ lb Na}_2\text{CO}_3 \text{ soln}}{80 \text{ lb Na}_2\text{CO}_3} \right|
 \end{aligned}$$

b. $m_{\text{Na}_2\text{CO}_3} = 764 \text{ lb/hr}$

System: Reactor plus separator (System B)

$$\begin{array}{cccccc}
 & \text{in} & \text{out} & \text{gen.} & \text{Consumption} & \text{accum} \\
 \text{Na}_2\text{S balance: } & \left[\frac{100(0.45)}{78} + \frac{R}{78} \right] - \frac{R}{78} + 0 - \left[\frac{100(0.45)}{78} + \frac{R}{78} \right] 0.90 & = & 0
 \end{array}$$

$$[1000(0.45) + R] (0.10) = R$$

a. $R = 50 \text{ lb/hr}$

Alternate solution

Na_2S is the limiting reactant (LR). Mole $\text{Na}_2\text{S} = (0.45)(1000)/78 = 5.77$. All of it reacts.

$$1.00 = \frac{(-1)(-1)\xi}{5.77}, \quad \xi = 5.77$$

Overall fraction conversion of Na_2S is 100%; $f_{\text{OA}} = 1$.

$$\frac{f_{\text{SP}}}{f_{\text{OA}}} = \frac{0.90}{1.00} = \frac{n_{\text{LR}}^{\text{freshfeed}}}{n_{\text{LR}}^{\text{freshfeed}} + n_{\text{LR}}^{\text{recycle}}} = \frac{5.77}{5.77 + R}$$

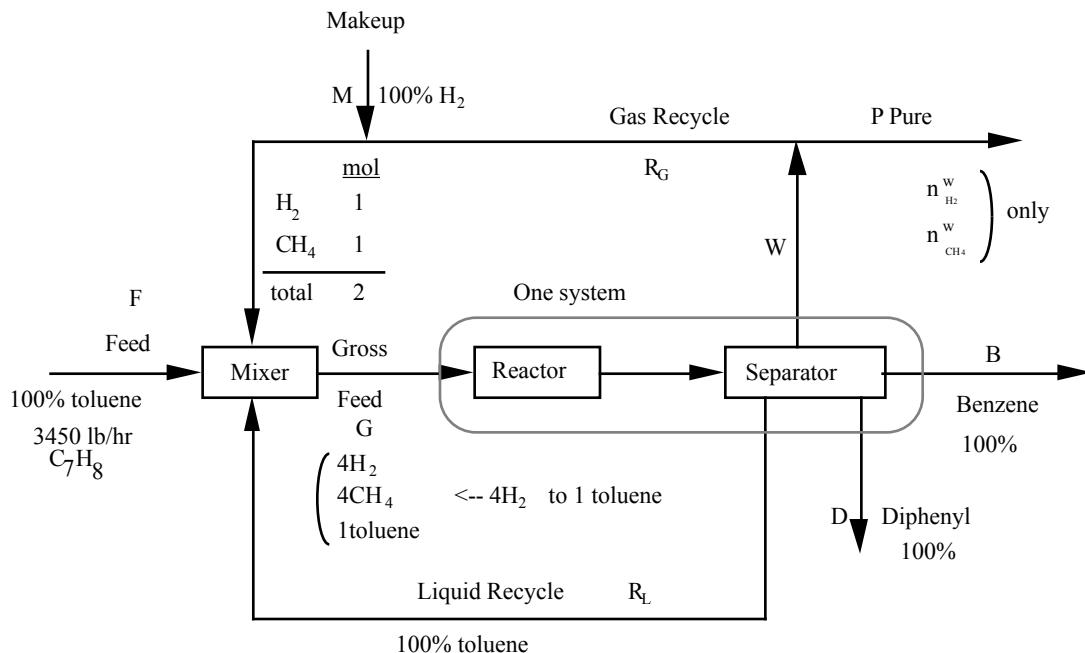
$$5.19 + 0.9R = 5.77 \quad \boxed{R = 0.64 \text{ lb mol}} \quad (\text{or } 50 \text{ lb})$$

Solutions Chapter 6

6.3.19

A basis of 1 hr requires the listing and solution of many simultaneous equations.

A basis of 100 mol of toluene in G is more convenient



Basis: 100 mol toluene in stream G (gross feed)

System: Reactor plus separator

Species balances

	In	Out	Gen	Cons.	
(1) toluene:	100	-R _L	+0	-100 (.80 + .08)	= 0
(2) H ₂ :	100 (4)	-n _{H₂} ^W	+ 0	-100 (4) (.80 + .08) $\left(\frac{1}{2}\right)$	= 0
(3) CH ₄ :	100 (4)	-n _{CH₄} ^W	+ 100(4)(.80 + .08)	-0	= 0

Solve above for R_L = 12 mol

$$\begin{aligned} n_{H_2}^W &= 64 \text{ mol} \\ n_{CH_4}^W &= 752 \text{ mol} \end{aligned} \quad \text{Total} = 816 \text{ mol}$$

Solutions Chapter 6

System : Mixer plus makeup point (Species balances but no reaction so In = Out)

	(F)	(M)	(R _G)	(R _L)	(G)
(1) Toluene:	F (1.0) +	0	+ 0	+ 12	= 100
(2) H ₂ :	0	+ M(1.0)	+ R _G $\left(\frac{64}{816}\right)$	+ 0	= 400
(3)CH ₄ :	0	+ 0	+ R _G $\left(\frac{752}{816}\right)$	+ 0	= 400

Solve (3) for R_G = 434 mol

Solve (1) for F = 88 mol M = 366

Change basis to 1 hour

$$\frac{3450 \text{ lb}}{92 \text{ lb}} \left| \frac{1 \text{ lb mol}}{\text{lb}} \right. = 37.5 \text{ lb mol of toluene in F}$$

$$\frac{100 \text{ lb mol tol in G}}{88 \text{ lb mol F}} \left| \frac{37.5 \text{ lb mol F}}{1 \text{ hr}} \right| \left| \frac{12 \text{ lb mol R}_L}{100 \text{ lb mol tol in G}} \right| = 5.11 \text{ lb mol R}_L/\text{hr}$$

$$\frac{100}{88} \left| \frac{37.5}{1} \right| \left| \frac{434 \text{ lb mol R}_G}{100 \text{ lb mol tol in G}} \right| = 185 \text{ lb mol R}_G/\text{hr}$$

If F = 37.5 lb mol of toluene is selected as the basis, you have to make the same balances as above plus benzene and diphenyl balances on the reactor plus separator because F is a known but G becomes an unknown.

The unknowns would be

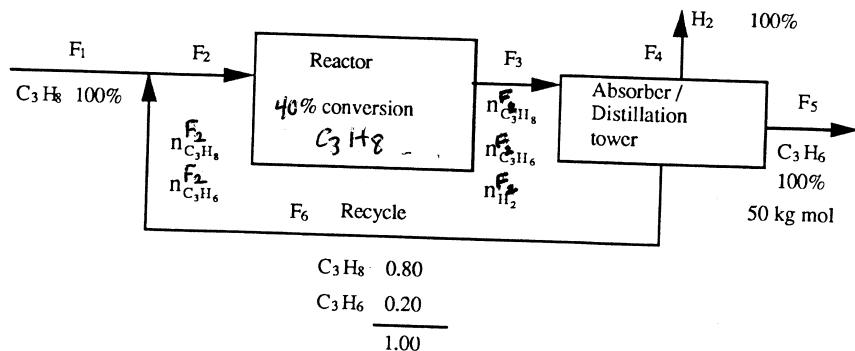
$$G, R_L, R_G, D, B, M, n_{H_2}^P, n_{CH_4}^P$$

Alternate solution

Calculate the extent of reaction for each reaction, and use them as shown in the book to get the outputs of the reactor plus separator system instead of using generation and consumption terms.

Solutions Chapter 6

6.3.20



Basis: 1 hr = 50 kg mol F_5

Unknowns:

$$F_1, F_4, F_6, n_{C_3H_8}^{F_2}, n_{C_3H_6}^{F_2}, n_{C_3H_8}^{F_3}, n_{C_3H_6}^{F_3}, n_{H_2}^{F_3} \quad (8)$$

Balances:

$$\begin{array}{ll}
 \text{Mixing Point:} & C_3H_8, C_3H_6 \\
 \text{Reactor:} & C_3H_8, C_3H_6, H_2 \\
 \text{Abs./Distil.:} & C_3H_8, C_3H_6, H_2
 \end{array} \quad (8)$$

Use overall balances as substitute for some of the above

Overall balances (element balances because of the reaction)

(In)	(Out)
C: $F_1(3) = F_5(3)$	$F_1 = 50 \text{ kg mol}$
H: $F_1(8) = F_4(2) + F_5(6)$	$F_4 = 50 \text{ kg mol}$
$8(50) = 2F_4 + 50(6)$	

Mixing point balances (no rxn):

(In)	(Out)
--------	---------

$$C_3H_8: F_1(1.0) + F_6(0.8) = n_{C_3H_8}^{F_2} = 50 + 0.8F_6$$

$$C_3H_6: F_1(0) + F_6(0.2) = n_{C_3H_6}^{F_2} = 0.2F_6$$

Solutions Chapter 6

Reactor plus absorber/distillation balances:

	<u>In</u>	<u>Out</u>	<u>Generated</u>	<u>Consumed</u>	
C ₃ H ₈ :	n _{C₃H₈} ^{F₂} -	F ₆ (0.80) (recycle)	+ 0	- 0.4n _{C₃H₈} ^{F₂}	= 0
			(50 + 0.8F ₆) - 0.80 F ₆ - 0.4 (50 + 0.8 F ₆) = 0		
Recycle:	F ₆ = 93.75 kg mol		n _{C₃H₈} ^{F₂} = 75 + 50 = 125 kgmol		
C ₃ H ₆ :	n _{C₃H₆} ^{F₂ -}	F ₆ (.20) - 50 + 0.40 (50+ 0.8F ₆)	- 0		= 0
		n _{C₃H₆} ^{F₂} = 18.75 kg mol			

Note: since F₂ = F₁ + F₆ = 50 + 93.75 = 143.75 kg mol (easier calculated this way)

$$n_{C_3H_6}^{F_2} = 0.2, F_6 = 18.75 \text{ kg mol}$$

$$F_2 = 18.75 + 125 = 143.75 \text{ kg mol}$$

Omit H₂ balance (Use C₃H₆)

Absorption/distillation tower

$$C_3H_6: n_{C_3H_6}^{F_3} = F_5 = 50 \text{ kgmol}$$

$$H_2: n_{H_2}^{F_3} = F_4 = 50 \text{ kgmol}$$

$$\text{total: } F_3 = F_4 + F_5 + F_6 = 50 + 50 + 93.75 = 193.75 \text{ kg mol}$$

$$n_{C_3H_8}^{F_3} = 193.75 - 100 = 93.75 = F_6$$

Summary (all kg mol):

(a)	F ₁ = 50	F ₄ = 50
	F ₂ = 143.75	F ₅ = 50
	F ₃ = 193.75	F ₆ = 93.75

(b) [100% (no. C₃H₈ exists)]

Alternate solution using extent of reaction

$$f_{OA} = 1 = \frac{-1(-1)\xi}{50} \quad \xi = 50$$

Solutions Chapter 6

$$f_{SP} = 0.4 = \frac{-1(-1)\xi}{n_{C_3H_8}^{\text{reactor feed}}} = \frac{50}{n_{C_3H_8}^{F_2}} \quad n_{C_3H_8}^{F_2} = 125 \text{ kg mol}$$

$$\text{Also } \frac{0.40}{1} = \frac{50}{50 + n_{C_3H_8}^{F_6}}$$

$$n_{C_3H_8}^{F_6} = 75 \text{ kg mol} \quad n_{C_3H_6}^{F_6} = \frac{0.20}{0.80}(75) = 18.75 \text{ kg mol}$$

$$n_{C_3H_8}^{F_2} = 125 = 50 + 0.8 F_6 \quad F_6 = 93.75$$

$$n_{C_3H_6}^{F_2} = n_{C_3H_6}^{F_6} + 0 = 18.75$$

$$F_2 = 18.75 + 125 = 143.75$$

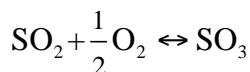
Similar calculations to these will yield the same results as in the original solution.

6.3.21

This is a steady state problem with reaction and recycle.

Step 5: Basis: 100 mol F

Steps 1, 2, 3 and 4: Make the overall balances first



			Calcd. mol	Calcd. mol fr
SO ₂	10.0	Use stoichiometry	9.50	0.100
O ₂	9.0	SO ₃ 0.95 (10) =	0.50	0.00525
N ₂	81.0	SO ₂ 0.05 (10) =	4.25	0.0446
		O ₂ 9.475	81.0	0.850
			95.25	1.000

Step 6: The unknowns are the 4 exit compositions plus the extent of reaction if it is to be used.

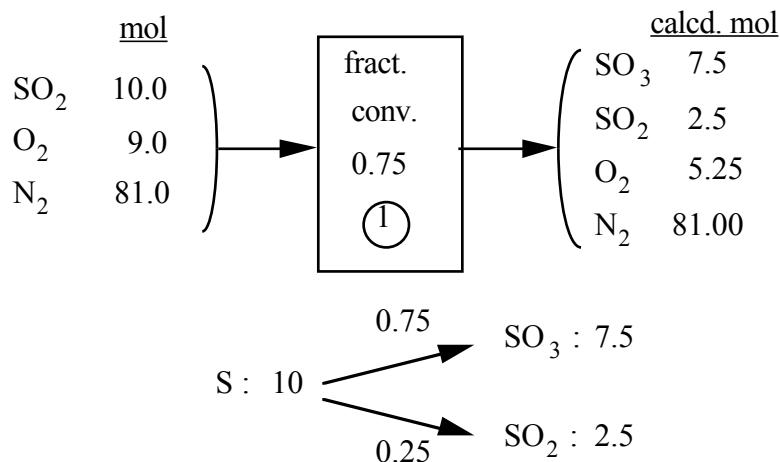
Steps 7, 8, and 9: We have 3 element balances plus the fraction conversion of the SO₂ to SO₃, or 4 species balances (SO₃, SO₂, N₂, O₂). We can use a mixture of element and species balances.

Solutions Chapter 6

Element S: 10 = 0.95 (10) + 0.05 (10) check is ok

Compound N₂: 81.0 = 81.0

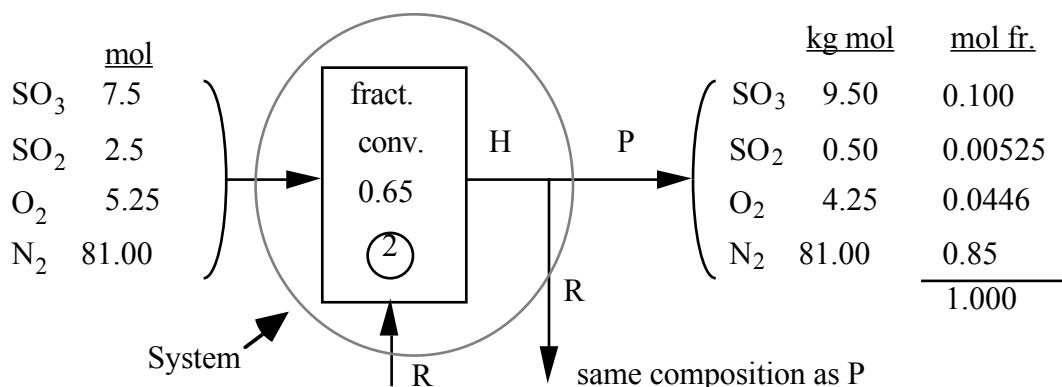
Select unit 1 as the system



Element 2O: 9.0 + 10.0 = 19 = 1.5 (7.5) + 2.5 + n_{O₂} = 11.25 + 2.5 + n_{O₂}

$$n_{O_2} = 5.25$$

Balance around converter 2 plus separator: Note we need H = P + R, and observe that the composition of H, P and R is the same.



Make a species balance on SO₂

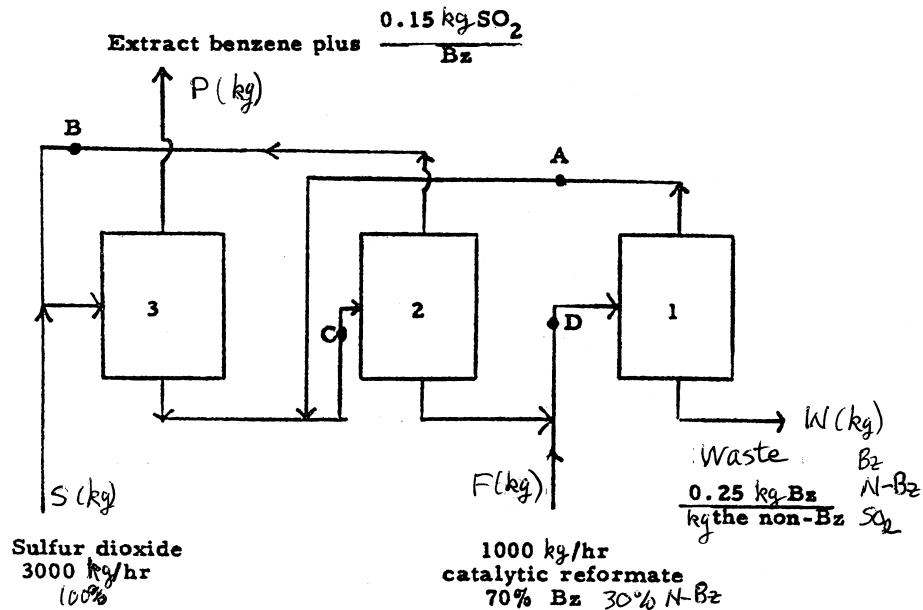
In	Out	Consumption	Generation
[2.5 + R(0.00525)] -	[0.50 + R(0.00525)] + 0		-[2.5 + R(0.00525)]0.65 = 0

$$R = 111 \text{ kg mol}$$

Solutions Chapter 6

6.3.22

Steps 2, 3, and 4: (Non Bz is non-benzene)



Step 5: Basis: 1 hr

Process is steady state, no reaction

Steps 2, 3 and 4:

Compositions:

$$\text{at P} \quad \text{SO}_2 \quad \frac{0.15 \text{ kg SO}_2}{1 + 0.15} = 0.130 \quad \text{at W} \quad \left. \begin{array}{l} m_{\text{Bz}}^W \\ m_{\text{NonBz}}^W \\ m_{\text{SO2}}^W \end{array} \right\} \sum = W$$

$$\text{Bz} \quad 1 - 0.130 \quad = \frac{0.870}{1.00}$$

Pick the overall process as the system

Steps 6 and 7:

Solutions Chapter 6

Unknowns: P, $3m_i^W$ (4)

Balances: Bz, SO₂, non Bz, $m_{Bz}^W/m_{nonBz}^W = 0.25$ (4)

Steps 8 and 9: Balances are in kg

$$\text{Total } 3000 + 1000 = P + W$$

$$\text{Bz: } 1000 (0.70) = P \left(\frac{1.00}{1.15} \right) + m_{Bz}^W$$

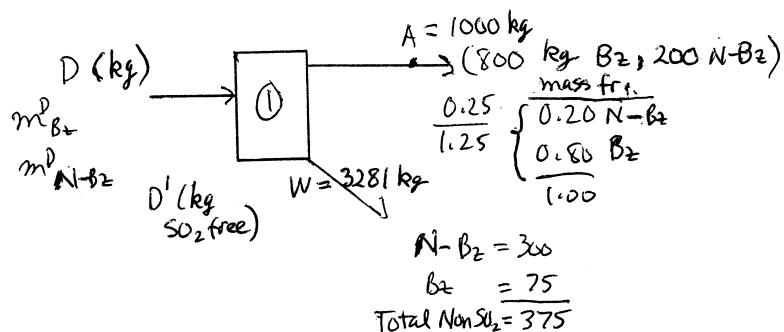
$$\text{Non Bz: } 1000 (0.30) = P (0) + m_{nonBz}^W \quad m_{nonBz}^W = 300 \text{ kg}$$

$$\text{SO}_2: \quad 3000 = P \left(\frac{0.15}{1.15} \right) + m_{SO_2}^W \quad m_{Bz}^W = 300 (0.25) = 75 \text{ kg}$$

a. Solution: $P = \boxed{719 \text{ kg}}$ $m_{SO_2}^W = 2906 \text{ kg}$

$$W = 3281 \text{ kg}$$

System: Unit 1



Steps 6 and 7:

Unknowns: m_{Bz}^D , m_{nonBz}^D , $m_{SO_2}^D$

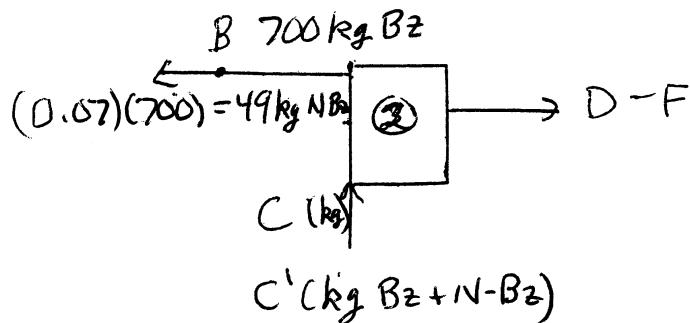
Balances: Bz, nonBz, SO₂

Steps 8 and 9: Balances are in kg

b. Bz + nonBz: $D' = A + 375$ $D' = 1000 + 375 = \boxed{1375 \text{ kg}}$

System: Unit 2

Solutions Chapter 6

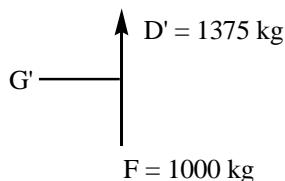


Steps 6 and 7:

Steps 8 and 9: Balances are in kg

Bz + nonBz: $C' = 749 + G'$

System: mixing point



$$G' = 1375 - 1000 = 375 \text{ kg}$$

c. $C' = 749 + 375 = \boxed{1124 \text{ kg}}$

6.3.23

Steady state process with reaction

Step 1, 2, 3, and 4: Get the amount of {reqd., excess} HNO₃ in G.

Step 5: Basis: 1 hr

$$\frac{1 \times 10^3 \text{ kg Glycerine}}{\text{92.11 kg Gly}} \left| \frac{1 \text{ kg mol Gly}}{\text{1 kg mol Gly}} \right. = 10.86 \text{ kg mol Gly}$$

Step 4: Glycerine



Required: HNO₃ is 3 (10.86) = 32.58 kg mol

Solutions Chapter 6

Excess: HNO_3 is 32.56 (.20) = 6.516
Total: 39.10 kg mol in G

Steps 6 and 7: System is overall

Unknown are F, P, $m_{\text{H}_2\text{SO}_4}^{\text{W}}$, and $m_{\text{H}_2\text{O}}^{\text{W}}$ ($\sum m_i = W$)

Equations are: C, H, S, O, N

(or you can use stoichiometry and make species balances, or use the extent of reaction)

C: $10.86 = 0.9650 P$ $P = 11.25 \text{ kg mol}$ or $11.25 (227.09)$

$$= 2556 \text{ kg} \quad (\text{a})$$

System is the mixing point

Unknowns: F, $m_{\text{H}_2\text{SO}_4}$, $m_{\text{H}_2\text{O}}$, R, G 5

Balances: H_2SO_4 , H_2O , HNO_3 and $m_{\text{H}_2\text{O}} + m_{\text{H}_2\text{SO}_4} + 39.10 = G$ 4

(a) Glycerine Feed $= \frac{1000}{92.11} = 10.86 \text{ kg mol}$

Nitroglycerine Produced $= \frac{1086 \text{ kg mol}}{\text{lb mol}} \left| \frac{227.98 \text{ kg}}{\text{lb mol}} \right. = 2466 \text{ kg}$

$0.9650 P = 2465$

$$P = 2555 \text{ kg} \quad (\text{a})$$

(b) Mol HNO_3 req'd $= \frac{10.86 \text{ mols Glyc.}}{\text{mol Glyc.}} \left| \frac{3 \text{ mol HNO}_3}{1 \text{ mol Glyc.}} \right. = 32.58 \text{ mol}$

Actual HNO_3 Req'd $= 1.200 (32.58) = 39.10 \text{ mol}$

HNO_3 in R $= 39.10 - 32.58 = 6.52 \text{ mol}$

$$= 6.52 (63.01) = 411 \text{ kg}$$

HNO_3 is 70.00% R, $0.7000R = 411$

Solutions Chapter 6

$$\boxed{R = 587 \text{ lb}}$$

(b)

(c) $\text{HNO}_3 \text{ in G} = 39.10 \text{ mol} = 2464 \text{ kg}$

$$\text{HNO}_3 \text{ in R} = 411 \text{ kg} \quad F + R = G$$

$$\text{HNO}_3 \text{ Balance: } F + 411 = 2464 \quad F = 2053 \text{ lb HNO}_3$$

F is 43.00% HNO_3 so that $0.4300 F = 2053$

$$\boxed{F = 4774 \text{ lb}} \quad (c)$$

(d) $\text{H}_2\text{SO}_4 \text{ in F} = 0.5000 (4774) = 2387 \text{ kg}$

$$= \text{H}_2\text{SO}_4 \text{ in W}$$

$$\text{H}_2\text{O in F} = 0.0700 (4774) = 334 \text{ kg}$$

$$\text{H}_2\text{O Generated by reaction} = 10.86 \text{ Mole Glyc} \times 3$$

$$= (10.86) (3) (18.02) = 587 \text{ kg}$$

$$\text{H}_2\text{O in Stream P} = 0.0350 (2555) = 89 \text{ kg}$$

$$\text{H}_2\text{O in W} = \text{H}_2\text{O in F} + \text{H}_2\text{O generated} - \text{H}_2\text{O in P}$$

$$= 334 + 587 - 89 = 832 \text{ kg}$$

<u>Component</u>	<u>kg</u>	<u>wt%</u>
H_2SO_4	2387	74.15
H_2O	$\frac{832}{3219}$	$\frac{25.85}{100.00}$

$$\boxed{\text{Stream W} = 3219 \text{ kg/hr}}$$

$$\begin{array}{ll} \text{H}_2\text{SO}_4 & = 74.15\% \\ \text{H}_2\text{O} & = 25.85\% \end{array}$$

(d)

Step 10:

Do numbers check?

$$\begin{array}{lll} \text{Glycerine} + F & = & P + W \\ 1000 + 4774 & = & 2555 + 3219 \\ 5774 & = & 5774 \end{array}$$

Solutions Chapter 6

6.3.24

- a. No. They all contain AN and/or NH₃.
- b. The bottom stream from the distillation column and the wastewater stream from the condenser are candidates. The bottoms stream from the distillation column contains no NH₃ and has the highest mass fraction of AN of any waste stream so that the entire stream could be fed to the scrubber.
- c. The change in the scrubber feed will not affect any of the stream flows or compositions upstream of the scrubber that are connected to the scrubber, namely those associated with the reactor and the subsequent condenser, nor any downstream flows not connected to the scrubber. A sequential set of material balances can be used to get the flows and concentrations in the rest of the process.

Basis: 1 second

- (1) The water flow rates will not change except for the stream going to treatment, which will be $(10.1 - 0.7) = 9.4 \text{ kg/s}$.
- (2) The AN clues in the streams can be determined from the following balances.

Let x be the kg of AN entering or leaving a particular unit.

Scrubber balance

$$x_{\text{Scrubber}}^{\text{In}} + 4.6 = x_{\text{Decanter}}^{\text{In}}$$

Decanter balance

$$x_{\text{Decanter}}^{\text{In}} = x_{\text{Distill}}^{\text{In}} + 5.5(0.073)$$

Distillation column plus two condenser plus stream jet plus product stream balance

$$x_{\text{Distill}}^{\text{In}} + 0 = x_{\text{Jet}}^{\text{Out}} + x_{\text{Product}}^{\text{Out}} + x_{\text{Scrubber}}^{\text{In}}$$

Distribution of AN entering the distillation column

$$\frac{x_{\text{Jet}}^{\text{Out}}}{x_{\text{Distill}}^{\text{In}}} = \frac{0.2}{4.2} \quad \frac{x_{\text{Product}}^{\text{Out}}}{x_{\text{Distill}}^{\text{In}}} = \frac{3.9}{4.2} \quad \frac{x_{\text{Scrub}}^{\text{In}}}{x_{\text{Distill}}^{\text{In}}} = \frac{0.1}{4.2}$$

One of these relations is redundant with the distillation column balance.

The solution of these equations is in kg (note the changes are quite small, hence the number of significant figures is exaggerated):

Solutions Chapter 6

$$x_{\text{Distill}}^{\text{In}} = 4.302 \quad x_{\text{Scrub}}^{\text{In}} = 0.102 \quad x_{\text{Decant}}^{\text{In}} = \quad x_{\text{Jet}}^{\text{Out}} = 0.205 \quad x_{\text{Prod}}^{\text{Out}} = 3.995$$

Because the changes are so small, the NH_3 concentration changes are negligible.

6.4.1

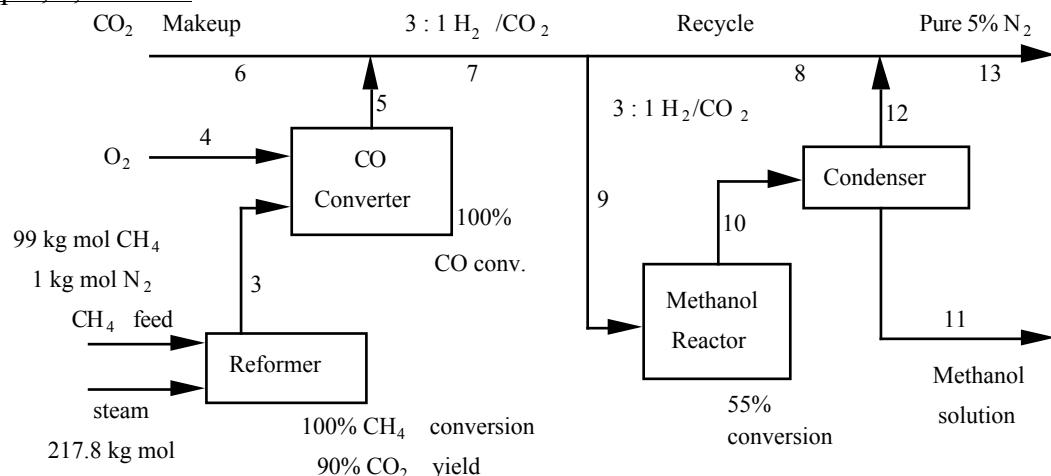
No purge stream exists out of the separator so that CO will build up.

6.4.2

By inspection you can see that the flow of C_1H_2 and H_2 in the separator is going the wrong way, hence any calculations make no sense.

6.4.3

Step 1, 2, 3 and 4:



Chemical Reactions

- $\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow \text{CO}_2 + 4\text{H}_2$ (main reformer rxn)
- $\text{CH}_4 + \text{H}_2 \rightarrow \text{CO} + 3\text{H}_2$ (reformer side rxn)
- $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$ (CO converter rxn)
- $\text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$ (methanol rxn)

CH_4 feed is 1% N_2 or 1 kg mol N_2

steam feed is 10% excess based on reaction (a).

Solutions Chapter 6

$$99 \text{ kg mol CH}_4 \left(2 \frac{\text{kg mol H}_2\text{O}}{\text{kg mol CH}_4} \right) = 198 \text{ kg mol steam}$$

$$1.1 (198) = 217.8 \text{ kg mol steam}$$

Step 5: Basis: 100 kg mol CH₄ in feed

Steps 6 and 7: Unknowns:

	6-CO ₂ makeup	10-reactor product
3-reformer product	7-3:1 H ₂ /CO ₂	11-Methanol solution
4-O ₂ feed, stoichiometric	8-recycle, H ₂ /CO ₂ =3	12-condenser tops
5-CO conv. products	9-reactor feed, H ₂ /CO ₂ =3	13-purge, 5% N ₂
<u>Balances:</u>		
	Reformer balance	Condenser balance
	CO conv. balance	purge/recycle balance
	CO ₂ makeup balance	
	Feed/recycle balance	
	Methanol reactor balance	

Steps 8 and 9: Solve balances serially.

Reformer balance gives stream 3

$$\text{CO}_2 = \frac{99 \text{ kg mol CH}_4 \text{ conv.}}{1 \text{ conv.}} \left| \begin{array}{l} 0.9 \text{ conv by (a)} \\ \hline \end{array} \right| \frac{1 \text{ kg mol CO}_2}{1 \text{ kg mol CH}_4} = 89.1 \text{ kg mol CO}_2$$

$$\text{CO} = 99(0.1) = 9.9 \text{ kg mol CO}$$

$$\begin{aligned} \text{H}_2\text{O reacted} &= \frac{2 \text{ kg mol H}_2\text{O}}{1 \text{ kg mol CO}_2} \left| \begin{array}{l} 89.1 \text{ kg mol CO}_2 \\ \hline \end{array} \right. \\ &+ \frac{1 \text{ kg mol H}_2\text{O}}{1 \text{ kg mol CO}} \left| \begin{array}{l} 9.9 \text{ kg mol CO} \\ \hline \end{array} \right. = 188.1 \text{ kg mol H}_2\text{O} \end{aligned}$$

$$\text{H}_2\text{O remaining} = 217.8 - 188.1 = 29.7 \text{ kg mol H}_2\text{O}$$

$$\text{H}_2 = 4(89.1) + 3(9.9) = 386.1 \text{ kg mol H}_2$$

Solutions Chapter 6

$$N_2 = 1 \text{ kg mol}$$

CO conv. balance gives streams 4 & 5:

Stream 4:

$$O_2 = \frac{9.9 \text{ kg mol CO}}{1 \text{ kg mol CO}} \left| \frac{(1/2) \text{ kg mol O}_2}{1 \text{ kg mol CO}} \right. = 4.95 \text{ kg mol O}_2$$

Stream 5:

$$CO_2 = 89.1 + 9.9 = 99 \text{ kg mol CO}_2$$

$$H_2O = 29.7 \text{ kg mol H}_2O$$

$$H_2 = 386.1 \text{ kg mol H}_2$$

$$N_2 = 1 \text{ kg mol N}_2$$

CO₂ makeup gives streams 6 and 7:

stream 7 is 3:1 H₂/CO₂

$$CO_2 = 386.1/3 = 128.7 \text{ kg mol CO}_2 \text{ needed}$$

Stream 6: $CO_2 = 128.7 - 99 = \boxed{29.7 \text{ kg mol CO}_2}$ b.

purge/recycle gives stream 13:

N₂ is inert species:

$$\text{stream 13} = \frac{1.0 \text{ kg mol N}_2}{0.05 \text{ kg mol N}_2 / \text{kg mol stream 13}} = 20 \text{ kg mol in stream 13}$$

Stream 13:

$$H_2/CO_2 = 3 \quad \text{Let } x = \text{mol frac. of CO}_2 \text{ in stream 13}$$

$$1 = 0.05 + 3x + 1x$$

$$4x = 0.95, \quad x = 0.2375$$

$$N_2 = 1 \text{ kg mol N}_2$$

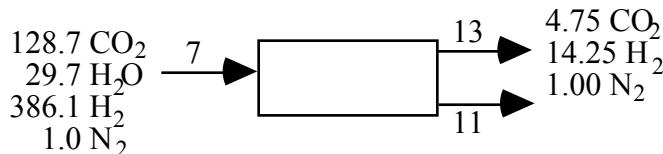
$$H_2 = 20(3)(0.2375) = \boxed{14.25 \text{ kg mol H}_2}$$

a.

Solutions Chapter 6

$$\text{CO}_2 = 20 (0.2375) = 4.75 \text{ kg mol CO}_2$$

Special balance gives stream 11:



1 rxn occurs

$$\text{CO}_2 \text{ reacted} = 128.7 - 4.75 = 123.95 \text{ kg mol CO}_2 \text{ reacted}$$

$$\text{H}_2 \text{ reacted} = 386.1 - 14.25 = 371.85 \text{ kg mol H}_2 \text{ reacted}$$

$$\text{CH}_3\text{OH produced} = 123.95 \text{ kg mol CH}_3\text{OH}$$

$$\text{H}_2\text{O produced} = 123.95 \text{ kg mol H}_2\text{O}$$

Stream 11:

$$\text{H}_2\text{O} = 29.7 + 123.95 = 153.65 \text{ kg mol H}_2\text{O}$$

$$\text{CH}_3\text{OH} = 123.95 \text{ kg mol CH}_3\text{OH}$$

$$\text{mass stream 11} = 153.65 (18) + 123.95 (32) = \boxed{6732.1 \text{ kg}}$$

d.

$$\text{wt. \% CH}_3\text{OH} = \frac{123.95 (32)}{6732.1} = \boxed{58.9\% \text{ CH}_3\text{OH wt. \%}}$$

Methanol reactor balance for 55% conversion

From special balance, each pass uses 123.95 kg mol CO₂

$$123.95 = 0.55 (\text{CO}_2)_{\text{in}} \text{ so } (\text{CO}_2)_{\text{in}} = 225.36 \text{ kg mol CO}_2$$

Stream 8 = stream 9 - stream 7

$$\text{Stream 8: CO}_2 = 225.36 - 128.7 = 95.66$$

$$\text{So } \frac{\text{recycle}}{\text{purge}} = \frac{95.66}{4.75} = \boxed{20.35}$$

c.

Solutions Chapter 7

7.1.1

$$n = \frac{pV}{RT} = \frac{15.5 \text{ mm Hg}}{760 \text{ mm Hg}} \left| \frac{14.7 \text{ psia}}{10.73 \frac{\text{psia ft}^3}{(\text{lb mol})(\text{°R})}} \right| \left| \frac{100 \text{ ft}^3}{(296)(1.8)\text{°R}} \right|$$

$$n = \frac{(15.5)(14.7)(100)}{(760)(10.73)(533)} = 0.00524 \text{ lb mol}$$

$$\text{lb H}_2\text{O} = (0.00524)(18) = \boxed{0.0944 \text{ lb H}_2\text{O}}$$

7.1.2 Basis: 1 L gas at 780 mm Hg and T

$$\frac{1\text{L}}{\text{L}} \left| \frac{780 \text{ mm Hg}}{760 \text{ mm Hg}} \right| = \boxed{1.026 \text{ L}}$$

7.1.3 $(pV)_1 = (pV)_2$

$$1 \times 1 = p \times 1.2$$

$$p = \frac{1}{1.2} = \boxed{0.83 \text{ atm}}$$

7.1.4 Specific volume: MW = molecular weight

$$\hat{V} = \frac{(R)(T)}{p} = \frac{(\bar{R}/\text{MW})T}{p} = \frac{(1545.3/28.97)(78 + 460)}{(14.7)(144)} = 13.56 \text{ ft}^3/\text{lb}_m$$

Molal specific volume:

$$\hat{V}_m = \frac{(\bar{R})(T)}{p} = \frac{(1545.3)(78 + 460)}{(14.7)(144)} = 392.8 \text{ ft}^3/\text{lb mol}$$

Note that

$$\hat{V} = \frac{\hat{V}_m}{\text{MW}} = \frac{392.8}{28.97} = 13.56 \text{ ft}^3/\text{lb}_m$$

Solutions Chapter 7

7.1.5

Assume $\rho_{H_2O} = 62.4 \text{ lb/ft}^3$, $p_{bar} = 14.696 \text{ psia}$

$$p = \frac{500 \text{ ft H}_2\text{O}}{33.91 \text{ ft H}_2\text{O}} \left| \frac{14.696 \text{ psia}}{33.91 \text{ ft H}_2\text{O}} \right| + 14.696 \text{ psia} = 231.387 \text{ psia}$$

$$\hat{V} = \frac{359 \text{ ft}^3}{\text{lb mol}} \left| \frac{14.696}{231.387} \right| \left| \frac{45 + 460}{32 + 460} \right| = 23.4 \frac{\text{ft}^3}{\text{lb mol}}$$

7.1.6

$$pV = nRT$$

$$T = \frac{pV}{nR} = \frac{121 \text{ kPa}}{0.0011 \text{ kg mol}} \left| \frac{25 \text{ L}}{1000 \text{ L}} \right| \left| \frac{1 \text{ m}^3}{8.314 \text{ (kPa)(m}^3)}$$
$$= 330.8 \rightarrow 331 \text{ K}$$

7.1.7

You must first convert the temperatures and pressures into absolute units:

$$460 + 70 = 530^\circ\text{R}$$

$$460 + 75 = 535^\circ\text{R}$$

atmospheric pressure = 29.99 in. Hg = 14.73 psia

$$\text{final pressure} = 29.99 \text{ in. Hg} + \frac{4 \text{ in. H}_2\text{O}}{12 \text{ in H}_2\text{O}} \left| \frac{29.92 \text{ in. Hg}}{33.91 \text{ ft H}_2\text{O}} \right|$$
$$\text{ft H}_2\text{O}$$
$$= 29.99 + 0.29 = 30.28 \text{ in. Hg absolute}$$

The simplest way to proceed, now that the data are in good order, is to apply the ideal gas law. Take as a basis, 16.01 ft³ (do not forget to include the volume of the O₂ tank in your system) of O₂ at 75°F and 30.28 in. Hg. Determine the initial pressure in the O₂ tank alone.

Solutions Chapter 7

$$p_1 = p_2 \left(\frac{V_2}{V_1} \right) \left(\frac{n_1}{n_2} \right) \left(\frac{T_1}{T_2} \right)$$

$$p_1 = 30.28 \text{ in. Hg} \left(\frac{16.01 \text{ ft}^3}{1 \text{ ft}^3} \right) \left(\frac{530^\circ\text{R}}{535^\circ\text{R}} \right) = 480 \text{ in. Hg absolute}$$

In gauge pressure,

$$p_1 = \frac{(480 - 29.99) \text{ in. Hg}}{29.92 \text{ in. Hg}} \left| \begin{array}{l} 14.696 \text{ psia} \\ \hline 29.92 \text{ in. Hg} \end{array} \right| = \boxed{221 \text{ psig}}$$

7.1.8

Basis: 5 L at 1 atm and T

Assume T is constant throughout the dive.

At the end of the dive the pressure is $p = \rho gh$, or easier let x = depth in m.

$$\frac{x \text{ m}}{10.34} \left| \begin{array}{l} 1 \text{ atm} \\ \hline 10.34 \end{array} \right| + 1 = p \text{ atm}$$

The pressure for 1 L is obtained from $p_1 V_1 = p_2 V_2$

$$p_2 = p_1 \left(\frac{V_1}{V_2} \right) = 1 \text{ atm} \left(\frac{5 \text{ L}}{1 \text{ L}} \right) = 5 \text{ atm}$$

$$\frac{x}{10.34} = 4 \quad \text{hence } x = \boxed{41.4 \text{ m}}$$

7.1.9

Basis: air at 30 psi and 75°F in volume of tire

(1) Initial State (2) Final State

$$p_1 = 44.7 \text{ psia} \quad p_2 = ?$$

$$T_1 = 535^\circ\text{R} \quad T_2 = 600^\circ\text{R}$$

$$V_1 = ? \quad V_2 =$$

Solutions Chapter 7

$$N_1 = ?$$

$$n_2 = ?$$

$$\frac{p_1 V_1}{p_2 V_2} = \left(\frac{n_1}{n_2} \right) \frac{R}{R} \left(\frac{T_1}{T_2} \right)$$

Assume volume is the same
The number of mols are the same

$$p_2 = p_1 \left(\frac{T_2}{T_1} \right) = (44.7) \left(\frac{600}{535} \right) = 50.2 \text{ psia}$$

$$50.2 - 14.7 = 35.5 \text{ psia} \quad \boxed{\text{just over the limit}}$$

7.1.10 Basis: 1 hr

a) $Q = v A$

$$Q = \frac{11.3 \text{ ft}}{\text{s}} \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \left(\frac{(18.0 \text{ in})^2}{(12 \text{ in})^2} \right) \pi = 2.875 \times 10^5 \frac{\text{ft}^3}{\text{hr}}$$

$$\text{In 1.0 hr } \boxed{2.875 \times 10^5 \text{ ft}^3}$$

b) $m = \rho v s$

$$m = 0.0796 \frac{\text{lb}_m}{\text{ft}^3} \left| \frac{11.3 \text{ ft}}{\text{s}} \right| \left| \pi \right| \left(\frac{(18.0)^2 \text{ in}^2}{(12 \text{ in})^2} \right) = 6.358 \frac{\text{lb}_m}{\text{s}}$$

$$\text{In 1 day: } \frac{6.358 \text{ lb}_m}{\text{s}} \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| \left| 24 \text{ hr} \right| = \boxed{5.49 \times 10^5 \text{ lb}_m}$$

Solutions Chapter 7

7.1.11

Apply $pV = nRT$ twice or use it once with R

Basis: 1 pound mole fg $\frac{V}{n} = \frac{(0.7302)(560)}{1.54}$

(1) 100°F (560°R) and 1.54 atm

(2) 32°F (492°R) and 1 atm (SC)

$$\begin{aligned}\frac{p_1 V_1}{p_2 V_2} &= \frac{T_1}{T_2} \quad \text{so } V_1 = V_2 \left(\frac{T_1}{T_2} \right) \left(\frac{p_2}{p_1} \right) \\ &= \frac{359 \text{ ft}^3}{1 \text{ lb mol}} \left| \frac{560^\circ\text{R}}{492^\circ\text{R}} \right| \frac{1 \text{ atm}}{1.54 \text{ atm}} = \boxed{\frac{265 \text{ ft}^3}{\text{lb mol}}}\end{aligned}$$

7.1.12

(a) $\boxed{1.987 \text{ cal}/(\text{g mol})(\text{K})}$ (b) $\boxed{1.987 \text{ Btu}/(\text{lb mol})(^\circ\text{R})}$

(c) $\frac{14.7 \text{ psia}}{492^\circ\text{R}} \left| \frac{359 \text{ ft}^3}{1 \text{ lb mol}} \right. = \boxed{10.73 \text{ (psia)} \left(\text{ft}^3 \right) / (\text{R})(\text{lb mol})}$

$$\begin{aligned}\text{(d)} \quad \frac{1.013 \times 10^5 \text{ N/m}^2}{273 \text{ K}} \left| \frac{22.4 \text{ m}^3}{1 \text{ kg mol}} \right| \frac{1 \text{ J}}{1 \text{ (N)} \text{ (m)}} \left| \frac{1 \text{ kg mol}}{10^3 \text{ g mol}} \right. \\ = \boxed{8.314 \text{ J}/(\text{g mol}) (\text{K})}\end{aligned}$$

(e) $\frac{1 \text{ atm}}{273 \text{ K}} \left| \frac{22,400 \text{ cm}^3}{1 \text{ g mol}} \right. = \boxed{82.06 \left(\text{cm}^3 \right) (\text{atm}) / (\text{K})(\text{g mol})}$

(f) $\frac{1 \text{ atm}}{492^\circ\text{R}} \left| \frac{359 \text{ ft}^3}{1 \text{ lb mol}} \right. = \boxed{0.7302 \left(\text{ft}^3 \right) (\text{atm}) / (\text{lb mol})(^\circ\text{R})}$

Solutions Chapter 7

7.1.13

Basis: 1 ft³ O₂ at 100°F, 740 mm Hg

$$n = \frac{(740)(14.7)(1)}{(760)(10.73)(560^{\circ}\text{R})} = 0.00238 \text{ lb mol}$$

Density at 100°F, 740 mm Hg

$$\rho = \frac{(0.00238)(32)}{1} = \boxed{\begin{array}{l} 0.0761 \text{ lb/ft}^3 \\ (1.22 \text{ g/liter}) \end{array}}$$

7.1.14

Basis: 1 kg mol gas at 200 kPa and 40°C

(a)

$$R = 8.31 \frac{(\text{kPa})(\text{m}^3)}{(\text{K})(\text{kg mol})} \quad T = 40 + 273 = 313 \text{ K}$$

MW = 44 kg/kg mol

p = 200 kPa

Density = p (MW)/RT

$$= \frac{200 \text{ kPa}}{313 \text{ K}} \left| \frac{44 \text{ kg}}{1 \text{ kg mol}} \right| \frac{1}{8.31 \frac{(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}} = \boxed{3.38 \text{ kg/m}^3}$$

(b) Specific gravity here is assumed to be density of propane at SC/density of air at SC.

$$\text{Sp. gr.} = \frac{p_{C_3H_8} n(MW_{C_3H_8})}{RT_{C_3H_8}} \left| \frac{p_{air} n(MW)_{air}}{RT_{air}} \right| = \frac{MW_{C_3H_8}}{MW_{air}} = \frac{44}{29} = \boxed{1.52}$$

Solutions Chapter 7

7.1.15

Basis: 1 lb mol gas at 760 mm Hg and 60°F

$$\text{Sp. gr.} = \frac{p_{C_3H_8} (MW_{C_3H_8})}{RT_{C_3H_8}} \left| \frac{\frac{800(44)}{560}}{\frac{p_{\text{air}}(MW)_{\text{air}}}{RT_{\text{air}}}} \right| = \frac{800(44)}{560} \left| \frac{520}{760} \right| \left| \frac{1}{29} \right| = 1.483$$

7.1.16

Basis: 1 m³ H₂ at 5°C and 110 kPa

a. $\frac{1 \text{ m}^3}{278} \left| \frac{273}{101.3 \text{ kPa}} \right| \left| \frac{110 \text{ kPa}}{22.4 \text{ m}^3} \right| \left| \frac{2 \text{ kg}}{1 \text{ kg mol}} \right| = [0.0952 \text{ kg/m}^3]$

b. $\frac{2 \text{ kg H}_2}{1 \text{ kg mol H}_2} \left| \frac{1 \text{ kg mol air}}{29 \text{ kg air}} \right| = [0.069] = \text{specific gravity}$

7.1.17

Basis: 2m³ at 200 kPa and 25°C

$$p_{CO_2} = 200(0.8) = [160 \text{ kPa}]$$

7.1.18

Basis: Gas at 30 psig and 20°C

Assume the barometric pressure = 14.7 psia

$$14.7 + 30.0 = 44.7 \text{ psia}$$

$$p_{O_2} = (44.7)(0.01) = [0.447 \text{ psia @ } 20^\circ C]$$

Solutions Chapter 7

7.1.19

Basis: 1 liter final volume

Assumptions:

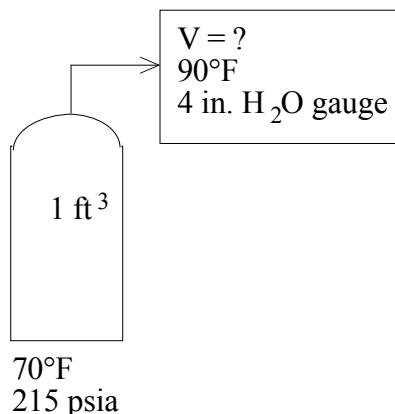
- (1) Temperature is constant
- (2) Ideal gas law applies

$$p_T = p_{O_2} + p_{N_2} = (760 + 760) = \underline{1,520 \text{ mm Hg}}$$

7.1.20

- a. F b. F c. T

7.1.21



$$460 + 70 = 530^\circ\text{R}$$

$$460 + 90 = 550^\circ\text{R}$$

atmospheric pressure = 29.92 in. Hg = std atm = 14.7 psia

$$\text{initial pressure} = \frac{200 \text{ psig} + 14.7 \text{ psia}}{14.7 \text{ psia}} \left| \frac{29.92 \text{ in. Hg}}{14.7 \text{ psia}} \right. = 437 \text{ in. Hg}$$

Solutions Chapter 7

$$\text{final pressure} = 29.92 \text{ in. Hg} + \frac{4 \text{ in. H}_2\text{O}}{\frac{12 \text{ in. H}_2\text{O}}{\text{ft H}_2\text{O}}} \left| \begin{array}{c} 29.92 \text{ in. Hg} \\ 33.91 \text{ ft H}_2\text{O} \end{array} \right|$$

$$= 29.92 + 0.29 = 30.21 \text{ in. Hg}$$

Basis: 1 ft³ of oxygen at 70°F and 200 psig

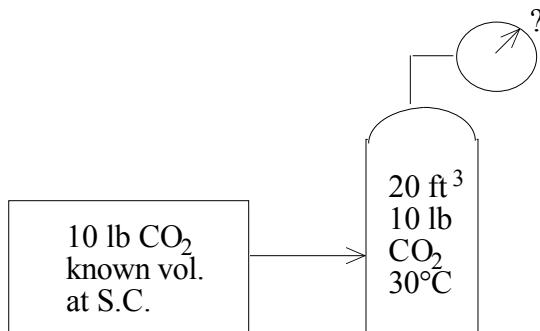
$$\text{final volume} = \frac{1.00 \text{ ft}^3}{\frac{550^\circ\text{R}}{530^\circ\text{R}}} \left| \begin{array}{c} 437 \text{ in. Hg} \\ 30.21 \text{ in. Hg} \end{array} \right|$$

$$= \boxed{15.0 \text{ ft}^3 \text{ at } 90^\circ\text{F and } 4 \text{ in. H}_2\text{O gauge}}$$

Formally, the same calculation can be made using

$$V_2 = V_1 \left(\frac{p_1}{p_2} \right) \left(\frac{T_2}{T_1} \right) \quad \text{since } n_1 = n_2$$

7.1.22



Solution

We can write (the subscript 1 stands for standard conditions, 2 for the conditions in the tank)

$$p_2 = p_1 \left(\frac{V_1}{V_2} \right) \left(\frac{T_2}{T_1} \right)$$

$$\underbrace{\frac{14.7 \text{ psia}}{V_1} \left| \frac{10 \text{ lb CO}_2}{44 \text{ lb CO}_2} \right| \frac{1 \text{ lb mol CO}_2}{1 \text{ lb mol}} \left| \frac{359 \text{ ft}^3}{20 \text{ ft}^3} \right| \frac{303 \text{ K}}{273 \text{ K}}}_{T_2} = p_2 = 66.6 \text{ psia}$$

Hence the gauge on the tank will read (assuming that it reads gauge pressure and that the barometer reads 14.7 psia) $66.6 - 14.7 = \boxed{51.9 \text{ psig}}$

Solutions Chapter 7

7.1.23

Basis: Data in the diagram

State 1 is before corking; state 2 is after equilibrium is reached after filling. Assume $p_A = p_{Z1} = 29.92$ in. Hg abs. $p_{Z2} = p_A + \rho_{Hg}gh = 29.92 + h$ where p_{Z2} is in inches Hg.

Use the ideal gas law: $p_{Z2} V_{Z2} = p_{Z1} V_{Z1}$

$$p_{Z2} = 29.92 (8/6) = 39.89 \text{ in. Hg}$$

$$39.89 = 29.92 + h \quad \text{or} \quad h = 9.97 \text{ in. Hg}$$

$$9.97 + 14 = 24 \text{ in. Hg}$$

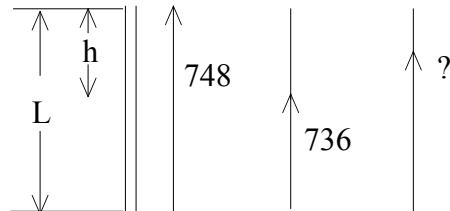
7.1.24

Basis: fixed amount of air in manometer

A = area of manometer

h = height of air, mm

L = length of manometer, mm



$$p_1 = 755 \quad p_2 = 740 \quad p_3 = 760$$

$$V_{air} = (h)(A)$$

$$\frac{p_1}{p_2} = \frac{V_2}{V_1} = \frac{h_2}{h_1}$$

$$p_1 = 755 - 748 = 7 \text{ mm Hg} \quad L = 748 + h_1 \quad (1)$$

$$p_2 = 740 - 736 = 4 \text{ mm Hg} \quad L = 736 + h_2 \quad (2) \quad 7Ah_1 = 4Ah_2$$

$$p_3 = 760 - (L - h_3) \quad \overline{12 + h_1 = h_2} \quad (3) \quad (h_2/h_1) = 7/4 \quad (4)$$

Solving (3) and (4): $h_1 = 16 \text{ mm}$ $L = 764 \text{ mm}$

$$7(A)(h_1) = [760 - (L - h_3)] (A) (h_3) \quad (5)$$

Solutions Chapter 7

Substituting values of h_1 , L in (5), one obtains:

$$h_3 = 18 \text{ mm}$$

The height of barometer = $L - h_3 = [751 \text{ mm Hg}]$

7.1.25 Basis: Flue gas at 1800°F, constant pressure, and given volume

1. Calculate the inlet cross-sectional area A :

$$A_i = \pi[(D_i)^2]/4 = \pi(4^2)/4 = 12.57 \text{ ft}^2$$

2. Calculate the inlet volumetric flow rate Q :

$$Q = (\text{velocity}) \times (\text{cross-sectional area}) = 25(12.57) = 314.16 \text{ ft}^3/\text{s}$$

3. Calculate the outlet volumetric flow rate using the ideal gas law:

$$Q_o = Q_i(T_o/T_i) = 314.16(460 + 550)/(460 + 1800) = 140.40 \text{ ft}^3/\text{s}$$

4. Calculate the outlet cross-sectional area:

$$A_o = Q_o/v_o = 140.40/20 = 7.02 \text{ ft}^2$$

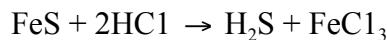
5. Calculate the outlet duct diameter:

$$(D_o)^2 = 4(A_o)/\pi = 4(7.02)/\pi$$

$$D_o = (4(7.02)/\pi)^{0.5} = [2.99 \text{ ft}]$$

7.1.26

Basis: 10 kg FeS (MW = 87.9)



$$\frac{10 \text{ kg FeS}}{87.9 \text{ kg FeS}} \left| \frac{1 \text{ kg mol FeS}}{\text{kg mol FeS}} \right. = 0.114 \text{ kg mol FeS}$$

Assume pressure most likely is gage. Absolute pressure = $15.71 + 76.0 = 91.71 \text{ cm Hg} = 122.2 \text{ kPa}$

$$V = \frac{nRT}{p} = \frac{0.114 \text{ kg mol FeS}}{(\text{kg mol})(\text{K})} \left| \frac{8.314(\text{kPa})(\text{m}^3)}{122.2 \text{ kPa}} \right| \left| \frac{(30 + 273)\text{K}}{} \right|$$

$$= [2.35 \text{ m}^3 @ 30^\circ\text{C and } 15.71 \text{ cm Hg gauge}]$$

Solutions Chapter 7

7.1.27

Basis: 1 hr = 500 lb waste (W)

Get $\mu\text{g}/\text{ft}^3$ at SC $1 \mu\text{g}/\text{mL} = 0.001\text{g}/\text{L}$; ignore HC in totaling W

$$\frac{500 \text{ lb W}}{1 \text{ lb}} \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| \left| \frac{0.01 \text{ g HC}}{1 \text{ g W}} \right| \left| \frac{427,000 \text{ ft}^3 \text{ SC}}{1 \text{ hr}} \right| = 5.32 \times 10^{-3} \text{ g HC}/\text{ft}^3 \text{ SC}$$

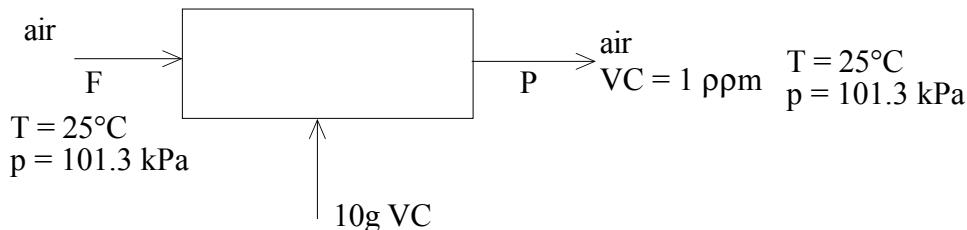
The minimum volume of flue gas is

a. $\frac{1 \text{ ft}^3 \text{ SC}}{5.32 \times 10^{-3} \text{ g HC}} \left| \frac{1 \text{ g}}{10^6 \mu\text{g}} \right| \left| \frac{10 \mu\text{g}}{\text{mL}} \right| \left| \frac{25 \text{ mL}}{1 \text{ hr}} \right| = 0.047 \text{ ft}^3 \text{ SC}$

b. $\frac{0.047 \text{ ft}^3 \text{ SC}}{427,000 \text{ ft}^3 \text{ SC}} \left| \frac{1 \text{ hr}}{1 \text{ hr}} \right| = 1.1 \times 10^{-7} \text{ hr}$

7.1.28

Basis: 1 min = 10 g VC



Apply $pV = nRT$ to get the volume of VC at SC and then use the mole fraction information to get the volume of air (the addition of VC to air has negligible effect on the volume)

$$\text{MW } \text{VC} = 78$$

$$V_{\text{VC}} = \frac{n_{\text{VC}} RT}{p} = \frac{0.0101 \text{ kg VC}}{1 \text{ kg mol VC}} \left| \frac{1 \text{ kg mol VC}}{78 \text{ kg VC}} \right| \left| \frac{8.314 \text{ (kPa)}(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| \left| \frac{298 \text{ K}}{101.3 \text{ kPa}} \right|$$

$$= 3.01 \times 10^{-3} \text{ m}^3 \text{ VC at SC}$$

Volume fraction is the same as mole fraction here.

$$\frac{3.01 \times 10^{-3} \text{ m}^3 \text{ VC at SC}}{1 \text{ m}^3 \text{ VC}} \left| \frac{10^6 \text{ m}^3 \text{ air}}{(1.06 \times 10^6) \text{ ft}^3/\text{min}} \right| = \boxed{3.01 \times 10^3 \text{ m}^3/\text{min}}$$

an absurd number!

Solutions Chapter 7

If a hood is used:

$$\text{area} = \frac{(30)(25) \text{ in}^2}{144 \text{ in}^2} \left| \frac{1 \text{ ft}^2}{\text{s}} \right| \left| \frac{100 \text{ ft}}{\text{s}} \right| \left(\frac{0.3048 \text{ m}}{1 \text{ ft}} \right)^3 \times \frac{60 \text{ s}}{\text{min}}$$

= $882 \text{ m}^3/\text{min}$ a smaller amount of air.

Besides inconvenience, the discharge concentration from the hood vent may be unacceptable.

7.1.29

Basis: 100 ppm of TCE (MW 131.5) in air

$$\rho = \frac{p \overline{MW}}{RT} \text{ where } \overline{MW} \text{ is the average MW. At 100 ppm, } \overline{MW} =$$

$$(100 \times 10^{-6})(131.5) + (1 - 100 \times 10^{-6})(29) = 29.013$$

The density is essentially the same as that of air.

7.1.30

Basis: 1 min

$$T = (68 + 460)/1.8 = 293K$$

$$\text{MW} = \text{benzene} = 78.11 \text{ g/g mol} \quad \rho_{Bz \text{ liq}} = 0.879 \text{ g/cm}^3$$

$$pV = nRT$$

$$R = 0.08206 \text{ (L)(atm)/(g mol)(K)}$$

$$n = \frac{2.5 \text{ cm}^3 \text{ liq}}{\text{min}} \left| \frac{0.879 \text{ g Bz liq}}{1 \text{ cm}^3} \right| \left| \frac{1 \text{ g mol Bz}}{78.11 \text{ g Bz}} \right| = 0.281 \frac{\text{g mol}}{\text{min}}$$

$$V = \frac{0.0281 \text{ g mol}}{\text{min}} \left| \frac{0.0206 \text{ (L)(atm)}}{(\text{g mol})(\text{K})} \right| \left| \frac{293K}{(740/760) \text{ atm}} \right| = 0.694 \frac{\text{L}}{\text{min}}$$

To dilute to 1.0 ppm, multiply by 10^6 or use $6.94 \times 10^5 \text{ L/min}$ ($695 \text{ m}^3/\text{min}$ or $24,500 \text{ ft}^3/\text{min}$).

Solutions Chapter 7

7.1.31

Basis: 1 m³ gas passing at 10°F and 1 atm. vs 60°F and 1 atm.

(assume p₁ = p₂), T₁ = 520°R; T₂ = 470°R

$$\frac{1 \text{ m}^3}{\left| \frac{520^\circ\text{R}}{470^\circ\text{R}} \right|} = 1.106 \text{ m}^3$$

Since the moles, and mass, are directly proportional to volume at constant pressure, % increase = 10.6%

7.1.32

Basis: CO₂ in cylinder

Volume of cylinder

$$\pi r^2 h = \pi \left(\frac{0.75}{4} \right)^2 (4.33) = 1.91 \text{ ft}^3$$

Assume 100% CO₂ in cylinder at 0°C

$$\frac{1.91 \text{ ft}^3}{\left| \frac{82.6 \text{ psia}}{14.7 \text{ psia}} \right| \left| \frac{530^\circ\text{R}}{492^\circ\text{R}} \right|} = 11.55 \text{ ft}^3 \text{ at } 14.7 \text{ psia, } 70^\circ\text{F}$$

If the machine has a 4 gal capacity

$$\frac{4 \text{ gal}}{\left| \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \right|} = 0.535 \text{ ft}^3 \text{ at } 14.7 \text{ psia and } 70^\circ\text{F}$$

You have more than enough CO₂ to fill the machine, if it operates under atmospheric pressure.

Solutions Chapter 7

7.1.33

Basis: 100 kg mol gas.

		<u>Mol</u>	<u>MW</u>	<u>kg</u>	<u>wt%</u>
a)	CH ₄	87	16	1392	77.5
	C ₂ H ₆	12	30	360	20.0
	C ₃ H ₈	1	44	44	2.5
Total		100		1796	100.0

b) composition in vol. percent = mol percent

$$\text{CH}_4 \quad 87\%$$

$$\text{C}_2\text{H}_6 \quad 12\%$$

$$\text{C}_3\text{H}_8 \quad 1\%$$

c) MW of gas = $\frac{1796 \text{ kg}}{100 \text{ kg mol}} = 17.96 \frac{\text{kg}}{\text{kg mol}}$

$$R = 8.314 \text{ (kPa)(m}^3\text{)/(kg mol)(K)} \quad T = 9^\circ\text{C} = 282.15\text{K}$$

$$\text{no. of moles of gas} = \frac{80 \text{ kg}}{17.96 \cancel{\text{ kg}}/\cancel{\text{ kg mol}}} = 4.45 \text{ kg mol}$$

$$V = \frac{nRT}{P} = \frac{4.45 \text{ kg mol}}{P} \left| \frac{8.314(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| \frac{282.15 \text{ K}}{600 \text{ kPa}}$$

$$= \boxed{17.4 \text{ m}^3}$$

d) density = $\frac{17.96 \text{ kg}}{1 \text{ kg mol}} \left| \frac{1 \text{ kg mol}}{22.415 \text{ m}^3 \text{ at SC}} \right| = 0.801 \text{ kg/m}^3$

e) Specific gravity = $\frac{\text{density of gas at } 9^\circ\text{C and } 600\text{kPa}}{\text{density of gas at SC}}$

$$\frac{600}{8.314} \left| \frac{1}{282} \right|$$

$$\frac{101.3}{8.314} \left| \frac{1}{273} \right|$$

$$= \boxed{3.55 \frac{\text{kg/m}^3 \text{ gas at } 9^\circ\text{C, } 600 \text{ kPa}}{\text{kg/m}^3 \text{ gas at SC}}}$$

Solutions Chapter 7

7.1.34

Basis: 100 mol mixture

a.

<u>Comp</u>	<u>Mol</u>	<u>Mol. Wt.</u>	<u>lb</u>	<u>Wt %</u>
Air	99	29	2870	94.72
Br ₂	<u>1</u>	159.8	<u>160</u>	<u>5.28</u>
	100		3030	100.00

b. Avg. Mol. Wt. = $\frac{3030}{100} = \boxed{30.3 \frac{\text{lb}}{\text{lb mol}}}$

c. sp.gr. at SC = $\frac{30.30}{29} = \boxed{1.045}$

d. sp.gr. = $\frac{30.30}{159.8} = \boxed{0.1895}$

e. sp.gr. =
$$\frac{(30.3)}{(359)} \left| \begin{array}{c} (492) \\ (29) \end{array} \right| \frac{(114.7)}{492} = \boxed{7.54}$$

$$\left| \begin{array}{c} (560) \\ 520 \end{array} \right| \frac{(14.7)}{30} = \boxed{29.92}$$

Solutions Chapter 7

7.1.35

Basis: 1 lb mol of gas mixture

At 20°C

$$p_{CO_2} = p_T y_{CO_2} = 0.20(740) = 148 \text{ mm Hg}$$

$$p_{O_2} = p_T y_{O_2} = 0.60(740) = 444 \text{ mm Hg}$$

$$p_{N_2} = p_T y_{N_2} = 0.20(740) = 148 \text{ mm Hg}$$

At 40°C the pressure is

$$\frac{740 \text{ mm Hg}}{293 \text{ K}} \left| \frac{313 \text{ K}}{\right.} = 790.5 \text{ mm Hg}$$

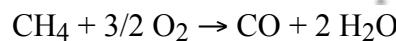
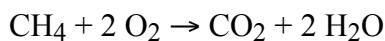
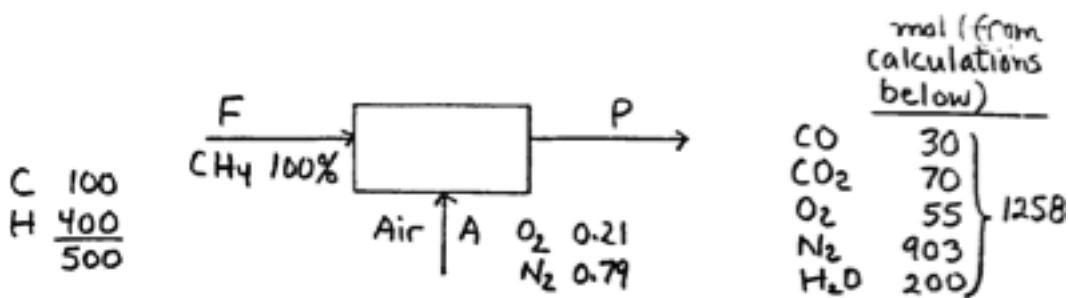
$$(p_T) y_{CO_2} = p_{CO_2} = (0.20)(790.5) = \boxed{158.1 \text{ mm Hg}}$$

$$(p_T) y_{O_2} = p_{O_2} = (0.60)(790.5) = \boxed{474.3 \text{ mm Hg}}$$

$$(p_T) y_{N_2} = p_{N_2} = (0.20)(790.5) = \boxed{158.1 \text{ mm Hg}}$$

7.1.36

Steps 1, 2, 3:



Step 4: Unknowns: P and all the compositions of P (5 unknowns)

Step 5: Balances: C, H, O, N + fact that 30% of C → CO

Solutions Chapter 7

Step 6: Basis: 100 mol F

Steps 7, 8:

$$\begin{aligned} \text{C balance: } 100 \text{ mol in CO} &= 30 \text{ mol} \\ \text{CO}_2 &= \underline{70} \text{ mol} \\ &\quad 100 \text{ mol} \end{aligned} \left. \begin{array}{l} \\ \\ \end{array} \right\} \text{out}$$

2N balance: Reqd. O₂: 200 mol

$$\text{XS O}_2: 0.20 (200) = \underline{40}$$

$$\text{Total O}_2 \text{ in} \quad 240 \text{ mol}$$

$$\text{total N}_2 \text{ in} = \frac{240 \text{ O}_2}{0.21 \text{ O}_2} \left| \frac{0.79 \text{ N}_2}{2} \right. = 903 \text{ mol} = n_{\text{N}_2} \text{ out}$$

$$2\text{H balance: mol H}_2\text{O out} = \text{mol H}_2 \text{ in} = \frac{400}{2} = 200 \text{ mol}$$

$$2\text{O balance: O}_2 \text{ in} - \text{O}_2 \text{ in CO, CO}_2, \text{H}_2\text{O} = \text{O}_2 \text{ out}$$

$$240 - \left(\frac{30}{2} + 70 + \frac{200}{2} \right) = 55 \text{ mol}$$

$$\text{alternate: XS O}_2 + \text{O}_2 \text{ not used for CO} = 40 + \frac{30}{2} = 55 \text{ mol}$$

$$p_{\text{CO}} = p_{\text{T}} y_{\text{CO}}$$

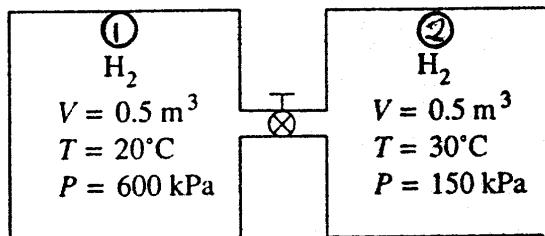
$$= (740) \left(\frac{30}{1258} \right)$$

$$= \boxed{17.7 \text{ mm Hg}}$$

Solutions Chapter 7

7.1.37

Steps 2, 3, 4:



Step 5: Basis: Gas listed in the figure

Steps 6 and 7:

Unknowns p (final), V (final); Equations: ideal gas laws

$$V_{\text{final}} = 1 \text{ m}^3$$

$$n_1 + n_2 = n_{\text{final}}$$

Steps 8 and 9:

$$n_1 = \frac{p_1 V_1}{RT_1} \quad n_2 = \frac{p_2 V_2}{RT_2} \quad n_f = \frac{p_f V_f}{RT_f}$$

$$\frac{(600 \text{ kPa})(0.5 \text{ m}^3)}{293 \text{ K}} + \frac{(150 \text{ kPa})(0.5 \text{ m}^3)}{303 \text{ K}} = \frac{p_f (\text{kPa})(1.0 \text{ m}^3)}{288 \text{ K}}$$

$$p_{\text{final}} = 366 \text{ kPa}$$

Solutions Chapter 7

7.1.38

Steps 2, 3, and 4: $p_1 = 55 + 14.7 = 69.7 \text{ psia}$

Step 5: Basis: Gas with given data

Steps 6 and 7: Unknowns: T_1, T_2, T_f, p_f ($V_f = 400 + 50 = 450 \text{ ft}^3$)

Equations:

$$p_1 V_1 = n_1 RT_1 \quad T_1 = T_2 = T_f$$

$$p_2 V_2 = n_2 RT_2$$

$$n_1 + n_2 = n_f$$

$$p_f V_f = n_f RT_f$$

$$n_1 = \frac{p_1 V_1}{RT} = \frac{400(69.7)}{RT}$$

$$n_2 = \frac{(50)(14.7)}{RT}$$

$$p_f V_f = \left(\frac{50(14.7) + 400(69.7)}{RT} \right) RT$$

$$p_f = \frac{50(14.7) + 400(69.7)}{450} = \frac{28635}{450} = \boxed{63.8 \text{ psia}} = \boxed{48.9 \text{ psig}}$$

7.1.39

Steps 2, 3, and 4:

$$100 \text{ psig} = 114.7 \text{ psia}$$

$$\text{MW} = \frac{28 \text{ lb}}{1 \text{ lb mole}}$$

$$60^\circ\text{F} = 520^\circ\text{R}$$

Step 5: Basis: $100 \text{ ft}^3 \text{ N}_2$ @ 100 psig and 60°F final moles

Final Moles:

Solutions Chapter 7

$$\frac{100 \text{ ft}^3}{14.7 \text{ psia}} \left| \frac{114.7 \text{ psia}}{14.7 \text{ psia}} \right| \left| \frac{492^\circ\text{R}}{520^\circ\text{R}} \right| \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| = 2.056 \text{ lb mol}$$

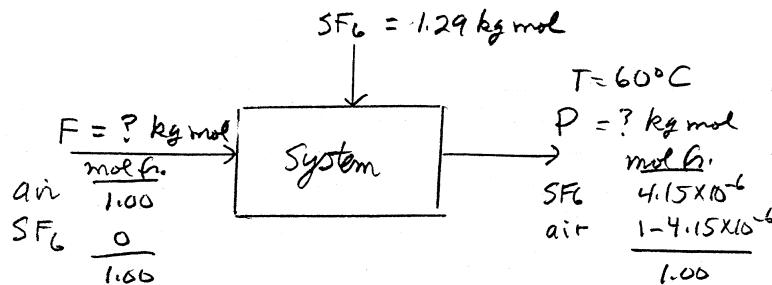
Initial moles: $2.056 + \frac{1}{28} = 2.092 \text{ lb mol}$

Initial pressure: $p = \frac{nRT}{V} = \frac{2.092 \text{ lb mol}}{100 \text{ ft}^3} \left| \frac{(80 + 460)^\circ\text{R}}{(lb \text{ mol})(^\circ\text{R})} \right| \left| \frac{0.7302(\text{ft}^3)(\text{atm})}{(lb \text{ mol})(^\circ\text{R})} \right| = [8.24 \text{ atm abs}] (121.2 \text{ psia})$
 (106.5 psig)

7.1.40

Step 5: Basis: 1 min

Steps 2, 3, and 4:



$$\frac{28.8 \text{ m}^3 \text{ at SC}}{22.4 \text{ m}^3 \text{ at SC}} \left| \frac{1 \text{ kg mol}}{1 \text{ kg mol}} \right| = 1.29 \text{ kg mol}$$

Step 6: Unknowns: P, F

Step 7: Indept. balances: air, SF6

Steps 8-9: Balances are in moles

$$\text{SF}_6: F(0) + 1.29 = P(4.15 \times 10^{-6}) \quad \text{hence } P = 3.098 \times 10^5 \text{ kg mol}$$

$$\frac{3.098 \times 10^5 \text{ kg mol}}{1 \text{ kg mol}} \left| \frac{22.4 \text{ m}^3 \text{ at SC}}{1 \text{ kg mol}} \right| \left| \frac{60 + 273}{273} \right| = [8.46 \times 10^6 \text{ m}^3/\text{min}]$$

Solutions Chapter 7

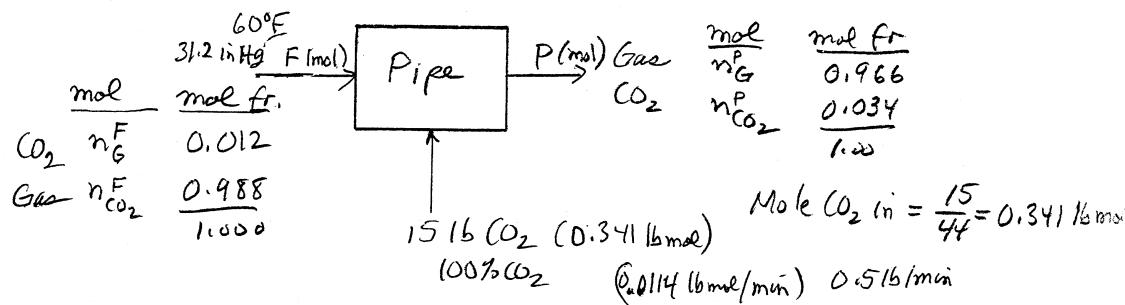
Alternate solution:

$$\frac{28.8 \text{ m}^3 \text{ at SC}}{\left| \frac{333\text{K}}{273\text{K}} \right| \frac{1}{4.15 \times 10^6}} = 8.46 \times 10^6$$

7.1.41

Step 5: Basis: 15 lb CO₂ added ≡ 30 min

Steps 2, 3, and 4:



Step 6: Unknowns: F, P

Step 7: Balances: Gas, CO₂

Steps 8 and 9: Balance overall on process in moles

$$\text{Gas: } 0.988 (\text{F}) = P(0.966)$$

$$\text{CO}_2: 0.012 (\text{F}) + 0.341 = P(0.034)$$

$$\text{Total: } \text{F} + 0.341 = \text{P}$$

$$F = 14.79 \text{ lb mol} \quad P = 15.13 \text{ lb mol}$$

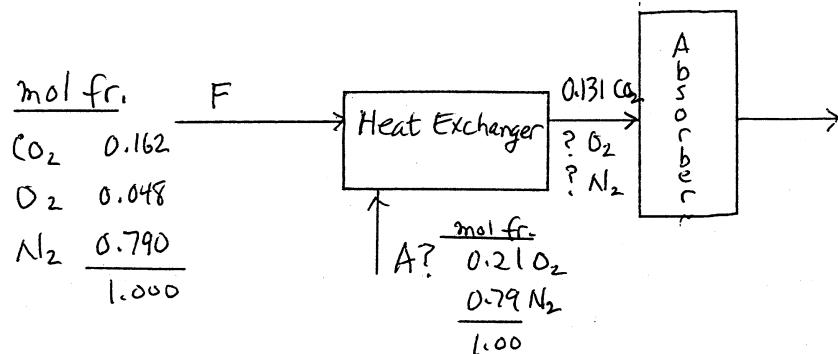
$$F = \frac{14.79 \text{ lb mol}}{30 \text{ min}} \left| \frac{31.2 \text{ in Hg}}{14.79 \text{ lb mol}} \right| \left| \frac{21.9(\text{in Hg})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})} \right| \left| \frac{(60 + 460)^\circ\text{R}}{14.79 \text{ lb mol}} \right| = \boxed{182 \text{ ft}^3/\text{min}}$$

at 60°F and 31.2 in Hg

Solutions Chapter 7

7.1.42

Steps 2, 3, and 4:



Step 5: Basis: 2 min

Steps 6, 7, 8 and 9:

$$\text{mol of gas out} = \frac{30,000 \text{ ft}^3}{760 \text{ mm Hg}} \left| \frac{720 \text{ mm Hg}}{520 \text{ R}} \right| \left| \frac{492 \text{ R}}{359 \text{ ft}^3} \right| = 75 \text{ mol}$$

$$\frac{60 \text{ mol gas}}{1 \text{ mol gas}} \left| \frac{0.162 \text{ mol CO}_2}{1 \text{ mol gas}} \right| = 9.7 \text{ mol CO}_2 \text{ in}$$

$$\frac{75 \text{ mol gas}}{1 \text{ mol gas}} \left| \frac{0.131 \text{ mol CO}_2}{1 \text{ mol gas}} \right| = 9.7 \text{ mol CO}_2 \text{ out}$$

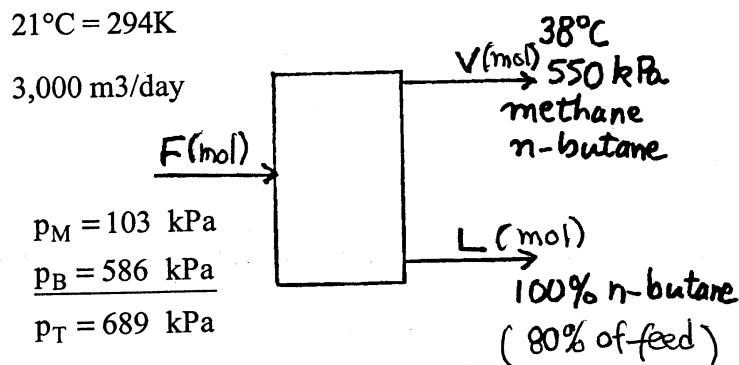
$$\text{mol of gas in} = \frac{47,800 \text{ ft}^3}{760 \text{ mm Hg}} \left| \frac{740 \text{ mm Hg}}{1060 \text{ R}} \right| \left| \frac{492 \text{ R}}{359 \text{ ft}^3} \right| = 60 \text{ mol}$$

Thus since there are more moles out than in, one may assume the system does contain a leak. Also, assuming a leak would bring no additional CO_2 into the system, the above CO_2 balance calculations indicate the given analysis is probably correct.

Solutions Chapter 7

7.1.43

Steps 2, 3 and 4:



Step 5: Basis: 1 day

Step 4:

mol in

$$pV = nRT$$

$$n = \frac{pV}{RT} = \frac{689 \text{ kPa}}{8.314 \text{ (kPa)}(m^3)} \left| \frac{3,000 \text{ m}^3}{294 \text{ K}} \right| \left(\frac{\text{kg mol})(\text{K})}{\text{m}^3} \right) = 845.635 \text{ kg mol/day}$$

$$y = \frac{p}{p_T} \quad y_B = \frac{586 \text{ kPa}}{689 \text{ kPa}} = 0.8505 \frac{\text{mol C}_4\text{H}_{10}}{\text{mol feed}}$$

Steps 6-9:

mol C₄H₁₀ out

$$L = \frac{845.635 \text{ kg mol F}}{\text{day}} \left| \frac{0.8505 \text{ mol C}_4\text{H}_{10}}{\text{mol feed}} \right| \left| \frac{0.8 \text{ mol C}_4\text{H}_{10}}{\text{mol C}_4\text{H}_{10} \text{ feed}} \right| =$$

$575.35 \frac{\text{mol C}_4\text{H}_{10}}{\text{day}}$

overall mol balance (no reaction)

$$F = L + V$$

Solutions Chapter 7

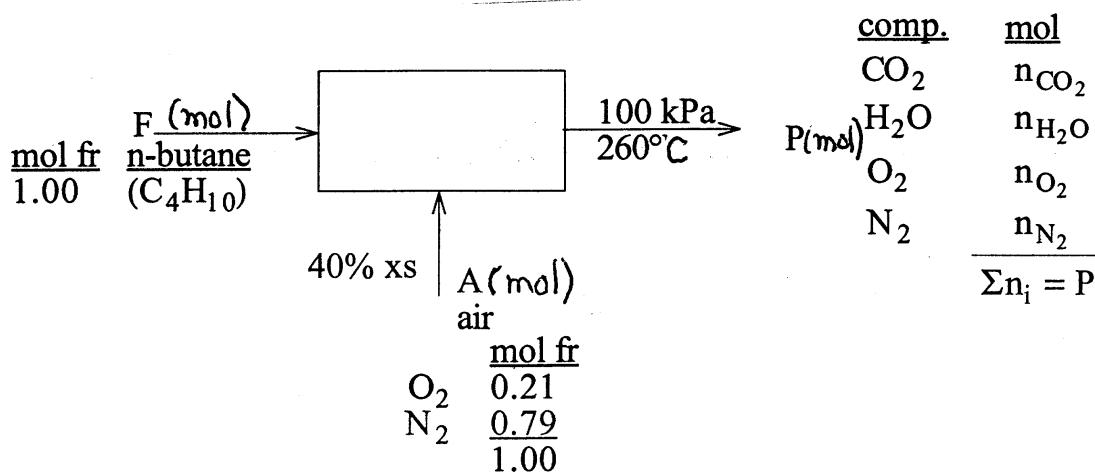
$$V = F - L = 845.635 - 575.35 = 270.26 \text{ kg mol}$$

$$pV = nRT$$

$$V = \frac{nRT}{p} = \frac{270.26 \text{ kg mol}}{p} \left| \frac{8.314 \text{ (kPa)} (m^3)}{(kg \text{ mol}) (K)} \right| \left| \frac{311 \text{ K}}{550 \text{ kPa}} \right| = 1,270.57 \text{ m}^3$$

7.1.44

Steps 1, 2, 3, 4: Steady state problem with a reaction.

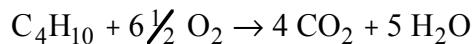


Step 5: Basis: 1 kg mol n-butane

Step 6: Unknowns are the moles in P (4) plus P.

Step 7: The element balances are C, H, O, N, and we can use $\Sigma n_i = P$ so we can get a unique solution. You can use element balances or compound balances. The former is easier.

Step 4: Calculate A given the 40.0% excess air.



$$\frac{1.00 \text{ kg mol } C_4H_{10}}{1 \text{ kg mol } C_4H_{10}} \left| \frac{6 \frac{1}{2} \text{ kg mol } O_2}{1 \text{ kg mol } C_4H_{10}} \right. = 6.5 \text{ kg mol } O_2$$

In

Solutions Chapter 7

$$6.5(0.40) = \frac{2.60 \text{ kg mol O}_2 \text{ xs}}{9.10 \text{ kg mol O}_2 \text{ total}}$$

$$9.10 (0.7\%_{0.21}) = 34.23 \text{ kg mol N}_2$$

Steps 7, 8, and 9:

Balances (kg mol)

	<u>In</u>	<u>Out</u>	
C:	1(4)	= n _{CO₂}	n _{CO₂} = 4
H:	1(10)	= n _{H₂O} (2)	n _{H₂O} = 5
O ₂ :	9.10	= n _{CO₂} + n _{O₂} + $\frac{n_{H_2O}}{2}$	n _{O₂} = 2.6
N ₂	34.23	= n _{N₂}	n _{N₂} = 34.23

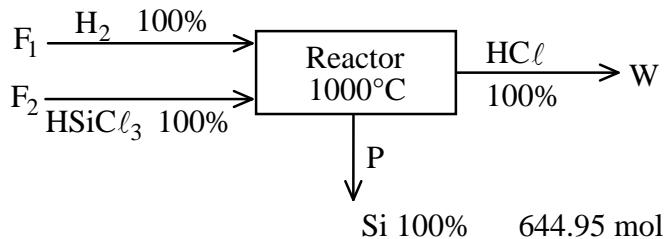
$$P = 4 + 5 + 2.6 + 34.23 = 45.83 \text{ kg mol}$$

$$V = \frac{nRT}{P} = \frac{45.83 \text{ kg mol}}{100.0 \text{ kPa}} \left| \frac{8.314(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| \frac{533.1 \text{ K}}{= [2.03 \times 10^3 \text{ m}^3]}$$

a.	flue gas analysis	<u>kg mol</u>	<u>mol%</u>
	CO ₂	4	9
	H ₂ O	5	11
	O ₂	2.6	6
	N ₂	<u>34.23</u>	<u>75</u>
	Total	45.83	100

Solutions Chapter 7

7.1.45



$$P = (D)(V) = D \left[\frac{\pi}{4} L (D_o^2 - D_l^2) \right] =$$

$$\frac{2.33 \text{ g}}{\text{cm}^3} \left| \frac{\pi}{4} \right| \left| 100 \text{ cm} \right| \left| \frac{(10 \text{ cm})^2 - (1 \text{ cm})^2}{28.086 \text{ g}} \right| = 644.95 \text{ g mol Si product}$$

Si balance

$$\frac{F_2 \text{ g mol HSiCl}_3}{1 \text{ g mol HSiCl}_3} \left| \frac{1 \text{ g mol Si}}{1 \text{ g mol HSiCl}_3} \right. = P \text{ g mol Si, hence } F_2 = P$$

H g mol balance

$$\frac{F_1 \text{ g mol H}_2}{1 \text{ g mol H}_2} \left| \frac{2 \text{ g mol H}}{1 \text{ g mol H}_2} \right. + \frac{F_2 \text{ g mol HSiCl}_3}{1 \text{ g mol HSiCl}_3} \left| \frac{1 \text{ g mol H}}{1 \text{ g mol HSiCl}_3} \right. = \frac{W \text{ g mol HCl}}{1 \text{ g mol HCl}} \left| \frac{1 \text{ g mol H}}{1 \text{ g mol HCl}} \right.$$

Cl mol balance

$$F_1(0) + \frac{F_2 \text{ g mol HSiCl}_3}{1 \text{ g mol HSiCl}_3} \left| \frac{3 \text{ g mol Cl}}{1 \text{ g mol HSiCl}_3} \right. = \frac{W \text{ g mol HCl}}{1 \text{ g mol HCl}} \left| \frac{1 \text{ g mol Cl}}{1 \text{ g mol HCl}} \right.$$

Solution:

$$F_2 = P = 1 \text{ g mol HSiCl}_3$$

$$3F_2 = W = 3 \text{ g mol HCl}$$

$$2F_1 + F_2 = W$$

$$F_1 = \frac{3 \text{ g mol} - 1 \text{ g mol}}{2} = 1 \text{ g mol H}_2$$

Solutions Chapter 7

$$\frac{1 \text{ g mol H}_2}{\text{g mol Si}} \left| \frac{644.95 \text{ g mol Si}}{\text{g mol Si}} \right. = 644.95 \text{ g mol H}_2$$

$$pV = nRT$$

$$V = \frac{nRT}{p}$$

$$= \frac{644.95 \text{ g mol}}{(\text{g mol})(\text{K})} \left| \frac{82.06 \text{ (cm}^3\text{)}(\text{atm})}{1 \text{ atm}} \right| \left| \frac{1273 \text{ K}}{1000 \text{ cm}^3} \right| \frac{1 \text{ L}}{1000 \text{ cm}^3}$$

$$= [67,373 \text{ L}]$$

7.1.46

Basis: 1 hr

a. $\frac{2.5 \times 10^{-7} \text{ g mol O}_2}{(10^3 \text{ cells})(\text{hr})} \left| \frac{2.9 \times 10^6 \text{ cells}}{\text{mL}} \right| \left| \frac{10^4 \text{ mL}}{10^3 \text{ mg mol}} \right| \left| \frac{10^3 \text{ mg mol}}{1 \text{ g mol}} \right| = \boxed{\frac{725 \text{ mg mol}}{\text{hr}}}$

b. $\frac{45 \text{ L gas}}{\text{h}} \left| \frac{0.40 \text{ L O}_2}{1 \text{ L gas}} \right| \left| \frac{110 \text{ kPa}}{10^3 \text{ L}} \right| \left| \frac{1 \text{ m}^3}{298 \text{ K}} \right| \left| \frac{(\text{kg mol})(\text{K})}{8.314(\text{kPa})(\text{m}^3)} \right|$

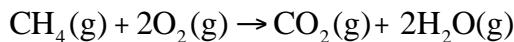
$$= 7.99 \times 10^{-4} \text{ kg mol/hr} \quad \text{or} \quad \boxed{799 \text{ mg mol/hr}}$$

c. Increase

7.1.47

Basis: 10^6 m^3 at SC of CH_4 burned completely

Ignore the oxidation of S, N, and C going to CO in the material balance to simplify the calculations. Including those products will have negligible effect on the N_2 and CO_2 produced.



Calculate the kg mol of CH_4 burned:

$$\frac{10^6 \text{ m}^3 \text{ at SC}}{22.415 \text{ m}^3} \left| \frac{\text{kg mol}}{\text{m}^3} \right. = 44,613 \text{ kg mol}$$

Solutions Chapter 7

Assume 10% excess air is used. Base the CO₂ on the emission factor value.

	<u>kg mol</u>			
	<u>(kg mol)</u>	<u>Emission factor</u>		
Required O ₂ entering: 44,613(2) =	89,226			
Excess O ₂ (0.1)(89,226)	8,923			
Total O ₂ :	98,149			
N ₂ entering: 98,149(79/21) =	369,227			
<u>Exit gas</u>				
CO ₂ produced:	44,613	43,812	0.086	
N ₂ exiting:	369,227	→	0.722	
H ₂ O exiting: (2)(44,613) =	89,226	→	0.174	
O ₂ exiting: (0.10)(89,226) =	8,923	→	0.017	
SO ₂ : (9.6)/64 =		0.15	2.9 × 10 ⁻⁷	
NO ₂ : { 3040/46 =		66	1.3 × 10 ⁻⁷	
{ 1600/46 =		35	6.8 × 10 ⁻⁵	
{ 1500/46 =		33	6.4 × 10 ⁻⁵	
CO { 1344/28 =		48	9.3 × 10 ⁻⁵	
{ 640/28 =		23	4.5 × 10 ⁻⁵	
Total (about)	511,200		1.00	

On a dry basis:

	<u>mol fr.</u>
SO ₂	3.5 × 10 ⁻⁷
NO ₂	1.6 × 10 ⁻⁴ , 8.2 × 10 ⁻⁵ , and 7.8 × 10 ⁻⁵ respectively
CO	1.1 × 10 ⁻⁴ and 5.5 × 10 ⁻⁵ , respectively

7.1.48

Basis: 10³ L of No. 6 fuel oil

$$\frac{10^3 \text{ L oil}}{1 \text{ cm}^3} \left| \frac{0.86 \text{ g}}{1 \text{ cm}^3} \right| \left| \frac{1000 \text{ cm}^3}{1 \text{ L}} \right| = 8.6 \times 10^5 \text{ g or } 8.6 \times 10^2 \text{ kg of oil}$$

To get the moles of pollution components alone in the gas produced, the kg have to be converted using MW (ignore the particulate matter)

	<u>kg</u>	<u>MW</u>	<u>g mol</u>	<u>m³ at SC on the basis of 10³/kg</u>
SO ₂	19 (0.84) = 15.96	64	249	6.5
SO ₃	0.69 (0.84) = 0.580	80	7.3	0.18
NO ₂	8	46	174	4.5

Solutions Chapter 7

CO	0.6	28	21	0.55
CO ₂	3025	44	6.875×10^4	1,790

Example of calculating the m³ at SC on the basis of 1 metric ton (10³ kg) of No. 6 fuel oil burned:

$$\text{SO}_2: \frac{0.249 \text{ kg mol}}{8.6 \times 10^2 \text{ kg oil}} \left| \frac{22.415 \text{ m}^3 \text{ at SC}}{1 \text{ kg mol}} \right| \left| \frac{10^3 \text{ kg oil}}{1 \text{ kg mol}} \right| = \boxed{6.5 \text{ m}^3 \text{ at SC}}$$

7.1.49

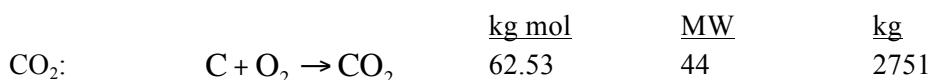
Basis: 10³ L of No. 6 fuel oil

$$\frac{10^3 \text{ L oil}}{1 \text{ cm}^3} \left| \frac{0.86 \text{ g}}{1 \text{ cm}^3} \right| \left| \frac{1000 \text{ cm}^3}{1 \text{ L}} \right| = 8.6 \times 10^5 \text{ g or } 8.6 \times 10^2 \text{ kg oil}$$

Calculate the kg mol of each compound in the oil:

	<u>Mass fraction</u>	<u>kg</u>	<u>MW</u>	<u>kg mol</u>
C	0.8726	750.4	12	62.53
H	0.1049	90.21	1.008	89.49
O	0.64×10^{-2}	5.5	16	0.34
N	0.28×10^{-2}	2.4	14	0.17
S	0.84×10^{-2}	7.2	32	0.23
ash	0.04×10^{-2}	0.3	-	-

Calculate the moles of product gas



S: The SO₂ and SO₃ are from the EPA data and Problem 13.55

	<u>kg</u>	<u>kg mol</u>
SO ₃ :	0.58	0.0073
SO ₂	15.96	0.249

If the S + O₂ → SO₂ is used as the product from the S in the oil, the value of 0.23 can be compared with 0.25 (ignoring the SO₃).

Solutions Chapter 7

7.1.50

The gas in the cell is composed partly of NO and partly of NO_2 . We can use the ideal gas law to calculate the total gram moles present in the cell.

Basis: 100 cm³ of gas at 170 kPa and 30°C

$$R = \frac{101.3 \text{ kPa}}{273 \text{ K}} \left| \frac{22.41 \text{ L}}{1 \text{ g mol}} \right| \frac{1000 \text{ cm}^3}{1 \text{ L}} = 8.316 \times 10^3 \frac{(\text{kPa})(\text{cm}^3)}{(\text{K})(\text{g mol})}$$

$$n = \frac{pV}{RT} = \frac{170 \text{ kPa}}{8.316 \times 10^3 \frac{(\text{kPa})(\text{cm}^3)}{(\text{K})(\text{g mol})}} \left| \frac{100 \text{ cm}^3}{303 \text{ K}} \right| = 0.00675 \text{ g mol}$$

If the mixture is composed of NO (MW = 30) and NO_2 (MW = 46), because we know the total mass in the cell we can compute the fraction of, say, NO. Let x = grams of NO; then $(0.291 - x)$ = g NO_2 . In a table format the calculation is

Component	g	Mol. Wt.	g mol
NO	x	30	$\frac{x}{30}$
NO_2	$0.291 - x$	46	$\frac{0.291 - x}{46}$
Total	0.291		0.00675

or

$$\frac{x}{30} + \frac{0.291 - x}{46} = 0.00675$$

$$0.0333x + (0.291 - x)(0.0217) = 0.00675$$

$$x = 0.0366 \text{ g}$$

The weight percent NO is

$$\frac{0.0366}{0.291} (100) = 12.5\%$$

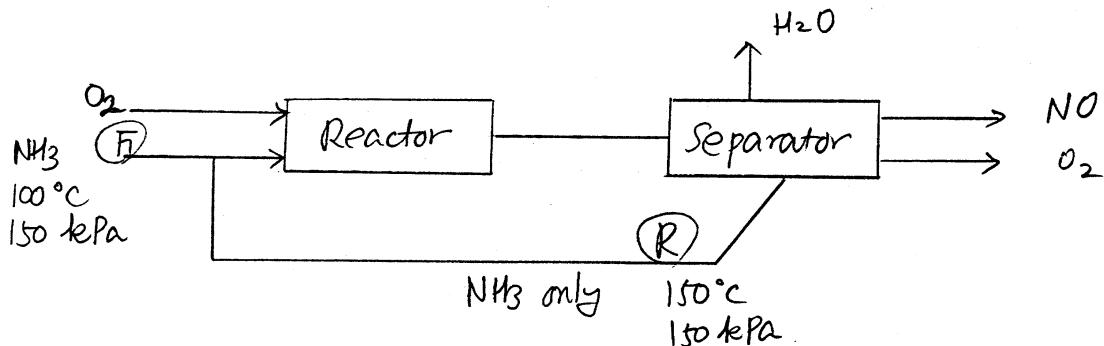
and the mole percent NO is

$$\frac{0.0366 \text{ g NO}}{0.00675 \text{ g mol total}} \left| \frac{1 \text{ g mol NO}}{30 \text{ g NO}} \right| (100) = 18\%$$

Can you let x be the mole fraction NO and obtain the same result? (Answer: Yes.)

Solutions Chapter 7

7.1.51



Basis: 1 mol of NH₃ fed

$$\text{NH}_3 \text{ balance: } (1 + R)(0.2) = R$$

$$0.8 R = 0.2$$

$$R = 0.25 \left(\frac{\text{mol NH}_3 \text{ recycled}}{\text{mol NH}_3 \text{ fed}} \right)$$

$$\frac{1 \text{ m}^3 (100^\circ\text{C}, 150 \text{ kPa}) \text{ NH}_3 \text{ fed}}{1 \text{ mol NH}_3 \text{ fed}} \left| \frac{0.25 \text{ mol recycled}}{(100 + 273)\text{K}} \right| \frac{(150 + 273)\text{K}}{(100 + 273)\text{K}}$$

$$= [0.284] \left(\frac{\text{m}^3 \text{ recycled at } 150^\circ\text{C, 150 kPa}}{\text{m}^3 \text{ NH}_3 \text{ fed at } 100^\circ\text{C, 150 kPa}} \right)$$

7.1.52

Process: Steady state with reaction and recycle

Step 5: Basis: 1 min 260L C₆H₆

Steps 2, 3, and 4: 950L H₂



Convert L → mol

Solutions Chapter 7

<u>feed</u>	$n = \frac{pV}{RT}$	$p = 150 \text{ kPa}$
-------------	---------------------	-----------------------

$$n_{H_2} = 45.96 \text{ g mol} \quad T = 100^\circ\text{C} + 273 = 373\text{K}$$

$$n_{C_6H_6} = 12.58 \text{ g mol} \quad R = 8.314 \frac{(kPa)(m^3)}{(kg\ mol)(K)}$$

Steps 6, 7, 8 and 9:

Select the overall system for the first balances.

	In	-	Out	+	generation	-	Consumption	= 0
H ₂ :	45.96	-	$n_{H_2}^\circ$	+	0	-	0.75(45.96)	= 0
C ₆ H ₆ :	12.58	-	$n_{C_6H_6}^\circ$	+	0	-	0.75(45.96) $\frac{1}{3}$	= 0
C ₆ H ₁₂ :	0	-	$n_{C_6H_{12}}^\circ$	+	0.75(45.96) $\frac{1}{3}$	-	0	= 0

$$\text{from 1: } n_{H_2}^\circ = 11.5 \text{ g mol}$$

$$\text{from 2: } n_{C_6H_6}^\circ = 1.09 \text{ g mol}$$

$$\text{from 3: } n_{C_6H_{12}}^\circ = 11.5 \text{ g mol}$$

b. Volumetric flow rates: $T = 200^\circ\text{C} = 473\text{K}$
 $P = 100 \text{ kPa} = 0.987 \text{ atm}$

$$V_{H_2} = \frac{(n_{H_2}^\circ)(RT)}{P} = 452 \text{ liters/min}$$

$$V_{C_6H_6} = 42.8 \text{ liters/min}$$

$$C_6H_{12} = 452 \text{ liters/min}$$

c. H₂ balance on Reactor + Separator

$$H_2: (45.95 + 0.90R) - (0.90R + 11.5) + 0 - 0.48(45.95 + 0.90R) = 0$$

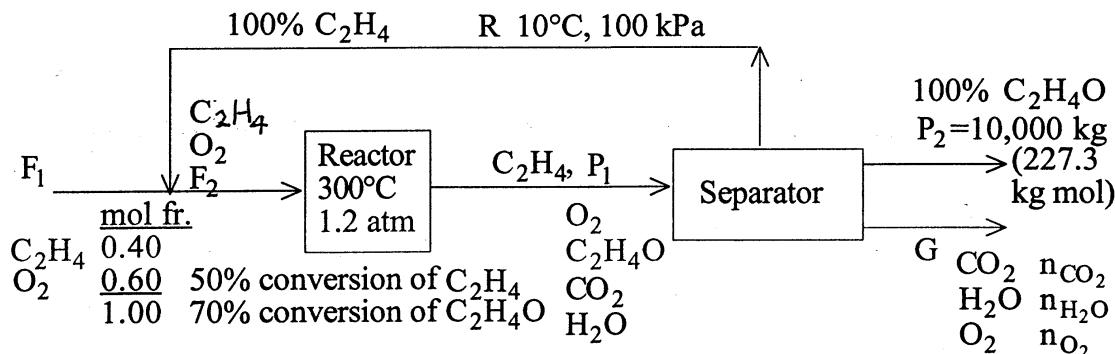
Substitute for $n_{H_2}^\circ$ and solve to get $R = 28.7 \text{ kg mol}$

Volumetric flow rate (R) = 890 liters/min

Solutions Chapter 7

7.1.53

Basis: 1 day = 10^4 kg C₂H₂O



If the overall system is chosen, the unknowns are F₁ and n_i, and three independent equations can be written from C, H, and O balances plus n_{CO₂} = n_{H₂O}.

Pick the system of the reactor plus separator, and use the data for the conversion.

Step 5: Basis

$$\frac{10,000 \text{ kg}}{\text{day}} \left| \frac{1.00 \text{ kg mol}}{44 \text{ kg}} \right. = 227.3 \text{ kg mol C}_2\text{H}_4\text{O/day}$$

Steps 6, 7, 8 and 9:

Mixing point: F₁ + R = F₂ $\Rightarrow 0.40F_1 + R = n_{C_2H_4}^{F_2}, 0.60F_1 = n_{O_2}^{F_2}$. Unknowns: F₁, F₂, R, n_{O₂}^F, n_{C₂H₄}^F

Reactor plus separator:

$$\text{C}_2\text{H}_4 \text{ balance: } \left[0.4 \left(\overset{\text{in}}{F_1} \right) + R \right] - \overset{\text{out}}{R} - \overset{\text{consumed}}{\overbrace{\left[0.4 \left(F_1 \right) + R \right] 0.5}} = 0$$

$$\text{C}_2\text{H}_4\text{O balance: } 0 - 227.3 + \overset{\text{generation}}{\overbrace{\left[F_1 (0.4) + R \right] (0.50)(0.70)}} = 0$$

$$F_1 = 811.79 \text{ kg mol/day}$$

$$R = 324.7 \text{ kg mol/day}$$

Solutions Chapter 7

$$F_1 + R = F_2 = 1136.49$$

$$(a) \frac{1136.5 \text{ kg mol}}{\text{day}} \left| \frac{22.40 \text{ m}^3 \text{ at SC}}{1 \text{ kg mol}} \right| \frac{1 \text{ day}}{24 \text{ hr}} = \boxed{1059 \text{ m}^3 \text{ at SC/hr}}$$

$$(b) \frac{324.71 \text{ kg mol of C}_2\text{H}_4 \text{ in } R}{(811.79)(0.40) \text{ kg mol of C}_2\text{H}_4 \text{ in } F_1} \left| \frac{22.40 \text{ m}^3 \text{ at SC}}{22.40 \text{ m}^3 \text{ at SC}} \right| \overbrace{\frac{283\text{K}}{273\text{K}}}^{\text{adjust recycle}} \frac{101.3 \text{ kPa}}{100 \text{ kPa}} = \boxed{1.05}$$

Overall balances (kg mol): unknowns n_1^{tr} (3) Balances (3)

$$\text{C: } \frac{F_1}{811.79 (0.40) (2)} = 227.3 (2) + n_{CO_2} \quad n_{CO_2} = 194.83$$

$$\text{H: } 811.79 (0.40) (4) = 227.3 (4) + n_W (2) \quad n_W = 194.83$$

$$\text{O: } 811.79 (0.60) (2) = 227.3 (1) + 194.83 (2)$$

$$+ 194.83 (1) + n_{O_2} (2) \quad n_{O_2} = 81.18$$

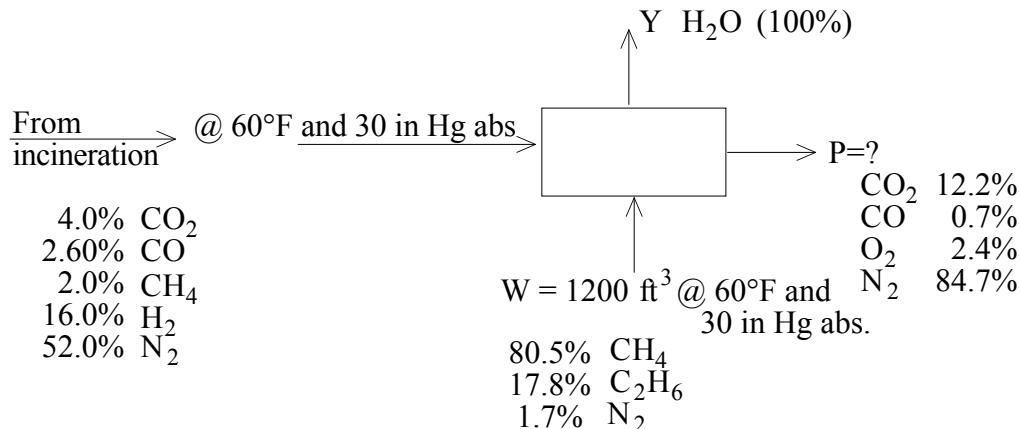
$$G = 194.83 + 194.83 + 81.18 = 470.84$$

$$\frac{470.84 \text{ kg mol P}_2}{\text{day}} \left| \frac{22.4 \text{ m}^3 \text{ at SC}}{\text{kg mol}} \right| \frac{353}{273} \frac{101.3}{100}$$

$$(c) = \boxed{1.38 \times 10^4 \text{ m}^3 \text{ gases/day at } 80^\circ\text{C and } 100 \text{ kPa}}$$

Solutions Chapter 7

7.1.54



Step 1, 2, 3, and 4: Steady state process with reaction.

Step 5: Basis: 1 min.

Step 6, 7, 8, 9:

Element balance: have C, H, O, N, and have 4 unknowns P, Y, F, A.

Basis: 1200 ft³ of W at 60°F and 20 in. Hg

$$\begin{array}{rcl}
 \text{Fin} & \text{Ain} & \text{Win} & \text{Yout} & \text{Pout} \\
 \text{C: } (0.04 + 0.26 + 0.02)F & + 0 & + (0.805 + 2 \times 0.178)W & - 0 - & (0.122 + 0.007)P = 0 \\
 \text{N}_2: (0.52)F & + 0.79A & + 0.017W & - 0 - & (0.847)P = 0 \\
 \text{H}_2: (0.04 + 0.16)F & + 0 & + (1.61 + 0.534)W & - Y - & 0 = 0 \\
 \text{O: } (0.08 + 0.26)F & + 0.42A & + 0 & - Y - & (0.244 + 0.007 + 0.048)P = 0
 \end{array}$$

Introduce W = 1200 ft³

$$\begin{array}{rcl}
 \text{C: } 0.32F + 0 + 1393.2 \text{ ft}^3 & - 0 - & 0.129P = 0 \\
 \text{N}_2: 0.52F + 0.79A + 20.4 \text{ ft}^3 & - 0 - & 0.847P = 0 \\
 \text{H}_2: 0.20F + 0 + 2572.8 \text{ ft}^3 & - Y - & 0 = 0 \\
 \text{O: } 0.34F + 0.42A + 0 & - Y - & 0.299P = 0
 \end{array}$$

Solve: $F = 3,975 \text{ ft}^3$

$$\begin{aligned}
 A &= 19,510 \text{ ft}^3 \\
 Y &= 3,370 \text{ ft}^3 \\
 P &= 20,660 \text{ ft}^3
 \end{aligned}$$

$$\text{Air in} = \frac{19,510 \text{ ft}^3 @ 60^\circ\text{F} \& 30 \text{ inches Hg}}{\left| \begin{matrix} 540^\circ\text{R} & 30 \text{ inches Hg} \\ 520^\circ\text{R} & 29.6 \text{ inches Hg} \end{matrix} \right|} = \boxed{20,535 \text{ ft}^3}$$

Solutions Chapter 7

7.1.55

Basis: 1 lb mol of 50% H₂ and 50% C₂H₄O

$$p_1 V_1 = n_1 R T_1 \quad p_2 V_2 = n_2 R T_2 \quad T_1 = T_2$$

$$\frac{p_1}{p_2} = \frac{n_1}{n_2} \quad \frac{760 \text{ mm Hg}}{700 \text{ mm Hg}} = \frac{1}{n_2} \text{ hence } n_2 = 0.922 \text{ lb mol}$$

Let y = mol of C₂H₆O formed

$$(0.5 - y) + (0.5 - y) + y = 0.922$$

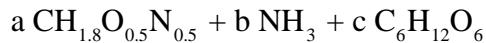
from which y = 0.079 lb mol C₂H₆O formed

$$\text{Degree of completion} = \frac{0.079}{0.50} \times 100 = \boxed{15.8\%}$$

7.1.56

C₆H₁₂O₆ is glucose and C₃H₈O₃ is glycerol

The reaction equation is



The amount of CO₂ measured (52.4L at 95 kPa and 300 K) is

$$\frac{52.4 \text{ L CO}_2}{1000 \text{ L}} \left| \frac{1 \text{ m}^3}{95 \text{ kPa}} \right| \left| \frac{300 \text{ K}}{8.314 \text{ (kPa)(m}^3\text{)}} \right| \frac{(\text{kg mol})(\text{K})}{\text{(kg mol)(K)(m}^3\text{)}} = 2 \times 10^{-3} \text{ kg mol or } 2.00 \text{ g mol}$$

Use element balances and specifications to get the coefficients in the reaction equation. Let c = 1 (divide both sides by c) be the basis for obtaining the coefficients: then there are 6 unknowns, 4 equations, and two specifications:

$$\text{C: } a + 6c = 3d + e$$

$$\text{H: } 1.8a + 3b + 12c = 8d + 2g$$

Solutions Chapter 7

$$O: \quad 0.5a + 6 = 3d + 2.00(2) + g$$

$$N: \quad 0.5a + b = 2b$$

Specifications:

$$\frac{f}{b} = 1 \quad \text{and} \quad \frac{e}{c} = 2$$

The solution of the equations is:

$$a = 7.27, \quad b = 3.64, \quad d = 1.09, \quad f = 3.64, \quad g = 1.64$$

The glycerol produced was 1.09 g mol, and

The biomass reacted was 7.27 g mol

7.2.1

- 1.a Immediate but approximate
- 2.e Exact but requires access to a handbook
- 3.b Good accuracy, needs calculation of z
- 4.c Good accuracy, more complicated calculation than b even in a program with a data base
- 5.e May require a long search to filter out a good value
For other answers, look at the answer to P15.1.

7.2.2

Will get the most accurate value, and be quick, assuming you have the handbook that contains the required data. For other answers, look at the answer to P15.1.

Solutions Chapter 7

7.2.3

Some valid answers are

- (1) continuous analytical functions, and these functions can be differentiated and integrated
- (2) higher accuracy (with complex equations)

7.2.4

$$z = 1 + \frac{B}{V} + \frac{C}{V^2} + \frac{D}{V^3}$$

The results for $\frac{p\hat{V}}{RT} = z$ are shown in the Excel table below. You can decide how much accuracy is needed.

p(atm)	4 terms	2 terms	1 term	% difference	
				2 from 4	1 from 4
0	1.00	1.00	1.00	0	0
10	0.95	0.95	1.00	0	-4.9
50	0.88	0.88	1.00	0	-13.3
100	0.77	0.76	1.00	-0.8	-29.8
200	0.80	0.79	1.00	1.6	-25.1
500	0.90	0.90	1.00	0	-10.7
1000	0.95	0.95	1.00	0	-3.6
5000	0.99	0.99	1.00	0	-1.1

7.2.5

$$a \Rightarrow (\text{atm}) \left(\frac{L}{g \text{ mol}} \right)^2$$

$$b \Rightarrow L/g \text{ mol}$$

$$\alpha \Rightarrow \text{dimensionless}$$

Solutions Chapter 7

7.2.6

Redlich-Kwong

$$p = \frac{RT}{(\hat{V} - b)} - \frac{a}{T^{1/2}\hat{V}(\hat{V} + b)}$$

$$a = 86,870 \text{ psia } (\text{°R})^{\frac{1}{2}} \left(\text{ft}^3/\text{lb mol} \right)^2$$

$$b = 0.3536 \text{ ft}^3/\text{lb mol}$$

$$n = \frac{63.9}{32} = 1.997 \text{ lb mol}$$

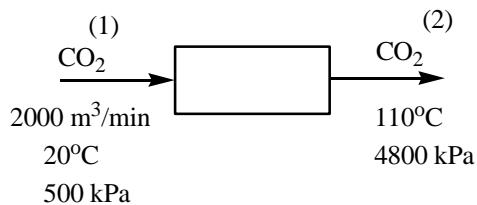
$$\hat{V} = \frac{V}{n} = \frac{6.7}{1.997} = 3.355 \text{ ft}^3/\text{lb mol}$$

Solving, $p = 1335 \text{ psia}$

Therefore, the reading on the pressure gauge is incorrect.

7.2.7

Basis: 1 min



Calculate the moles entering the compressor:

$$p_r = \frac{500}{101.3 \text{ atm}} \text{ atm} = 0.068 \quad T_r = \frac{(20 + 273)\text{K}}{304.2 \text{ K}} = 0.96$$

$$p_r = \frac{4800}{101.3 \text{ atm}} \text{ atm} = 0.650 \quad T_r = \frac{(110 + 273)\text{K}}{304.2 \text{ K}} = 1.26$$

$$a = 3.6 \times 10^6 \text{ atm} \left(\frac{\text{cm}^3}{\text{g mol}} \right)^2 = 364.68 \text{ kPa} \left(\frac{\text{m}^3}{\text{kg mol}} \right)^2$$

Solutions Chapter 7

$$b = 42.8 \frac{\text{cm}^3}{\text{g mol}} = 0.0428 \frac{\text{m}^3}{\text{kg mol}} , R = 8.314 \frac{(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}$$

Use Van der Waals' equation:

$$\left(p + \frac{n^2 a}{V^2} \right) (V - nb) = nRT$$

As the initial guess for the number of moles in State 1 use the ideal gas law

$$n_1 = \frac{p_1 V_1}{RT_1} = \frac{(500)(2000)}{(8.314)(293)} = 410.5 \text{ kg mol}$$

The number of moles at condition (1) is obtained from

$$\left(500 + \frac{n_1^2 (364.68)}{2000^2} \right) (2000 - 0.0428 n_1) = (8.314)(293)n_1$$

From Polymath (on the CD)

$$n_1 = \boxed{420 \text{ kg mol}}$$

Calculate the m³ exiting the compressor:

Insert into Vander Waals' equation new parameters:

$$p = 4800 \text{ kPa} \quad T = 383 \text{ K} \quad n = 420 \text{ kg mol}$$

Solve for V

$$V = \boxed{246 \text{ m}^3 \text{ at } 383\text{K} \text{ and } 4800 \text{ kPa}}$$

Solutions Chapter 7

7.2.8

Basis: 460 kg CO₂

a. RK Equation:

$$\frac{460 \text{ kg CO}_2}{44 \text{ kg}} \left| \frac{1 \text{ kg mol}}{\text{kg mol}} \right. = 10.455 \text{ kg mol CO}_2$$

T_c = 304.2 K, p_c = 7385 kPa

$$a = 6458 \text{ (kPa)} (m^6) (K^{0.5}) / (\text{kg mol})^2$$

$$b = 0.0297 \text{ m}^3/\text{kg mol}$$

$$R = 8.314 \frac{(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})}$$

$$\hat{V} = \frac{V}{n} = \frac{10.4 \text{ m}^3}{10.455 \text{ kg mol}} = 0.995 \frac{\text{m}^3}{\text{kg mol}}$$

$$p = \frac{(8.314)(290)}{0.995 - 0.0297} - \frac{6458}{0.995(0.995 + 0.0297)(290)^{1/2}}$$

$$= [2.126 \times 10^3 \text{ kPa}]$$

b. SRK Equation:

Data as above: T/T_c = 290/304.2 = 0.953

$$a' = \frac{0.42748(8.314)^2(304.2)^2}{7358} = 379.2 \text{ (kPa)} (m^6) / (\text{kg mol})^2$$

$$b = \frac{0.08664(8.314)(304.2)}{7358 \times 10^3} = 0.0297 \text{ m}^3/\text{kg mol}$$

$$p = \frac{(8.314)(290)}{0.995 - 0.0297} - \frac{(379.2)(1.040)}{0.995(0.995 + 0.0297)}$$

$$\kappa = 0.480 + (1.574)(0.225) - 0.176(0.225)^2 = 0.843$$

$$\lambda = [1 + 0.843(1 - 0.953^{\frac{1}{2}})]^2 = 1.040$$

$$p = 2.111 \times 10^3 \text{ kPa} \quad \text{No significant difference.}$$

Solutions Chapter 7

7.2.9

Basis: 100 ft³ of NH₃ at 20 atm and 400°F

Part I. Calculate the moles of NH₃:

Data:

$$T_c = 405.3 \text{ K} \rightarrow 729.5^\circ\text{R}$$

$$P_c = 111.3 \text{ atm} \rightarrow 1636 \text{ psia}$$

$$= 0.250 \quad 400^\circ\text{F} \rightarrow 860^\circ\text{R}$$

$$R = 10.73 \text{ (psia)} (\text{ft}^3) / (\text{lb mol}) (\text{°R}) \quad 20 \text{ atm} = 293.9 \text{ psia}$$

$$T_r = T/T_c = 860/729.5 = 1.179$$

$$p = \frac{RT}{\hat{V} - b} - \frac{a\alpha}{\hat{V}(\hat{V} + b) + b(\hat{V} - b)}$$

$$\alpha = [1 + \kappa(1 - T_r^{1/2})]^2 \quad 0.9890$$

$$\kappa = 0.37464 + 1.54226\omega - 0.26992\omega^2 = 0.1276$$

$$a = 0.45724 \left(\frac{R^2 T_c^2}{P_c} \right) = 17,124$$

$$b = 0.07780 \left(\frac{RT_c}{P_c} \right) = 0.3722$$

From Polymath:

$$\hat{V} = 29.9 \text{ ft}^3/\text{lb mol}$$

$$\frac{100}{29.9} = 3.34 \text{ lb mol NH}_3 \rightarrow 56.8 \text{ lb NH}_3$$

Solutions Chapter 7

Part II: Calculate the final pressure

$$\text{Final } \hat{V} = \frac{5 \text{ ft}^3}{3.34 \text{ lb mol}} = 1.497 \text{ ft}^3/\text{lb mol}$$

350°F 810°R

Introduce \hat{V} into the PR equation. From Polymath

$$p = \frac{(10.73)(810)}{1.497 - 0.3722} - \frac{17,124(0.984)}{1.497(1.497 + 0.3722) + 0.3722(1.497 - 0.3722)}$$

$$= \boxed{2462 \text{ psia}}$$

7.2.10

Basis: CO₂ at 81 psig and 25°C

Pressure in can (81.0 psig + 14.7 psia) (1 atm/14.7 psia) = 6.51 atm

Temperature 25°C ⇒ 298.15K T_c = 304.2 K

$$V = \pi(4.05 \text{ cm})^2(17.0 \text{ cm}) = 876 \text{ cm}^3 \quad p_c = 72.9 \text{ atm}$$

$$n = ? \text{ CO}_2 \quad \omega = 0.225$$



Using Peng-Robinson equation

$$n^3(ba\alpha - b^2RT - b^3p) - n^2(V)(a\alpha - 2bRT - 3b^2p) - n(V^2)(bp - RT) - V^3p = 0$$

Equations ⇒

$$f(n) = n^3q - n^2(z) - n(V^2)(bp - RT) - V^3p = 0$$

$$q = ba\alpha - b^2RT - b^3p$$

$$z = a\alpha - 2bRT - 2b^2p$$

$$a = 0.45724 \left(\frac{R^2 T_c^2}{p_c} \right) = 3.908 \cdot 10^6$$

Solutions Chapter 7

$$b = 0.07780(RT_c / p_c) = 26.64$$

$$T_r = 298.15/304.2 = 0.980$$

$$(T_r)^{1/2} = 0.990$$

$$\alpha = \left[1 + \kappa \left(1 - \frac{T}{T_c} \right)^{1/2} \right]^2 \quad 1.007$$

$$\kappa = 0.37464 + 1.54226\omega - 0.26992\omega^2 = 0.7080$$

$$R = 82.06 \text{ (cm}^3\text{)(atm)(g mol)(K)}$$

The ideal gas law gives 0.233 mol CO₂

$$T = 298.18 \text{ K}$$

$$p = 6.51 \text{ atm}$$

Introduce the values into the PR equation to get n = 0.2420 mol CO₂

$$\frac{0.2420 \text{ mol CO}_2}{1 \text{ mol CO}_2} \left| \frac{1 \text{ mol NaHCO}_3}{1 \text{ mol CO}_2} \right| \frac{84.00 \text{ g NaHCO}_3}{1 \text{ mol Na HCO}_3} = \boxed{20.3 \text{ g NaHCO}_3}$$

7.2.11 For propane: T_c = 369.9K, p_c = 42.0 atm, ω = 0.152

$$\kappa = 0.37464 + 1.5422(0.152) - 0.26992(0.152)^2 \quad 0.60283$$

$$\alpha = [1 + 0.60283(1 - 0.00686)]^2 \quad 0.992$$

Propane Coefficients

_____ a _____ b _____

RK	$180.5 \times 10^6 \text{ (atm)(K}^{1/2}\text{)}(\text{cm}^6)/(\text{g mol})^2$	$62.7 \text{ cm}^3/\text{g mol}$
PR	$10.04 \times 10^6 \text{ (atm)(cm}^6)/(\text{g mol})^2$	$56.3 \text{ cm}^3/\text{g mol}$

Computer results:

Redlich-Kwong: $\boxed{1193.14 \text{ cm}^3/\text{g mol}}$

Peng-Robinson: $\boxed{1168.91 \text{ cm}^3/\text{g mol}}$

Determine the volume at condition of state 2 (383 K, 4800 kPa)

$$\left(4800 + \frac{(419.9)^2(364.68)}{V_2^2} \right) (V_2 - (0.0428)(419.9)) \quad (419.9)(8.314)(383)$$

$$\boxed{V = 246 \text{ m}^3} \text{ at state 2}$$

Solutions Chapter 7

7.2.12

For CO₂, $\omega = 0.225$ and $T_c = 304\text{ K}$, $p_c = 72.9 \text{ atm or } 7385 \text{ kPa}$

$$R = 8.314 \text{ (kPa)} (\text{m}^3)/(\text{kg mol}) (\text{K})$$

$$a = 6458 \text{ (kPa)} (\text{m}^6) (\text{K}^{0.5})/(\text{kg mol})^2$$

$$b = 0.0297 \text{ m}^3/(\text{kg mol})$$

$$1200 = \frac{(8.314)(290)}{(\hat{V} - 2.97 \times 10^{-2})} - \frac{6458}{\hat{V}(\hat{V} + 2.97 \times 10^{-2})(290)^{1/2}}$$

$$\hat{V} = 1.876 \text{ m}^3/\text{kg mol from Polymath}$$

$$n_{\text{CO}_2} = \frac{V}{\hat{V}} = \frac{10.4}{1.876} = 5.54 \text{ kg mol}$$

$$n_{\text{CO}_2} = \frac{5.54 \text{ kg mol}}{1 \text{ kg mol}} \left| \frac{48 \text{ kg}}{1 \text{ kg mol}} \right| = \boxed{266 \text{ kg CO}_2}$$

7.2.13

$$p = \frac{nRT}{V - nb} - \frac{n^2 a}{V^2} \quad T = 492.0^\circ\text{R}$$

$$a = \left(p - \frac{nRT}{V - nb} \right) \left(-\frac{V^2}{n^2} \right) \quad R = 0.7302 \frac{(\text{ft}^3)(\text{atm})}{(\text{lb mol})(^\circ\text{R})}$$

Basis: 1.0 lb mol

$$200 \text{ atm} = \frac{1.0 \text{ lb mol} \left| 0.7302 \frac{(\text{ft}^3)(\text{atm})}{(\text{lb mol})(^\circ\text{R})} \right|_{492.0^\circ\text{R}}}{(1.806 \text{ ft}^3 - (1.0 \text{ lb mol})b)} - \frac{(1.0 \text{ lb mol})^2 a}{(1.86 \text{ ft}^3)^2}$$

$$200 = \frac{359.3(\text{ft}^3)(\text{atm})}{(1.860 \text{ ft}^3 - b)} - 0.2891 a$$

similarly

Solutions Chapter 7

$$1000 = \frac{359.3(\text{ft}^3)(\text{atm})}{(0.741 \text{ ft}^3 - b)} - 1.82a$$

$$a = \left(1000 - \frac{359.3}{0.741 - b} \right) \left(-\frac{1}{1.82} \right)$$

$$200 = \frac{359.3}{(1.860 - b)} - (0.289) \left(-\frac{1}{1.82} \right) \left(1000 - \frac{359.3}{0.741 - b} \right)$$

$$200 = \frac{359.3}{(1.860 - b)} + 158.8 - \frac{57.07}{(0.741 - b)}$$

$$41.20 = \frac{359.3}{(1.860 - b)} - \frac{57.07}{(0.741 - b)}$$

$$b = 0.4808 \frac{\text{ft}^3}{\text{lb mol}}$$

$$a = 209.3(\text{atm}) \left(\frac{\text{ft}^3}{\text{lb mol}} \right)^2$$

7.2.14

- a. Solution by compressibility factor method:

Basis: 80 lb water at 900°K

$$\hat{V} = \frac{10 \text{ ft}^3}{80 \text{ lb}} \left| \frac{18 \text{ lb}}{1 \text{ lb mol}} \right| \left| \frac{1 \text{ cm}^3/\text{g mol}}{0.016 \text{ ft}^3/\text{lb mol}} \right| = 140.8 \text{ cm}^3/\text{g mol}$$

$$T_c = 647.4 \text{ K}; \quad p_c = 218.3 \text{ atm from Appendix D1 (217.6 atm for the CD)}$$

$$V_{ci} = \frac{RT_c}{p_c} = \frac{82.06(\text{cm}^3)(\text{atm})}{(\text{°K})(\text{g mol})} \left| \frac{647.4 \text{ K}}{218.3 \text{ atm}} \right| = 243 \text{ cm}^3/\text{g mol}$$

$$V'_r = \frac{\hat{V}}{V_{ci}} = \frac{140.8}{243} = 0.579; \quad T_r = \frac{T}{T_c} = \frac{900}{647.4} = 1.39$$

From the compressibility charts, $p_r = 1.9$

Solutions Chapter 7

$$p = p_r p_c = (1.9)(218.3) = \boxed{415 \text{ atm}}$$

b. solution using the Redlich-Kwong equation of state:

$$p = \frac{RT}{(\hat{V}-b)} - \frac{a}{T^{1/2}\hat{V}(\hat{V}+b)} \text{ where } a = 0.4278 \frac{R^2 T_c^{2.5}}{p_c}$$

$$b = 0.0867 \frac{RT_c}{p_c}$$

$$a = \frac{0.4278 \left[\frac{82.06 \frac{(\text{cm}^3)(\text{atm})}{(\text{K})(\text{g mol})}}{218.3 \text{ atm}} \right]^2 (647.4 \text{ K})^{2.5}}{1.407 \times 10^8 \frac{(\text{cm}^3)^2 (\text{atm})(\text{K})^{1/2}}{(\text{g mol})}} = 1.407 \times 10^8 \frac{(\text{cm}^3)^2 (\text{atm})(\text{K})^{1/2}}{(\text{g mol})}$$

$$b = \frac{0.0867 \left| \frac{82.06(\text{cm}^3)(\text{atm})}{(\text{K})(\text{g mol})} \right| \frac{647.4 \text{ K}}{218.3 \text{ atm}}}{21.1 \frac{\text{cm}^3}{\text{g mol}}} = 21.1 \frac{\text{cm}^3}{\text{g mol}}$$

$$p = \frac{(82.06)(900)}{(140.8 - 21.1)} - \frac{1.407 \times 10^8}{(900)^{1/2}(140.8)(140.8 + 21.1)} = (617 - 206) \text{ atm}$$

$$= \boxed{411 \text{ atm}}$$

7.2.15

For ethane: $T_c = 516.3$ and $p_c = 63.0$ atm

a. Use Van der Waals' equation.

Basis: Ethane at 100°F and 2000 psig (MW = 30)

$$p = 2014.7 \text{ psia} \quad V = 1.0 \text{ ft}^3 \quad T = 560^\circ\text{R}$$

$$a = \left(5.50 \times 10^6 \text{ atm} \left(\frac{\text{cm}^3}{\text{g mol}} \right)^2 \right) \left(3.776 \times 10^{-3} \right) = 2.07 \times 10^4 \text{ psia} \left(\frac{\text{ft}^3}{\text{lb mol}} \right)^2$$

$$b = \left(65.1 \frac{\text{cm}^3}{\text{g mol}} \right) \left(1.60 \times 10^{-2} \right) = 1.04 \frac{\text{ft}^3}{\text{lb mol}}$$

$$\left(p + \frac{an^2}{V^2} \right) \left(\frac{V}{n} - b \right) = RT$$

$$n^3 \left(\frac{ba}{V^2} \right) - n^2 \left(\frac{a}{V} \right) + n(pb + RT) - pV = 0$$

Solutions Chapter 7

$$n^3 - 0.962n^2 + 0.376n - 0.0936 = 0$$

Iterate to find value of n.

Use Excel to solve this cubic equation to obtain a positive, real answer.

$$n = 0.594 \text{ lb mol} \text{ or } 17.8 \text{ lb ethane}$$

b. Use the compressibility factor method.

<u>p_c</u>	<u>T_c</u>	<u>p_r</u>	<u>T_r</u>	<u>z from the compressibility charts</u>
709 psia	549°R	2.84	1.02	0.43

$$\text{mass} = \frac{1(\text{ft})^3}{560^\circ\text{R}} \left| \frac{2014.7 \text{ psia}}{0.43} \right| \left| \frac{(\text{°R})(\text{lb mol})}{10.73(\text{psia})(\text{ft})^3} \right| \left| \frac{30 \text{ lb}}{\text{mol}} \right| = 23.4 \text{ lb ethane}$$

7.2.16

a. Van der Waals equation

$$a = \left(\frac{27}{64} \right) \frac{R^2 T_c}{p_c} \quad b = \left(\frac{1}{8} \right) \frac{RT_c}{p_c}$$

Methane $T_c = 190.7 \text{ K}$ $p_c = 45.8 \text{ atm}$

Propane $T_c = 369.9 \text{ K}$ $p_c = 42.0 \text{ atm}$

$$\text{Methane: } \frac{190.7}{45.8} = 4.16 \quad \text{Propane: } \frac{369.9}{42.0} = 8.81$$

Propane will be higher
for both coefficients

b. SRK equation:

$$a' = \frac{0.42748 R^2 T_c}{p_c} \quad b = \frac{0.08664 RT_c}{p_c}$$

Answer is same as for (a); propane
will be higher for both coefficients

Solutions Chapter 7

7.2.17

$$p_{\text{abs}} = p_g + \text{barometric pressure} \quad T = 273 - 50 = 223 \text{ K}$$

$$p_{\text{abs}} = 39 + 1 = 40 \text{ atm}$$

Basis: 1 g mol H₂

<u>H₂ Coefficients</u>	<u>a</u>	<u>b</u>
Van der Waals	$0.246 \times 10^6 \text{ (atm)(cm)}^6 / (\text{g mol})^2$	$26.6 \text{ (cm)}^3 / \text{g mol}$
Redlich-Kwong	$1.439 \times 10^6 \text{ (atm)(K}^{1/2}\text{)(cm)}^6 / (\text{g mol})^2$	$18.5 \text{ (cm)}^3 / \text{g mol}$

Computer results

$$\text{Van der Waals: } 471.78 \text{ cm}^3 / \text{g mol}$$

$$\text{Redlich-Kwong: } 471.26 \text{ cm}^3 / \text{g mol}$$

$$\frac{5L}{L} \left| \frac{1000 \text{ cm}^3}{471.78 \text{ cm}} \right| \frac{1 \text{ g mol}}{471.78 \text{ cm}} = [10.60 \text{ g mol (van der Waals)}]$$

$$5(1000)/471.26 = [10.61 \text{ g mol (Redlich - Kwong)}]$$

7.2.18

For CO₂, $\omega = 0.225$ and $T_c = 304.2 \text{ K}$, $p_c = 72.9 \text{ atm}$

$$a = 62.75 \times 10^6 \text{ (atm)(K}^{1/2}\text{)(cm)}^6 / (\text{g mol})^2$$

$$b = 29.9 \text{ cm}^3 / \text{g mol}$$

Computer results:

$$\text{Redlich-Kwong} = [1559.6 \text{ cm}^3 / \text{g mol}]$$

$$\text{The experimental molar volume} = \frac{6250 \text{ cm}^3}{4 \text{ g mol}} = [1562.5 \text{ cm}^3 / \text{g mol}]$$

Solutions Chapter 7

7.3.1

Basis: 7 lb N₂ or 7/28 = 0.25 lb mol N₂

a. $p = \frac{nRT}{V} = \frac{0.25 \text{ lb mol}}{0.75 \text{ ft}^3} \left| \frac{(120 + 460)^\circ R}{(lb \text{ mol})(^\circ R)} \right| \frac{0.732(\text{atm})(\text{ft}^3)}{(lb \text{ mol})(^\circ R)}$
 $= 141 \text{ atm}$

b. $T_c = 126.3 \text{ K}$ $p_c = 33.54 \text{ atm}$ $T_r = \frac{580}{(126.3)(1.8)} = 2.55$

$$V'_r = \frac{\hat{V}}{\frac{RT_c}{p_c}} = \frac{\frac{0.75 \text{ ft}^3}{0.25 \text{ lb mol}}}{\frac{(1.314) \frac{(\text{atm})(\text{ft}^3)}{(lb \text{ mol})(K)}}{33.54 \text{ atm}}} = 0.607$$

From the compressibility charts

$$p_r = 4.3 \quad \text{so that} \quad p = p_r p_c = (4.3)(33.54) = 144 \text{ atm}$$

Note: You calculate z from T_r and V'_r, and then use $p = \frac{znRT}{V}$

7.3.2

Basis: 2 g mol C₂H₄

$$p_c = 50.5 \text{ atm} \quad T_c = 283.1 \text{ K}; p = ? \quad T = 95 + 273.1 = 368.1 \text{ K}$$

$$\hat{V}_{C_2} = \frac{RT_c}{p_c} = \frac{82.06(\text{cm}^3)(\text{atm})}{(g \text{ mol})(K)} \left| \frac{283.1 \text{ K}}{50.5 \text{ atm}} \right| = 460 \text{ cm}^3/\text{g mol}$$

$$\hat{V} = \frac{418 \text{ cm}^3}{2} = 209 \text{ cm}^3/\text{g mol}$$

$$\frac{\hat{V}}{\hat{V}_{ci}} = \hat{V}_{ri} = 0.45 \quad T_r = \frac{368.1}{283.1} = 1.30$$

From chart, p_r = 2, hence p = 101 atm.

Use of the Pitzer ascentric factor would require a trial and error solution.

Solutions Chapter 7

7.3.3

Basis: 3 lb mol of gas at 252°C and 463 psia.

Volume = 50 ft³

$$R = \frac{(1 \text{ atm})(359 \text{ ft}^3)}{(1 \text{ lb mol})(273 \text{ K})} = 1.315 \frac{(\text{atm})(\text{ft}^3)}{(\text{lb mol})(\text{K})}$$

$$z = \frac{\left(\frac{463 \text{ psia}}{14.7 \frac{\text{psia}}{\text{atm}}} \right) (50 \text{ ft}^3)}{(3 \text{ lb mol}) \left(1.315 \frac{(\text{atm})(\text{ft}^3)}{(\text{lb mol})(\text{K})} \right) (273 + 252^\circ\text{C})} = 0.76$$

The Pitzer ascentric factor is not as convenient to use as the compressibility charts.

From compressibility charts (see the CD for better precision)

$$z = 0.76 \quad T_r = \frac{525}{500} = 1.05$$

$$p_r = 0.7$$

Thus

$$\frac{463 \text{ psia}}{p_c} = 0.7$$

$$p_c \cong \boxed{661 \text{ psia}} (45.0 \text{ atm})$$

Solutions Chapter 7

7.3.4

Basis: 1 lb n-octane

$$T_c = 1025^\circ R \quad p_c = 24.6 \text{ atm} \quad MW = 114$$

$$p_r = \frac{27}{24.6} = 1.10$$

To get the temperature of the gas

$$\frac{1 \text{ lb}}{114 \text{ lb}} \left| \frac{1 \text{ lb mol}}{114 \text{ lb}} \right| \left| \frac{359 \text{ ft}^3 \text{ SC}}{1 \text{ atm}} \right| \left| \frac{1 \text{ atm}}{27 \text{ atm}} \right| \left| \frac{T \text{ K}}{273 \text{ K}} \right| z = 0.20 \text{ ft}^3$$

$$T_z = 845 \quad zT_R = 845/1025 = 0.825$$

From the compressibility Chart Fig. 14.4b (expanded in the CD)

read $T_r = 1.16$, so that $T = (1.16)(1025) = [1189^\circ R]$ ($729^\circ F$)

Alternate solution: Calculate $z = 0.71$ and use $pV = znRT$.

7.3.5

Basis: 50 lb CO₂ ($50/44$) = 1.138 lb mol CO₂

$$V = 5.0 \text{ ft}^3 \quad p = 1600 + 14.7 = 1614.7 \text{ psia}$$

$$P_c = 1070 \text{ psia} \quad T_c = 547.5^\circ R$$

$$p_r = \frac{1614.7}{1070} = 1.51 \quad \hat{V} = \frac{5.0}{1.138} = 4.40 \text{ ft}^3/\text{lb mol}$$

$$V_{ci} = 5.50 \text{ ft}^3/\text{lb mol} \quad \text{so that} \quad V_{ri} = \frac{4.40}{5.50} = 0.800$$

T_r from Figure 14.4b is (expanded in the CD) is 1.44

$$T = (1.44)(547.5) = [788^\circ R] \quad (328^\circ F)$$

The Pitzer ascentric factor is less convenient to use for this problem.

Solutions Chapter 7

7.3.6

Basis: 10 kg CH₄

$$\text{MW CH}_4 = 16.03 \quad \frac{10 \text{ kg}}{16.03 \text{ kg}} \left| \frac{1 \text{ kg mol}}{\text{kg}} \right. = 0.624 \text{ kg mol}$$

T_c = 305.4 K and p_c = 4883 kPa

V = 0.0250 m³ p = 14,000 kPa gauge = 14,015 kPa absolute

$$p_r = \frac{14,015}{4883} = 2.87$$

$$\hat{V}_{ci} = \frac{RT_c}{p_c} = \frac{(8.314)(305.4)}{4883} = 0.520 \text{ m}^3/\text{kg mol}$$

$$V_r = \frac{0.0250}{0.520} = 0.048$$

From the compressibility chart, T_r ≈ 1.05 hence T = (1.05)(305.4) = 321 K

7.3.7

Basis: 1 ft³ CH₄

pV = nRTz p = 214.7 psia

$$R = \frac{10.73(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ\text{R})}$$

T_c = 191 °K → 344 °R p_c = 45.79 atm → 672.9 psia

$$T_r = 540/344 = 1.57 \quad p_r = \frac{214.3}{214.7} = 1.0$$

z = 0.975

$$n = \frac{(214.3)(1)}{(10.73)(540)(0.975)} = 0.038 \text{ lb mol}$$

weight (mass) = (0.038) (16.03) = 0.608 lb

By use of the Pitzer ascentric factor ($\omega = 0.008$ for CH₄)

$$z = z^0 + z^1 \omega = 0.976 + 0.024 (0.008) = 0.976$$

Solutions Chapter 7

7.3.8

Basis: 25L of CO₂ at 25°C and 200 kPa

For CO₂: p_c = 7385 kPa

$$T_c = 304.2 \text{ K}$$

$$p_r = \frac{p}{p_c} = \frac{200 \text{ kPa}}{7385 \text{ kPa}} = 0.0271$$

$$T_r = \frac{T}{T_c} = \frac{(25 + 273) \text{ K}}{304.2^\circ \text{ K}} = 0.98$$

From the compressibility chart, at these coordinates, z ≈ 0.99

$$pV = nzRT$$

$$n = \frac{200 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{1 \text{ atm}}{101.3 \text{ kPa}} \right| \left| \frac{25 \text{ L}}{0.08206(\text{L})(\text{atm})} \right| \left| \frac{(\text{g mol})(\text{K})}{298 \text{ K}} \right| \left| 0.99 \right|$$

$$= 2.04 \text{ g mol}$$

$$m = (2.04)(44) = 87.9 \text{ g} \quad \text{or} \quad \boxed{0.0879 \text{ kg}}$$

7.3.9

Basis: 106 ft³ at 60°F and 14.7 psia

$$p_r V_r = z_r n_r R_r T_r \quad \text{at the reservoir}$$

$$pV = znRT \quad \text{at SC}$$

$$T_r = \frac{T}{T_c} = \frac{120 + 460}{191(1.8)} = \frac{580}{344} = 1.69$$

$$p_r = \frac{p}{p_c} = \frac{1000}{(45.79)(14.7)} = \frac{1000}{674} = 1.48$$

$$z_r = 0.95$$

$$V_r = V \left(\frac{p}{p_r} \right) \left(\frac{T_r}{T} \right) \left(\frac{z_r}{z} \right) = 10^6 \left(\frac{14.7}{1000} \right) \left(\frac{120 + 460}{60 + 460} \right) \left(\frac{0.95}{1} \right) = \boxed{15,600 \text{ ft}^3}$$

Solutions Chapter 7

7.3.10

Basis: 1 kg propane

For propane: $T_c = 370 \text{ K}$ $p_c = 4255 \text{ kPa}$

$$\text{and } \bar{R} = 0.18855 \text{ (kPa)(m}^3\text{)/(kg)(K)}$$

$$\text{Reduced temperature} = T_r = \frac{T}{T_c} = \frac{230 + 273.2}{370} = 1.36$$

$$\text{Reduced pressure} = p_r = \frac{p}{p_c} = \frac{6000}{4255} = 1.408$$

From a generalized compressibility chart

at $p_r = 1.408$ and $T_r = 1.36$, $z \approx 0.80$

$$\text{Since } pV = znRT, \quad \hat{V} = \frac{zRT}{p}$$

$$\hat{V} = \frac{(0.80)(0.18855)(503.2)}{(6000)} = \boxed{0.0127 \text{ m}^3/\text{kg}}$$

7.3.11

- a) Yes g) No
- b) No h) No
- c) Yes
- d) No
- e) Yes
- f) No

Solutions Chapter 7

7.3.12

Basis: 1 g mol C₆H₅C1 (MW = 112.56)

$$p_c = 4518 \text{ kPa} \quad T_c = 632.4 \text{ K}$$

$$p_r = \frac{230}{4518} = 0.051 \quad T_r = \frac{380}{632.4} = 0.601$$

These values fall below the gaseous region in the compressibility chart here C₆H₅C1 is not a gas. It is a liquid (sp.gr = 1.107), so that the volume is $(1)(112.56)/1.107 = 102 \text{ cm}^3$

7.3.13

The answer is it depends on the gas temperature and the pressure. If $pV = znRT$ applies, the ideal gas law is represented by $z = 1$, and for a non-ideal gas, z can be greater or less than 1. The pressure is $p = \frac{znRT}{V}$. So $p_{\text{real}} = p_{\text{ideal}} z$, for fixed V and for a fixed number of moles and temperature (the volume of cylinder is fixed). The pressure prediction by the ideal gas law will be conservative (higher than the true pressure) for $z < 1$, and lower than the true pressure for $z > 1$.

7.3.14

Basis: Data on gases cited in problem.

a. The cubic feet associated with “165 ft³” and “240 ft³” probably means that the values are the respective volumes of an ideal gas at standard conditions, because the volumes calculated for the gases in part **b.** below are quite different than the stated values.

b. To find the amount of gas in the cylinder, first find the approximate volume in the cylinder.

$$V_{\text{cyl}} = \frac{\pi d^2 h}{4} = \frac{(3.14)(9)^2(52)}{(4)(1728)} = 1.914 \text{ ft}^3$$

Use the gas law as ratios:

$$\frac{p_2 V_2}{p_1 V_1} = \frac{z_2 R T_2}{z_1 R T_1}$$

Solutions Chapter 7

$$V_2 = V_1 \left(\frac{P_1}{P_2} \right) \left(\frac{Z_2 T_2}{Z_1 T_1} \right)$$

For C₂H₄:

$$T_c = 283 \text{ K}, P_c = 50.5 \text{ atm}$$

$$\text{Assume } T_1 = 80^\circ\text{F} = 540^\circ\text{R} = 300^\circ\text{K}$$

$$\left. \begin{aligned} T_r &= \frac{300}{283} = 1.06 \\ P_r &= \frac{1515}{(14.7)(50.5)} = 2.05 \end{aligned} \right\} Z_1 = 0.35$$

$$(\text{At standard conditions: } Z_2 = 1.00)$$

$$V_2 = (1.914) \left(\frac{1515}{14.7} \right) \left(\frac{1}{0.35} \right) \left(\frac{492}{540} \right) = 514 \text{ ft}^3$$

For CH₄:

$$T_c = 191 \text{ K}, P_c = 45.8 \text{ atm}$$

$$T_r = \frac{300}{191} = 1.57 \quad P_{r_2} = \frac{2015}{(14.7)(45.8)} = 2.98$$

$$Z_2 = 0.84$$

$$V_2 = (1.914) \left(\frac{2015}{14.7} \right) \left(\frac{1}{0.84} \right) \left(\frac{492}{540} \right) = 285 \text{ ft}^3$$

$$\text{MW of C}_2\text{H}_4 = 28 \qquad \qquad \text{MW of CH}_4 = 16$$

$$\text{wt of C}_2\text{H}_4 = \frac{(514)}{(359)} \left| \frac{28}{16} \right| = 40.1$$

$$\text{wt of CH}_4 = \frac{(285)}{(359)} \left| \frac{16}{28} \right| = 12.7$$

$$\text{Therefore } \text{wt}_{\text{C}_2\text{H}_4} > \text{wt}_{\text{CH}_4}$$

c. For C₂H₄:

$$pV = znRT = z \frac{m}{MW} RT$$

Solutions Chapter 7

$$m = \frac{pV(MW)}{zRT} = \frac{(1515)(1.91)(28)}{(0.35)(10.73)(590)}$$

$$= \boxed{40 \text{ lb C}_2\text{H}_4}$$

For CH₄:

$$m = \frac{(2015)(1.91)(16)}{(0.84)(10.73)(540)} = \boxed{12.7 \text{ lb CH}_4}$$

Check with cylinder:

$$163 - 90 = 123 \text{ lb cylinder} \quad 105 - 9.5 = 135 \text{ lb cylinder}$$

7.3.15

a) $p_1 V_1 = z_1 n_1 R T_1 \quad R = \text{constant}$

$$p_a V_1 = z_2 n_2 R T_1 \quad V_1 = \text{constant, the vol. of cylinder}$$

$$\frac{p_1}{p_2} = \frac{z_1 n_1}{z_2 n_2} \quad T_c = 133.0 \text{ K}$$

$$T_r = \frac{T}{T_c} = \frac{24.44 + 273}{133} = 2.24 \quad p_c = 34.5 \text{ atm}$$

$$p_{r_1} = \frac{2000 \text{ psig} + 14.7}{14.7 \text{ psig/atm}} \Big| \frac{1}{34.5 \text{ atm}} = 3.97$$

$$p_{r_2} = 3.80$$

$$\left. \begin{array}{l} z_1 = 1.0 \\ z_2 = 1.0 \end{array} \right\} \text{Ideal gas behavior}$$

$$\frac{p_1}{p_2} = \left(\frac{n_1}{n_2} \right) \left(\frac{1.0}{1.0} \right) = \frac{n_1}{n_2}$$

Solutions Chapter 7

$$n_{CO} = \frac{pV}{RT} = \frac{14.7 \text{ psia}}{536^\circ R} \left| \frac{175 \text{ ft}^3}{10.73 \frac{(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ \text{R})}} \right| = 0.447 \text{ lb mol}$$

$$V_{cylinder} = \frac{n_{CO} RT_1}{p_1}$$

$$V_c = \frac{0.447 \text{ lb mol}}{2014.7 \text{ psia}} \left| \frac{10.73 (\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ \text{R})} \right| \left| \frac{536^\circ \text{R}}{1.276 \text{ ft}^3} \right| = 1.276 \text{ ft}^3$$

$$n_{final, CO} = \frac{p_2 V_c}{RT} = \frac{1924.7 \text{ psia}}{10.73 \frac{(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ \text{R})}} \left| \frac{1.276 \text{ ft}^3}{536^\circ \text{R}} \right| = 0.427 \text{ lb mol}$$

$$n_{CO, lost} = (0.447 - 0.427) \text{ lb mol} \cong 0.020 \text{ lb mol}$$

$$\text{rate of loss} = \frac{0.020 \text{ lb mol}}{48 \text{ hr}} = \boxed{4.167 \times 10^{-4} \frac{\text{lb mol}}{\text{hr}}}$$

b)

$$n_{air} = \frac{pV}{RT} = \frac{14.7 \text{ psia}}{536.0^\circ R} \left| \frac{1600 \text{ ft}^3}{10.73 \frac{(\text{psia})(\text{ft}^3)}{(\text{lb mol})(^\circ \text{R})}} \right| = 4.09 \text{ lb mol air}$$

$$100 \text{ ppm} = 100 (10^{-6}) (4.09 \text{ lb mol}) = 4.09 \times 10^{-4} \text{ lb mol}$$

$$t = \frac{4.09 \times 10^{-4}}{4.167 \times 10^{-4} \frac{\text{lb mol}}{\text{hr}}} = 0.982 \text{ hr}$$

c)

$$t = 67 \text{ hr} \quad n_{CO} = \frac{4.167 \times 10^{-4}}{1600 \text{ ft}^3} \left| 67 \right| = 0.0279 \text{ lb mol}$$

$$C_{CO} = \frac{0.0279 \text{ lb mol}}{1600 \text{ ft}^3} = \boxed{1.75 \times 10^{-5} \frac{\text{lb mol}}{\text{ft}^3}}$$

- d) The CO alarms would go on to alert people in the building.

Solutions Chapter 7

7.3.16

- a) The density of the gas must be 2.0 g/m^3 . MW is Si is 28.086 so
 $\hat{V} = (2/28.086) = 0.0712 \text{ g mol/cm}^3$. Let T = 298K. Also z = 1 at $T_r = 1.98$ and V_{r_i} very large.

$$p = \frac{zRT}{\hat{V}} = \frac{1}{\left(\frac{\text{g mol}}{\text{m}^3}\right)} \left(\frac{8.314 \text{ Pa} \cdot \text{m}^3}{\text{mol} \cdot \text{K}} \right) \left(\frac{298 \text{ K}}{1 \text{ m}} \right)^3 = 2.48 \times 10^9 \text{ Pa}$$

- b) For a lower pressure, use a less dense gas (lower MW).
c) At too high a temperature, you cannot get adequate density.

7.3.17

Basis: 240 ft³ methane at 80°F and 1964.7 psia. Assume the number of moles does not change.

$$\frac{p_1 V_1}{p_2 V_2} = \frac{n R T_1 z_1}{n R T_2 z_2}$$

$$\frac{p_1}{p_2} = \frac{T_1 z_1}{T_2 z_2}$$

$$T_2 = \frac{T_1 z_1 p_2}{z_2 p_1}$$

Calculation of z_1

$$\text{Methane} \Rightarrow T_c = 190.7 \text{ K} \quad p_c = 45.8 \text{ atm}$$

$$T_1 = 80^\circ\text{F} \Rightarrow 299.82 \text{ K}$$

$$T_{r_1} = \frac{299.82 \text{ K}}{190.7 \text{ K}} = 1.572$$

$$p_{r_1} = \frac{133.7 \text{ atm}}{45.8 \text{ atm}} = 2.919$$

$$\therefore z_1 = 0.83$$

Solutions Chapter 7

Calculation of z_2

$$p_1 = (1950 \text{ psig} + 14.7 \text{ psia}) \left(\frac{1 \text{ atm}}{14.7 \text{ psia}} \right) = 133.7 \text{ atm}$$

$$p_2 = (3000 \text{ psig} + 14.7 \text{ psia}) \left(\frac{1 \text{ atm}}{14.7 \text{ psia}} \right) = 205.08 \text{ atm}$$

$$p_r = \frac{205.08 \text{ atm}}{45.8 \text{ atm}} = 4.478$$

$$V = 240 \text{ ft}^3 \left(2.832 \times 10^{-2} \text{ m}^3 / 1 \text{ ft}^3 \right) \left(100 \text{ cm}^3 / 1 \text{ m}^3 \right)$$

$$= 6.797 \times 10^6 \text{ cm}^3$$

$$\hat{V}_{c_i} = \frac{RT_c}{p_c} = \frac{82.06 \text{ (cm}^3\text{)(atm)/(g mol)(K)}(190.7\text{K})}{45.8 \text{ atm}}$$

$$= 341.68 \frac{\text{cm}^3}{\text{g mol}}$$

$$n = \frac{p_1 V_1}{z_1 R T_1} = \frac{(45.8 \text{ atm})(6.797 \times 10^6 \text{ cm}^3)}{(299.82\text{K})(82.06)(0.83)}$$

$$= 15244.5 \text{ g mol}$$

$$\therefore \hat{V} = \frac{V}{n} = \frac{6.797 \times 10^6 \text{ cm}^3}{15244.5 \text{ g mol}} = 445.87 \frac{\text{cm}^3}{\text{g mol}}$$

$$\therefore V_{r_i} = \frac{\hat{V}}{\hat{V}_{c_i}} = \frac{445.87}{341.68} = 1.305$$

$$\therefore z_2 = 1.06$$

$$T_2 = \frac{T_1 z_1 p_2}{z_2 p_1} = \frac{540^\circ R (0.83) (3014.7 \text{ psia})}{1.06 (1964.7 \text{ psia})}$$

$T_2 = 649^\circ R$

 $(189^\circ F)$

Solutions Chapter 7

7.4.1

Basis: 33.6 lb gas



$$T = 180^{\circ}\text{F} (640^{\circ}\text{R}) P = \\ 2400 + 14.7 = 2415 \text{ psia}$$

$$pV = znRT$$

Basis: 100 mol gas

	<u>mol</u>	<u>mol.wt.</u>	<u>lb</u>
--	------------	----------------	-----------

CO ₂	10	44	440
CH ₄	40	16	640
C ₂ H ₄	<u>50</u>	28	<u>1400</u>
	100		2560

$$n = \frac{33.6}{24.8} = 1.35 \text{ lb mol}$$

$$T_c' = 0.10 (304.2) + 0.40 (190.7) + 0.50 (283.1) = 248.25 \text{ K}$$

$$p_c' = 0.10 (72.9) + 0.40 (45.8) + 0.50 (50.5) = 50.86 \text{ atm}$$

$$p_r' = \frac{p}{p_c'} = \frac{2415}{(50.86)(14.7)} = 3.23$$

$$T_r' = \frac{T}{T_c'} = \frac{640}{(248.25)(1.8)} = 1.43$$

From Fig. in text, $z \approx .75$

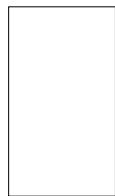
$$V = \frac{znRT}{p} = \frac{0.75 | 1.35 \text{ lb mol} | 10.73(\text{psia})(\text{ft}^3) | 640^{\circ}\text{R} |}{| (\text{lb mol})(^{\circ}\text{R}) | | 2415 \text{ psia} |}$$

= 2.88 ft³ at 180 °F, 2415 psia of gas is cylinder volume

Solutions Chapter 7

7.4.2

0.20 EtOH
 0.80 CO₂
 1.00



T = 500K
 V = 180 cm³/g mol

p = ?

Basis: gas as above

$$p_c' = (0.20)(63.0) + (0.80)(72.9) = 70.92 \text{ atm}$$

$$T_c' = (0.20)(516.3) + (0.80)(304.2) = 346.6 \text{ K}$$

$$p_r' = ? = \frac{p}{p_c} = \frac{p}{70.92}$$

$$T_r' = \frac{500}{346.6} = 1.44$$

$$V_{ci}' = \frac{RT_c'}{p_c} = \frac{(1 \text{ atm})(22.4 \text{ L})}{(273 \text{ K})(1 \text{ g mol})} \left| \frac{1000 \text{ cm}^3}{1 \text{ L}} \right| \left| \frac{346.6 \text{ K}}{70.92 \text{ atm}} \right| = 401 \text{ cm}^3/\text{g mol}$$

$$V_{ri}' = \frac{180}{401} = 0.45$$

From the compressibility chart, p_r ≈ 2.5, p ≈ 177 atm

Solutions Chapter 7

7.4.3

Basis: 540 kg gas @ 393 K, 3500 kPa absolute

<u>Component</u>	<u>kg</u>	<u>kg mol</u>	<u>mole fraction</u>	<u>p_c, atm</u>	<u>T_c, K</u>
CH ₄	100	6.25	0.321	45.8	191
C ₂ H ₆	240	8.00	0.412	48.2	305
C ₃ H ₈	150	3.41	0.175	42.1	370
N ₂	<u>50</u>	<u>1.79</u>	<u>0.092</u>	33.5	126
Total	540	19.45	1.000		

$$T_c' = (0.321)(191) + (0.412)(305) + (0.175)(370) + (0.092)(126) = 262.8 \text{ K}$$

$$p_c' = (0.321)(45.8) + (0.412)(48.2) + (0.175)(42.1) + (0.092)(33.5) = 44.96 \text{ atm}$$

$$T_r' = \frac{3.93}{262.8} = 1.50$$

$$p_r' = \frac{3500}{44.96} \left| \frac{1 \text{ atm}}{101.3} \right. = 0.77$$

From Nelson and Obert Chart, z' = 0.935

MW (average) = 540/19.45 = 27.8 kg/kg mol

$$\begin{aligned} \rho &= \frac{3500 \text{ kPa}}{393 \text{ K}} \left| \frac{\text{---}}{0.935} \right| \left| \frac{27.8 \text{ kg}}{\text{kg mol}} \right| \left| \frac{(\text{K})(\text{kg mol})}{8.31 (\text{kPa})(\text{m}^3)} \right| \\ &= \boxed{\frac{31.9 \text{ kg}}{\text{m}^3 \text{ at } 393\text{K and } 3500 \text{ kPa}}} \end{aligned}$$

Solutions Chapter 7

7.4.4

Use Kay's Method

$$p_c' = \sum n_i p_{c_i}; T_c' = \sum n_i T_{c_i}$$

<u>Component</u>	<u>n</u>	<u>p_c</u>	<u>np_c</u>	<u>T_c</u>	<u>nT_c</u>
C ₂ H ₄	0.57	50.5	28.8	283	61.2
A	0.40	48.0	19.2	150.7	60.2
He	0.03	10.26	<u>0.308</u>	13.19	<u>0.395</u>

$$\sum n_i p_{c_i} = 48.31 \quad \sum n_i T_{c_i} = 221.8$$

$$p_r' = \frac{120}{48.3} = 2.49 \quad T_r' = \frac{298}{221.8} = 1.342 \quad \therefore z = 0.70$$

$$V = \frac{(0.70)(82.05)(298)}{(120)} = [142.8 \text{ cm}^3/\text{g mol}]$$

$$\% \text{ diff} = \left(\frac{142.8 - 140}{140} \right) 100 = [2.00\%]$$

7.4.5

Basis: 30ft³ mixture of 100 atm and 300°F

<u>Comp</u>	<u>Mol. frac</u>	<u>T_c</u>	<u>p_c</u>	<u>T_c'</u>	<u>p_c'</u>
C ₂ H ₄	0.60	283	50.5	170	30.3
A	0.40	150.7	48	60.2	19.2
				230.2	49.5

$$T_r' = T/T_c' = \frac{760}{(230.2)(1.8)} = 1.835$$

$$p_r' = \frac{p}{p_c'} = \frac{100}{49.5} = 2.02$$

$$z = 0.95$$

Solutions Chapter 7

$$\text{Avg. Mol. wt.} = (0.60)(28) + (0.40)(40) = 32.8 \text{ lb/lb mol}$$

$$pV = znRT$$

$$n = \frac{pv}{zRT} = \frac{(100)(14.7)(300)}{(0.95)(10.71)(760)} = 57.0 \text{ lb mol}$$

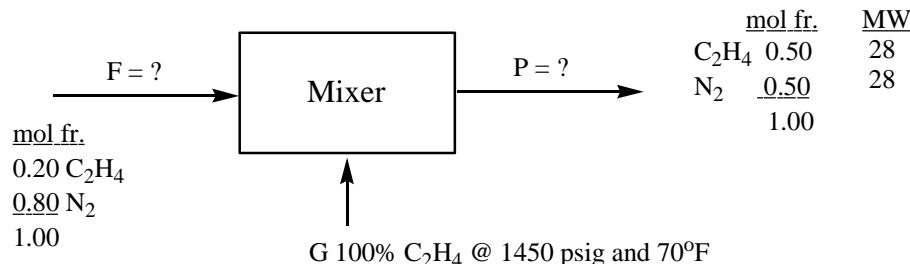
Assume capacities are given at storage conditions. Then type IA is selected because it is the cheapest.

$$\text{Number of tanks required} = \frac{(57.0)(32.8)}{62} = \boxed{30}$$

7.4.6

Steps 2, 3, and 4:

Assume a continuous process although a batch process would be acceptable and give the same results.



Step 5: Basis: G at given conditions

Steps 6 and 7:

Unknowns: F, P
 Balances: C₂H₄, N₂, (or total)

degrees of freedom = 0

Steps 8 and 9:

Calculate G:

$$T_r = \frac{70 + 460}{508.3} = 1.044$$

Solutions Chapter 7

$$p_r = \frac{1450 + 14.7}{735} = 1.992$$

$$z = 0.34$$

$$V = \frac{(359)(n)(14.7)(530)(0.34)}{(1465)(492)} = \frac{(2640)}{(1728)}$$

$$n = \frac{(2640)(1465)(492)}{(1728)(359)(14.7)(530)(0.34)} = 1.157 \text{ lb mol}$$

Balances:



$$F = 1.928 \text{ lb mol} \quad P = 3.085 \text{ lb mol}$$

7.4.7

Basis: Gas at 50 atm and 600°R

From the compressibility charts:

$$p_r = \frac{50}{14.3} = 3.5$$

$$T_r = \frac{600}{40.0 + 460} = 1.2$$

$$z = 0.58$$

$$Q = \frac{100,000 \text{ std ft}^3}{\text{hr}} \left| \frac{1 \text{ lb mol}}{359 \text{ std ft}^3} \right| \frac{359(0.58) \text{ act ft}^3}{1 \text{ lb mol}} \left| \left(\frac{1}{50} \right) \right| \frac{600}{492} = \boxed{1415 \text{ actual ft}^3/\text{hr}}$$

or use $pV = znRT$ twice

$$\frac{p_2 V_2}{p_1 V_1} = \frac{z_2 n_2 R T_2}{z_1 n_1 R T_1}$$

$$V_2 = V_1 \left(\frac{T_2}{T_1} \right) \left(\frac{p_1}{p_2} \right) \left(\frac{z_2}{z_1} \right)$$

Solutions Chapter 7

$$= 100,000 \left(\frac{600}{492} \right) \left(\frac{1}{50} \right) \left(\frac{0.58}{1.00} \right)$$

$$= 1415 \text{ actual ft}^3/\text{hr}$$

7.4.8

Basis: initial gas at 200 psig and final gas at 1000 psig

$$\text{MW C}_2\text{H}_4 = 28$$

$$p_{r_1} = \frac{214.7/14.7}{50.5}^{\text{initial}} = 0.290 \quad p_{r_2} = \frac{1015/14.7}{50.5}^{\text{final}} = 1.37$$

$$T_{r_1} = 1.05$$

$$T_{r_2} = 1.05$$

$$z_1 = 0.90$$

$$z_2 = 0.35$$

Use $pV = znRT$

$$\frac{n_2}{n_1} = \frac{p_2}{p_1} \left(\frac{z_2}{z_1} \right)^{-1} = \frac{1015}{215} \left(\frac{0.35}{0.90} \right)^{-1} = 12.14$$

Alternate way to get z is to use the Pitzer ascentric factor.

$$z = z^0 + z^1 \omega$$

$$z_1 = 0.910 + (-0.023)(0.085) = 0.91$$

$$z_2 = 0.37 + (0.1059)(0.085) = 0.38$$

Material balance

$$\begin{aligned} W_1 + W_c &= 222 \\ W_2 - W_1 &= 28 \text{ lb} \quad n_2 - n_1 = 28/28 = 1 \quad (\text{II}) \\ W_2 + W_c &= 250 \end{aligned}$$

Solve (I) and (II) to yield $n_1 = 0.089$

$$\text{and } n_2 = 1.089$$

Solutions Chapter 7

a. Mass of gas initially = $(0.089)(28) = 2.49 \text{ lb}$

$$(28 \text{ lb}) (\$0.41/\text{lb}) = \$11.48 \text{ billing}$$

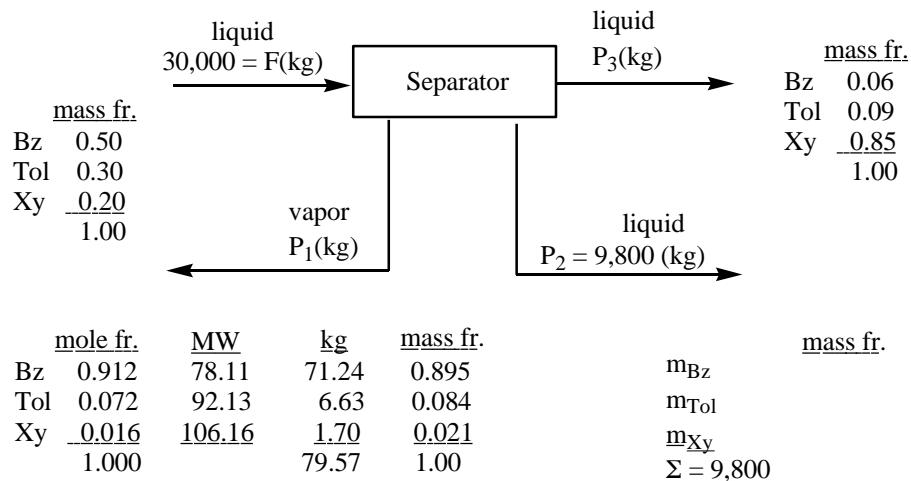
b. Wt. of cylinder = $(222 - 2.49) \text{ lb} = 219.5 \text{ lb}$

c. $V = \frac{n_1 z_1 RT}{p_1} = \frac{0.089}{0.9} \left| \frac{10.73}{214.7} \right| \frac{298(1.8)}{2.17 \text{ ft}^3}$

7.4.9

Step 5: Basis: 1 hr.

Steps 2, 3, and 4: Steady state, open system



Convert F to moles and then to mass:

$$\text{Basis: } 100 \text{ kg} = F$$

Component	kg	MW	kg mol	mol fr.	T _c (K)	p _c (atm)
Bz	50	78.11	0.640	0.592	562.6	48.6
Tol	30	92.13	0.324	0.299	593.9	40.3
Xy	20	106.16	0.118	0.109	619	34.6
	100		1.082	1.000		

Solutions Chapter 7

Calculate the kg of F; get z:

$$T'_c = 562.6 (0.592) + 593.9 (0.299) + 619 (0.109) = 578.1$$

$$p'_c = 48.6 (0.592) + 40.3 (0.299) + 34.6 (0.109) = 44.6$$

$$T_r = \frac{607\text{K}}{578.1\text{K}} = 1.05 \quad p_r = \frac{26.8 \text{ atm}}{44.6 \text{ atm}} = 0.60$$

$$z = 0.80$$

Together mass of feed:

$$n = \frac{pV}{zRT} = \frac{26.8 \text{ atm}}{0.80} \left| \frac{483 \text{ m}^3}{1 \text{ atm}} \right| \left| \frac{101.3 \text{ kPa}}{8.314(\text{kPa})(\text{m}^3)} \right| \left| \frac{(\text{kg mol})(\text{K})}{607 \text{ K}} \right|$$

$$= 324.7 \text{ kg mol}$$

$$F = (324.7)(100)/(1.082) = 30,017 \text{ kg, say } 30,000 \text{ kg}$$

The material balances are in kg.

Step 6: Unknowns: $P_1, P_3, m_{Bz}, m_{Tol}, m_{Xy}$

Step 7: Balances:

Bz

$$\frac{m_{Bz}}{m_{xy}} = \frac{3}{2} = 1.5$$

Xy

$$\sum m_i = 9,800$$

Step 8: The balances in kg are (only 3 are independent mass balances)

$$(1) \quad Bz \quad 30,000 (0.50) = P_1 (0.895) + m_{Bz} + P_3 (0.06)$$

$$(2) \quad Tol: \quad 30,000 (0.30) = P_1 (0.084) + m_{Tol} + P_3 (0.09)$$

$$(3) \quad Xy: \quad 30,000 (0.20) = P_1 (0.021) + m_{Xy} + P_3 (0.85)$$

$$(4) \quad Total \quad 30,000 = P_1 + 9,800 + P_3$$

Solutions Chapter 7

$$(5) \quad m_{Bz} + m_{Tol} + m_{Xy} = 9800$$

$$(6) \quad m_{Bz} = 1.5m_{Xy}$$

Step 9:

Solution: Using (1), (2), (3), (5), and (6) via Polymath

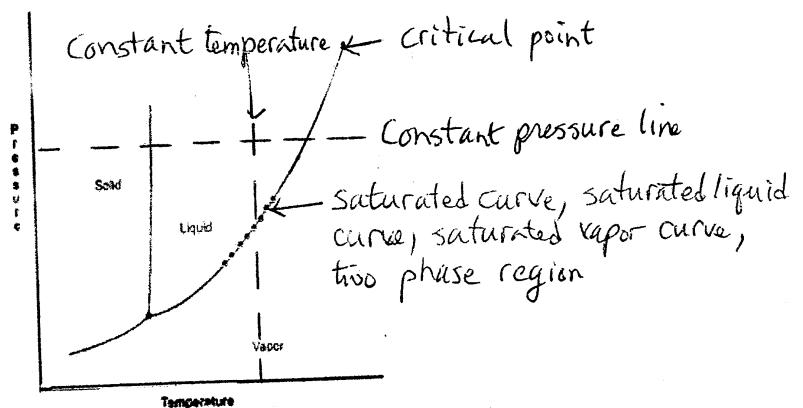
	<u>kg</u>	<u>mass fr.</u>
$P_3 = 5500 \text{ kg/hr}$	$m_{Bz} = 1518$	0.156
$P_1 = 14,700 \text{ kg/hr}$	$m_{tol} = 7270$	0.745
	$m_{Xy} = \underline{1012}$	<u>0.103</u>
	9800	1.00

Solutions Chapter 8

8.2.1

- a. (1); b. (2); c. (3); d. (4); e. (3); f. (1)

8.2.2



8.2.3

$$F = 2 - P + C = 2 - 2 + 2 = \boxed{2}$$

8.2.4

$$F = 2 - P + C$$

- (a) $F = 2 - 2 + 1 = \boxed{1}$
(b) $F = 2 - 3 + 2 = \boxed{1}$

8.2.5

$$\begin{aligned}C &= 1 \\P &= 2 \\F &= 2 - 2 + 1 = 1\end{aligned}$$

8.2.6

$$C = 3 \text{ (O}_2, \text{N}_2, \text{H}_2\text{O)}$$

$$P = 2$$

$$F = 2 - 2 + 3 = \boxed{3}$$

Solutions Chapter 8

8.2.7

The number of components is 3, but one independent reaction exists among them so that $C = 2$



$$P = 2$$

$$F = 2 - 2 + 2 = [2]$$

8.2.8

$$(1) F = 2 - P + C$$

The rank of	<u>CaCO₃(s)</u>	<u>CaO(s)</u>	<u>CO₂(g)</u>
Ca	1	1	0
C	1	0	1
O	3	1	2

$$\begin{bmatrix} 1 & 0 & 9 \\ 1 & 1 & 0 \\ 3 & 2 & 0 \end{bmatrix}$$
 is only 2 so $C = 2$

$$P = 3 \text{ hence } F = 2 - 3 + 2 = 1$$

8.2.9

- (a) 40°C; (b) 190°C; (c) 60°C; (d) Compound B

8.2.10

- (e)

Solutions Chapter 8

8.2.11

- a. $F = 2 - P + C$
 $C = 3$
 $P = 2$ (assume that p is not unreasonably high)

$$F = 2 - 2 + 3 = \boxed{3}$$

- b. Possible variables are: pressure
mol or mass fraction of
 H_2O
acetic acid
ethyl alcohol } only 2 are independent

8.2.12

(a) $F = 2 - P + C = 2 - P + 2$
if $F = 0$
 $P = 4 - F$
Max $\boxed{P = 4}$

(b) $F = 2 - P + C$
 $3 = 2 - 2 + C$ $\boxed{C = 3}$

8.3.1

All true

8.3.2

- (a) higher; (b) lower; (c) higher; (d) lower; (e) no change; (f) lower;
(g) higher; (h) lower; (i) higher; (j) lower; (k) lower; (l) higher

8.3.3

From the p-T diagram for water you can see that raising the pressure by a large amount on ice at constant temperature causes the water to go from the solid phase to the liquid phase.

Solutions Chapter 8

8.3.4

The vapor pressure of methanol is less than that of gasoline so that at lower temperatures the fuel-to-air mixture is insufficient for combustion.

Automotive parts can be made of alcohol tolerant materials such as stainless steel or other corrosion resistant materials and additives to the methanol, such as 15% gasoline, can help solve the problem of difficult cold-weather engine starts.

8.3.5

	Appendix G (T is in K)	CD (T is in °C)
(a) Acetone at 0°C	$\ln(p^*) = 16.6513 - \frac{2940.46}{T - 35.93}$ $p^* = 70.51 \text{ mm Hg}$	$\log_{10}(p^*) = 7.2316 - \frac{1277.03}{T + 237.23}$ $p^* = 70.55 \text{ mm Hg}$
(b) Benzene at 80°F	$\ln(p^*) = 15.9008 - \frac{2788.51}{T - 52.36}$ $p^* = 102.73 \text{ mm Hg}$	$\log_{10}(p^*) = 6.90565 - \frac{1211.033}{T + 220.79}$ $p^* = 102.74 \text{ mm Hg}$
(c) Carbon tetrachloride at 300 K	$\ln(p^*) = 15.8742 - \frac{2808.19}{T - 45.99}$ $p^* = 123.81$	$\log_{10}(p^*) = 6.8941 - \frac{1219.58}{T + 227.17}$ $p^* = 122.89 \text{ mm Hg}$

Solutions Chapter 8

8.3.6

Fit the Antoine Equation using the three data points to get A, B, and C. In mm Hg

kPa	mm Hg
2.53	18.98
15.0	112.54
58.9	441.90

$$\ln(18.98) = A - \frac{B}{C + (-40 - 273)} = 2.9434$$

$$\ln(112.54) = A - \frac{B}{C + (-10 - 273)} = 4.7233$$

$$\ln(441.90) = A - \frac{B}{C + (-20 - 273)} = 6.0911$$

The solution from Polymath is

$$A = 16.5386 \quad B = 2707.43 \quad C = -33.8541$$

$$\text{At } 40^\circ\text{C, } \ln(p^*) = 16.538 - \frac{2707.43}{-33.85 + (40 + 273)}$$

$$p^* = 939 \text{ mm Hg (125 kPa)}$$

8.3.7

At the triple point, all the phases (solid, liquid and vapor) exist in equilibrium. Therefore, the vapor pressure of liquid ammonia = the vapor pressure of solid ammonia

$$15.16 - 3063/T = 18.7 - 3754/T$$

$$T = 195 \text{ K}$$

8.3.8

No. It is a typo. Probably the number was 98.8°C because if you equate the pressures from the two equations, T = 371.75K, or 98.7°C.

Solutions Chapter 8

8.3.9

For benzene (p* is in mm Hg and T in K)

$$\ln(p^*) = 15.9008 - \frac{2788.51}{T - 52.36} \quad p^* = 760 \text{ mm Hg} \quad \ln(p^*) = 6.6331$$

T = 353K agrees with data base on CD

For toluene

$$\ln(p^*) = 16.0137 - \frac{3096.52}{T - 53.67} \quad p^* = 760 \text{ mm Hg}$$

T = 383.7 agrees with data base on CD

8.3.10

Merge the two equations (A1 MW = 27)

$$W = 10^{-4} = 5.83 \times 10^{-2} \frac{(p_v)(27)^{1/2}}{T^{1/2}} \quad \text{where } p_v = \frac{[10^{(8.79 - \frac{1.594 \times 10^4}{T})}]}{T^{1/2}}$$

The solution from Polymath is

$$T = 1492 \text{ K}$$

8.3.11

All of the values of specific volume are obtained using $\hat{V} = x_{\text{vapor}} \hat{V}_{\text{vapor}} + (1-x_{\text{vapor}}) \hat{V}_{\text{liquid}}$ with \hat{V} data from the steam tables.

(a) $\hat{V} = 0.5 (1.673) + 0.5 (0.001043) = 0.837 \text{ m}^3/\text{kg}$

(b) $\hat{V} = 0.5 (0.6058) + 0.5 (0.001073) = 0.303 \text{ m}^3/\text{kg}$

(c) $\hat{V} = 0.3 (350.8) + 0.7 (0.01613) = 105.25 \text{ ft}^3/\text{lb}$

(d) $\hat{V} = 0.7 (1.8431) + 0.3 (0.0187) = 1.296 \text{ ft}^3/\text{lb}$

Solutions Chapter 8

8.3.12

- (a) T; (b) F; (c) T; (d) T; (e) F; (f) T

8.3.13

Basis: 2.10 lb water

Specific volume: $\hat{V} = (1 - x) \hat{V}_l + x \hat{V}_g$

$$\text{Specific volume of water} = \hat{V}_l = \frac{0.35}{2} = 0.175 \text{ m}^3/\text{kg}$$

From the steam tables:

Specific volume of saturated liquid,

$$\hat{V}_l = 0.001\ 088 \text{ m}^3/\text{kg}$$

specific volume of saturated vapor =

$$\hat{V}_g = 0.414 \text{ m}^3/\text{kg}$$

$$\text{Then, } 0.175 = (1 - x) 0.001\ 088 + x (0.414)$$

$$\text{The quality} = \boxed{x = 0.42}$$

8.3.14

Since the two phases coexist in equilibrium, we have a saturated mixture, and the pressure must be the saturation pressure at the given temperature:

$$p = p^* @ 90^\circ\text{C} = \boxed{70.14 \text{ kPa}}$$

At 90°C, \hat{V}_l and \hat{V}_g values are $V_l = 0.001036 \text{ m}^3/\text{kg}$ and $\hat{V}_g = 2.361 \text{ m}^3/\text{kg}$

Add the volume occupied by each phase:

$$\begin{aligned} V &= V_l + V_g = m \hat{V}_l + m_g \hat{V}_g \\ &= (8 \text{ kg})(0.001 \text{ m}^3/\text{kg}) + (2 \text{ kg})(2.361 \text{ m}^3/\text{kg}) = \boxed{4.73 \text{ m}^3} \end{aligned}$$

Solutions Chapter 8

8.3.15

$$v = \frac{Q}{A} = \frac{m\hat{V}}{A}$$

where

v = velocity, ft/s

\hat{V} = specific volume of the fluid, ft^3/lb

A = pipe cross sectional area, ft^2

\hat{V} can be obtained from the steam tables: $\hat{V} = 0.9633 \text{ ft}^3/\text{lb}$

The area is $A = \pi d^2 / 4 = \frac{\pi}{4} \left(\frac{2.9}{12} \right)^2 = 0.046 \text{ ft}^2$

$$v = \frac{25,000 \text{ lb}}{\text{hr}} \left| \frac{0.9633 \text{ ft}^3}{\text{lb}} \right| \left| \frac{\text{ft}}{0.046 \text{ ft}^2} \right| = 5.24 \times 10^5 \frac{\text{ft}}{\text{hr}} \quad \text{or } \boxed{145 \text{ ft/s}}$$

8.3.16

The hot oil vaporized the water, and the increase in volume in the system caused the damage.

8.3.17

Use data from the steam tables at the initial condition of $p = 101.33 \text{ kPa}$ and saturated water (i.e. two phases):

$$\hat{V}_{\text{liq}} = 1.044 \text{ cm}^3/\text{g} \text{ and } \hat{V}_{\text{vap}} = 1673.0 \text{ cm}^3/\text{g}.$$

Then the mass of both phases in the container can be calculated:

$$m_{\text{liq}} = (0.03 \text{ m}^3) (100 \text{ cm/m})^3 / 1.044 \text{ cm}^3/\text{g} = 28,376 \text{ g}$$

$$m_{\text{vap}} = 2.97 \text{ m}^3 (100 \text{ cm/m})^3 / 1673.0 \text{ cm}^3/\text{g} = \underline{1,775 \text{ g}}$$

$$m_{\text{total}} = 30,511 \text{ g}$$

Solutions Chapter 8

At the final conditions all of the liquid has been evaporated, and only saturated vapor will exist having a specific volume of:

$$V_{\text{vap}} = (3.00 \text{ m}^3) (100 \text{ cm/m})^3 / 30,511 \text{ g} = 98.3 \text{ cm}^3/\text{g}$$

Interpolating in the steam tables

$$(212-T) \text{ } ^\circ\text{C} / (212-214) \text{ } ^\circ\text{C} = (99.09-98.3) \text{ cm}^3/\text{g} / (99.09-95.28) \text{ cm}^3/\text{g}$$

$$\boxed{T = 212^\circ\text{C}}$$

$$(1985.2-p) \text{ kPa} / (1985.2-2065.1) \text{ kPa} = (99.09-98.3) \text{ cm}^3/\text{g} / (99.09-95.28) \text{ cm}^3/\text{g}$$

$$\boxed{p = 2002 \text{ kPa}}$$

8.3.18

Basis: 10 lb of water

Specific volume: $\hat{V} = \frac{10.0}{2.01} = 4.975 \text{ ft}^3/\text{lb}$

From the paper steam tables (in ft^3/lb) at 80 psia:

$$\hat{V}_{\text{liq}} = 0.0176 \quad \hat{V}_{\text{vapor}} = 5.476$$

Mass balance:

$$m_L + m_V = 2.01$$

Volume balance:

$$10.0 = m_L(0.0176) + m_V(5.476)$$

Mass of liquid is 0.184 lb

Mass of vapor is 1.826 lb

The volume of liquid is

$$V_{\text{liq}} = m_{\text{liq}} \hat{V}_{\text{liq}} = (0.184)(0.0176) = \boxed{3.28 \times 10^{-3} \text{ ft}^3}$$

The volume of vapor is

Solutions Chapter 8

$$V_{\text{vapor}} = m_{\text{vap}} \hat{V}_{\text{vapor}} = (10.0 - 3.28 \times 10^{-3}) = \boxed{9.997 \text{ ft}^3}$$

Quality is $1.826 / 2.01 = \boxed{0.908}$

8.3.19

DATA:

<u>Log (T)</u>	<u>(log (T))²</u>	<u>(log (T))³</u>	<u>vp</u>
5.6101	31.4727	176.5329	0.61130
5.7038	32.5331	185.5619	3.53600
5.7991	33.6295	195.0204	17.21000
5.8861	34.6462	203.9313	62.15000
5.9402	35.2856	209.6027	128.80000
5.9915	35.8976	215.0795	245.60000
6.0403	36.4847	220.3767	437.00000
6.0868	37.0488	225.5079	733.20000
6.1527	37.8561	232.9186	1454.00000
6.2146	38.6214	240.0166	2637.00000

$$\ln p^* = a + b \ln T + c(\ln T)^2$$

$$+ d(\ln T)^3$$

THE COEFFICIENTS ARE

-1199.2548	a	-79.0261	c
532.2715	b	3.9638	d

8.3.20

Based on data from the steam tables:

State 1: liquid

State 3: solid

State 5: liquid (saturated)

State 2: superheated vapor

State 4: saturated vapor

State 6: vapor (saturated)

You can calculate the properties of a mixture of vapor and liquid in equilibrium (for a single component) from the individual properties of the saturated vapor and saturated liquid by averaging the properties of the two saturated phases. The weights are the respective amounts of each phase.

Solutions Chapter 8

8.3.21

Based on data from the steam tables:

State 1: saturated vapor

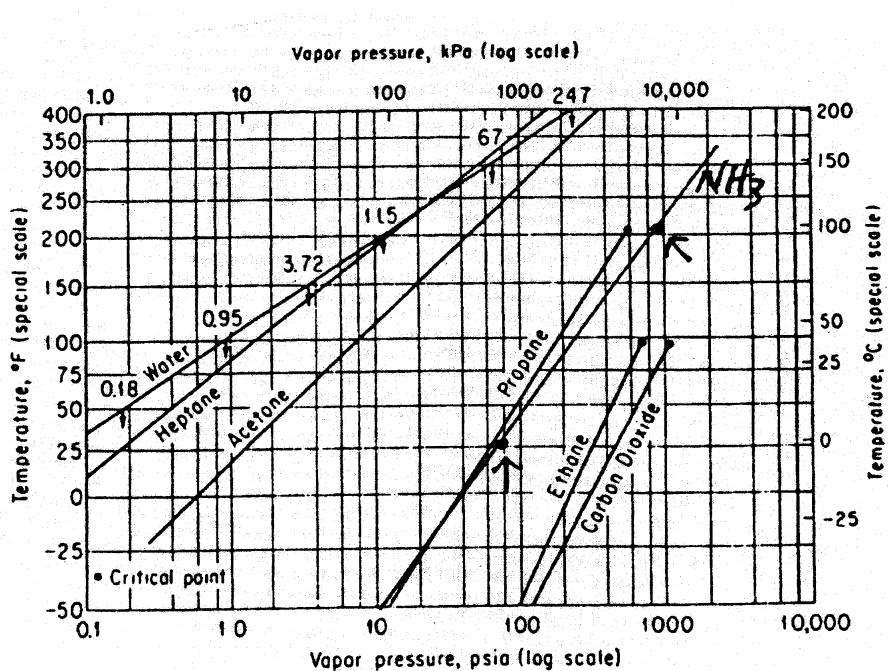
State 3: two phase (saturated liquid and vapor)

State 2: saturated liquid

State 4: superheated vapor

8.3.22

Prepare a Cox chart as described in the text. Use semi-log paper with the horizontal axis \log_{10} . Obtain vertical scale rules by use of steam properties at even integers for the temperature. Or you can use Antoine Equation, Appendix G, to get 2 points and draw a line between them.



$$T_{\text{critical}} (\text{°F})$$

$$p_{\text{cox chart}}^{\text{critical}} (\text{psia})$$

$$p^{\text{critical}} (\text{psia})$$

(a) Acetone	454	670	691
(b) Heptane	512	700	397
(c) Ammonia	270	1500	1636
(d) Ethane	89.7	750	708

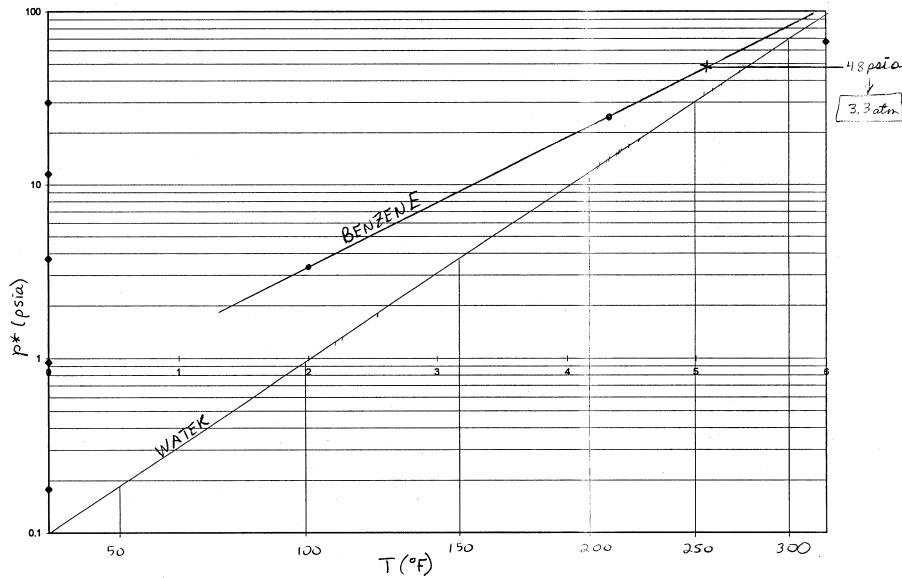
Solutions Chapter 8

8.3.23

Steps for preparing a Cox Chart (using water as the reference substance):

1. On logarithmic paper, set up the pressure scale on one axis. The other axis will be a nonlinear temperature scale, which will be set up by the following method.
2. Draw a diagonal line from the origin to the opposite corner of the graph.
3. From the steam tables, obtain values for the vapor pressure of water at evenly spaced temperature increments.
4. Plot these vapor pressures along the diagonal line.
5. Now, beginning with the first point on the diagonal, draw a line extending from that point to the temperature axis and label the intersection as the corresponding temperature for that vapor pressure.
6. Repeat step five for every point on the diagonal line. This process will establish the temperature scale.
7. Using the established temperature scale, plot the data for benzene and draw a line through the points.
8. From this line, obtain the vapor pressure for benzene at 125°F.

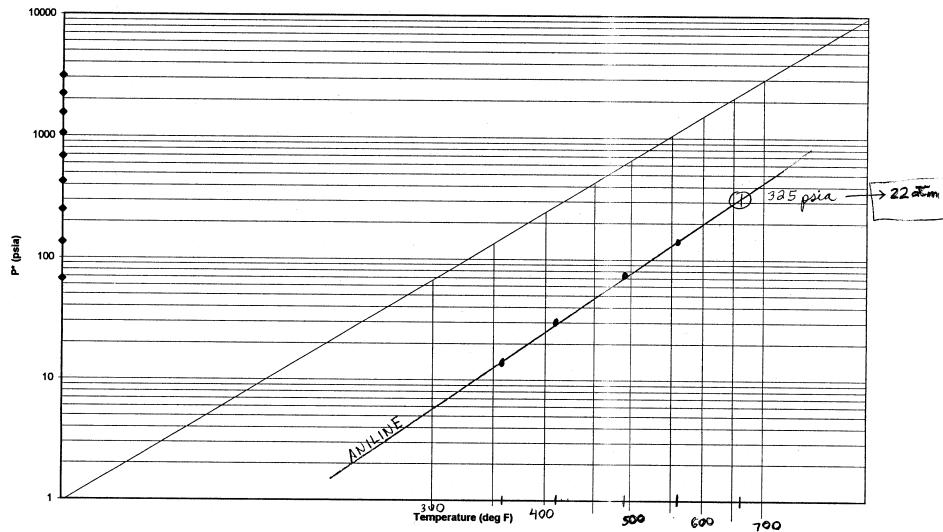
The vapor pressure for benzene at 125°C (257°F) is estimated to be 3.3 atm.



Solutions Chapter 8

8.3.24

The procedure is the same as outlined for P16.28. The result from the Cox chart is that the vapor pressure for aniline at 350° is 22 atm.



8.3.25

From the CD that accompanies the text the respective vapor pressures at 300K are in increasing value

	<u>p^* in mm Hg</u>	<u>PEL (ppm)</u>
Ethanol	65.8	1000
Methanol	139.7	200
MTBE	294	100

The relative values of p^* are about the same as the inverse of the relative values of the PEL.

8.4.1

(a) Volume increases

(b) Pressure increases

Solutions Chapter 8

8.4.2

Basis: Data given in problem statement

H ₂ O	dry N ₂
27°C	27°C
p [*] = 3.536 kPa	p = 101.3 kPa

$$(a) \ p_T = p_{N_2} + p_{H_2O} = (101.3 + 3.536) \text{ kPa} = \boxed{104.8 \text{ kPa}}$$

$$(b) \ \frac{n_{H_2O}}{n_{N_2}} = \frac{p_{H_2O}}{p_{N_2}} = \frac{3.536 \text{ kPa}}{101.3 \text{ kPa}} = \boxed{0.0349}$$

8.4.3

$$T = -20^\circ\text{C}$$

$$p^* = 14.1 \text{ mm Hg}$$

O ₂
N ₂
C ₆ H ₁₄

$$p_t = 760 \text{ mm Hg}$$

$$p_{\text{air}} = 760 - 14.1 = 745.9 \text{ mm Hg}$$

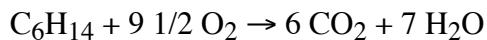
$$p_{C_6H_{14}} = p_{O_2} = 14.1 \text{ mm Hg}$$

Basis: 760 mol saturated gas (or use 100 mol)

p \Rightarrow moles

		<u>mol</u>
O ₂	.21 (745.9)	= 156.6
N ₂	.79 (745.9)	= 589.3
C ₆ H ₁₄		= <u>14.1</u> 760

For complete combustion



14.1 mol C₆H₁₄ required 14.1 (9.5) = 134 mol O₂ required

156.6 - 134 = 22.60 mol O₂ excess

$$\frac{22.60}{134} \times 100 = \boxed{17 \%}$$

Solutions Chapter 8

8.4.4

mol. wt. $\text{CCl}_3\text{NO}_2 = 164.5$

Basis: 1 mol saturated gas

	<u>mol fr.</u>
CCl_3NO_2	0.02
air	<u>0.98</u>
	1.00

$$\frac{100 \text{ kPa}}{1 \text{ mol gas}} \left| \begin{array}{c} 0.02 \text{ mol } \text{CCl}_3\text{NO}_2 \\ 760 \text{ mm Hg} \end{array} \right| \frac{101.3 \text{ kPa}}{15.0 \text{ mm Hg}} = 15.0 \text{ mm Hg}$$

- (a) Using linear interpolation, which may introduce a slight error, 15.0 mm Hg corresponds to

$$\left(\frac{15.0 - 13.8}{18.3 - 13.8} \right)(5) = 1.3 + 15 = \boxed{16^\circ\text{C}} \quad (289.5\text{K})$$

- (a) Basis: 100 m³ at 100 kPa and 16.5°C

$$\frac{100 \text{ m}^3 \text{ air}}{101.3 \text{ kPa}} \left| \begin{array}{c} 100 \text{ kPa} \\ 273 \text{ K} \end{array} \right| \frac{273 \text{ K}}{289.5 \text{ K}} \left| \begin{array}{c} 1 \text{ kg mol air} \\ 22.4 \text{ m}^3 \text{ air at SC} \end{array} \right|$$

$$\frac{0.02 \text{ mol } \text{CCl}_3\text{NO}_2}{0.98 \text{ mol air}} \left| \begin{array}{c} 164.5 \text{ kg } \text{CCl}_3\text{NO}_2 \\ 1 \text{ kg mol } \text{CCl}_3\text{NO}_2 \end{array} \right| = \boxed{13.95 \text{ kg}}$$

8.4.5

Basis: 1 mol air

$$y = 0.12 \quad p_{\text{H}_2\text{O}} = p_{\text{T}}(0.12) = 101.3 \text{ kPa} (0.12)$$

$$= 12.2 \text{ kPa}$$

The dewpoint is the temperature at which $p_{\text{H}_2\text{O}}^* = 12.2 \text{ kPa}$, or from the steam tables 323K or $\boxed{50^\circ\text{C}}$

Solutions Chapter 8

8.4.6

Assume the tank with air fills with the hazardous liquid vapor at 80°F. The pressure in the tank with air will become after the transfer $(10 + 14.7) + 13 = \boxed{37.7 \text{ psia}}$ hence the seal will possibly rupture during the transfer

8.4.7

At 60°F, $p_{\text{H}_2\text{O}}^* = 0.52$ in Hg; at 75°F, $p^* = 0.87$ in Hg

Basis: 12,000 ft³ air at 75°F and 29.7 in Hg absolute

$$\frac{12,000 \text{ ft}^3}{359 \text{ ft}^3 \text{ at SC}} \left| \frac{1 \text{ lb mol}}{29.92 \text{ in Hg total}} \right| \frac{0.52 \text{ in Hg H}_2\text{O}}{492^\circ\text{R}} \left| \frac{492^\circ\text{R}}{535^\circ\text{R}} \right| \frac{18 \text{ lb H}_2\text{O}}{\text{lb mol}} = \boxed{9.62 \text{ lb H}_2\text{O}}$$

8.4.8

Basis: 1 gal benzene (sp. gr. 0.879, MW 78.1) at 750 mm Hg, 70°F

$$\text{Moles of air} = \frac{(3600 \text{ ft}^3)(750)(14.7)}{(10.73)(760)(530)} = 9.18 \text{ lb mol}$$

$$\text{Moles of benzene} = \frac{(1)(1\text{ft}^3)(0.879)(62.4)}{(7.48)(78)} = 0.094 \text{ mol}$$

$$n_{\text{Total}} = 9.18 + 0.094 = 9.274 \text{ mol}$$

$$y_{\text{Bz}} = \frac{0.094}{9.274} = 0.0101$$

mol % = $\boxed{1.01\%}$ therefore beneath explosive limit

Solutions Chapter 8

8.4.9

Basis: 350 ft³ C₂H₂ – O₂ mixture at 25°C, 745 mm Hg

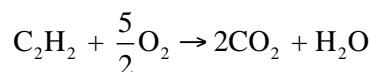
$$n_1 = \frac{pV}{RT} = \frac{(745)(14.7)(350)}{(760)(10.73)(298)(1.8)} = 0.874 \text{ lb mol}$$

$$n_2 = \left(\frac{745}{760} \right) \left(\frac{14.7}{10.73} \right) \left(\frac{300}{333} \right) \left(\frac{1}{1.8} \right) = 0.671 \text{ lb mol}$$

$$p_{H_2O}^* \text{ at } 60^\circ\text{C} = 149.4 \text{ mm Hg}$$

$$y_{H_2O \text{ at 2}} = \frac{149.4}{745} = 0.201$$

$$n_{H_2O} = (0.201)(0.671) = 0.135 \text{ lb mol}$$



You get 1 mol H₂O/mol C₂H₂ on reaction

Therefore moles C₂H₂ = 0.135

$$\text{mol O}_2 = 0.874 - 0.135 = 0.739 \text{ lb mol}$$

$$y_{O_2 \text{ at 1}} = \frac{0.739}{0.874} = 0.845$$

$$V_{O_2} = (0.845)(350) = [296 \text{ ft}^3] \text{ at 745 mm and } 25^\circ\text{C}$$

$$V_{C_2H_2} = 350 - 296 = [54 \text{ ft}^3] \text{ at 745 mm and } 25^\circ\text{C}$$

8.4.10

Elephant seals have an average body temperature several degrees higher than ours. That means their breath can hold a bit more moisture than ours, and on that day, that extra moisture could have been just enough for condensation to occur.

But there are other reasons the elephant seals' breath may have been easier to see. It could be that it was a few degrees colder on the beach than where the observer was sited. And, as you know if you have ever experimented with seeing your breath, the bigger the volume of air, the more moisture available to condense out and so the condensed moisture was more visible.

Solutions Chapter 8

8.4.11

(a) p_{Bz}^* exists if saturation occurs. Then, with $p_{tot} = 100 \text{ kPa}$

$p_{Bz} = 100 (0.014) = 1.4 \text{ kPa}$, which corresponds to

-11°C from Perry

or use Antoine Eqn. and solve for T ($p_{Bz}^* = 10.5 \text{ mm Hg}$) (-15°C from the CD)

$$\ln(10.5) = 15.9008 - \frac{2788.51}{T - 52.36}$$

b) Repeat for $p_{Bz}^* = 8.0 \text{ kPa}$ (60 mm Hg) corresponding to 15.4°C

8.4.12

Assume equilibrium.

At 75°F , from the Antoine equation, the vapor pressure of benzene is 90 mmHg. Assume the barometer is 760 mm Hg abs.

$$\frac{\text{mol Bz}}{\text{mol air}} = \frac{p_B^*}{p_t - p_B^*} = \frac{90}{760 - 90} = 0.13 \frac{\text{mol Bz}}{\text{mol air}}$$

- The OSHA limit is 1 ppm over 8 hours. The above greatly exceeds this limit.
- No, because the garage is probably not well ventilated, and also if a water heater is in the garage, the LEL (Lower Explosive Limit) may be exceeded.

8.4.13

Basis: 50 ft³ air at 29.92 in. Hg and 70°F

$$p_{H_2O}^* \text{ at } 50^\circ\text{F} = 0.36 \text{ in Hg}$$

The amount of water per hour is

$$\frac{50 \text{ ft}^3}{\text{min}} \left| \frac{60 \text{ min}}{1 \text{ hr}} \right| \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| \left| \frac{429^\circ\text{R}}{530^\circ\text{R}} \right| \left| \frac{0.36 \text{ in. Hg of H}_2\text{O}}{29.92 \text{ in. Hg total}} \right| \left| \frac{18 \text{ lb}}{\text{lb mol}} \right| = \boxed{\frac{1.68 \text{ lb H}_2\text{O}}{\text{hr}}}$$

Alternate solution: make air and water balances.

Solutions Chapter 8

8.4.14

Basis: 1 lb air

If the air is saturated, $p_{C_8}^* = 2.36$ in Hg and $p_{air} = 29.66 - 2.36 = 27.30$ in Hg.

$$\frac{p_{C_8}^*}{p_{air}} = \frac{2.36}{27.30} = 0.0864 \frac{\text{mol C}_8}{\text{mol air}}$$

$$(a) \frac{\text{lb air}}{\text{lb C}_8} = \frac{27.30 \text{ mol Air}}{2.36 \text{ mol C}_8} \left| \frac{29 \text{ lb air}}{1 \text{ lb mol air}} \right| \left| \frac{1 \text{ lb mol C}_8}{114.2 \text{ lb C}_8} \right| = \boxed{2.94 \frac{\text{lb air}}{1 \text{ bC}_8}}$$

$$(b) \frac{2.36 \text{ mol C}_8}{(27.30 + 2.36) \text{ mol total}} = \frac{n_{C_8}}{n_{tot}} = \boxed{0.080} \text{ which is also the fraction of the volume.}$$

$$(c) \frac{2.94 \text{ lb air}}{\text{lb C}_8} \left| \frac{1 \text{ lb mol air}}{29 \text{ lb air}} \right| \left| \frac{359 \text{ ft}^3 \text{ at SC}}{1 \text{ lb mol air}} \right| \left| \frac{580^\circ \text{R}}{492^\circ \text{R}} \right| \left| \frac{29.92 \text{ in Hg}}{29.66 \text{ in Hg}} \right| \\ = \boxed{43.3 \text{ ft}^3} \text{ at } 120^\circ \text{F and } 29.6 \text{ in. Hg/lb octane}$$

8.4.15

At equilibrium, the pressure of Hg is its vapor pressure

$$\frac{p_{Hg}}{p_t} = \frac{n_{Hg}}{n_t} = \frac{p_{Hg}^*}{p_{air}} = \frac{1.729 \times 10^{-4} \text{ g mol Hg}}{99.5 \text{ g mol air}}$$

Note: $p_t = p_{air} + p_{Hg} = p_{air}$ for all purposes so $\frac{1.729 \times 10^{-4} \text{ g mol Hg}}{99.5 \text{ g mol total gas}}$

Basis: $1.729 \times 10^{-4} \text{ g mol Hg}$

$$\frac{1.729 \times 10^{-4} \text{ g mol Hg}}{1 \text{ g mol Hg}} \left| \frac{200.59 \text{ g}}{1 \text{ g mol Hg}} \right| \left| \frac{1000 \text{ mg}}{1 \text{ g}} \right| = 38.14 \text{ mg Hg}$$

$$V = \frac{nRT}{p} =$$

$$\frac{99.5 \text{ g mol air}}{99.5 \text{ kPa}} \left| \frac{293.15 \text{ K}}{99.5 \text{ kPa}} \right| \left| \frac{8.314(\text{kPa})(\text{m}^3)}{(\text{kg mol})(\text{K})} \right| \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| = 2.44 \text{ m}^3 \text{ at } 20^\circ \text{C and } 99.5 \text{ kPa}$$

Solutions Chapter 8

$15.65 \frac{\text{mg}}{\text{m}^3}$ at 20°C and 99.5 kPa .

Level is not acceptable.

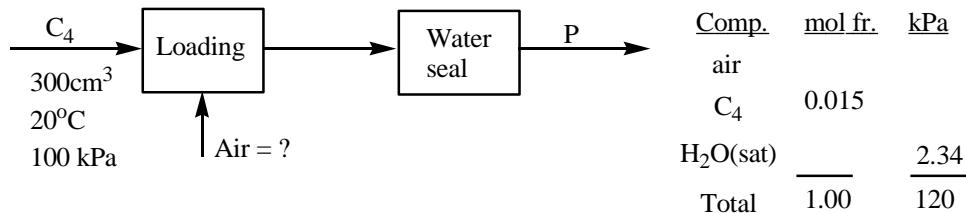
A mercury spill can be cleaned up reasonably effectively by dusting with sulfur, then vacuuming with a vacuum cleaner specifically designed for mercury pick-up, which prevents the escape of mercury vapor.

The instructor should point out to the student that the assumption of the “no ventilation” is not a very good approximation unless the surface of the mercury is rather large or there is truly no ventilation in the storeroom.

8.4.16

Step 5: Basis: 1 min

Steps 2, 3, and 4: System is loading plus water seal, steady state, open



$$p_{\text{H}_2\text{O}}^* \text{ at } 20^\circ\text{C} = 2.34 \text{ kPa}$$

$$n_{\text{C}_4} = \frac{pV}{RT} = \frac{100.0 \text{ kPa}}{293.15 \text{ K}} \left| \frac{300 \text{ cm}^3}{\left(\frac{1 \text{ m}}{100 \text{ cm}} \right)^3} \right| \left| \frac{(\text{kg mol})(\text{K})}{8.314(\text{kPa})\text{m}^3} \right|$$

$$= 1.231 \times 10^{-5} \text{ kg mol} = 1.231 \times 10^{-2} \text{ g mol C}_4$$

Steps 6, 7, 8, and 9:

At P, the mole fraction of water is $2.34/120 = x_{\text{H}_2\text{O}} = 0.0195$

The moles of P come from a C₄ balance (C₄ is a tie element)

$$1.231 \times 10^{-2} = 0.015P \quad P = 0.821 \text{ g mol}$$

Solutions Chapter 8

Then the air in is

$$0.821 (1 - 0.0195 - 0.015) = 0.793 \text{ g mol}$$

$$V = \frac{nRT}{p} = \frac{0.793 \times 10^{-3} \text{ kg mol}}{100 \text{ kPa}} \left| \frac{293.15 \text{ K}}{(kg \text{ mol})(K)} \right| \frac{8.314 \text{ (kPa)(m}^3\text{)}}{(kg \text{ mol})}$$

$$V = 1.93 \times 10^{-2} \text{ m}^3 \text{ at } 100.0 \text{ kPa and } 20^\circ\text{C per min}$$

8.4.17

Basis: 1 hr

The question really is: does the Hg condense at 150°F, or is it still a vapor (and thus not collected).

$$\text{The moles of Hg are: } 40,000 (0.023 \times 10^{-2}) \left| \frac{\text{lb Hg}}{200 \text{ lb Hg}} \right| \frac{1 \text{ lb mol Hg}}{32 \text{ lb}} = 0.046 \text{ lb mol}$$

The moles of gas are (ignoring the Hg):

$$\frac{40,000 \text{ lb gas}}{32 \text{ lb gas}} \left| \frac{1 \text{ lb mol gas}}{32 \text{ lb gas}} \right| = 1250 \text{ lb mol}$$

$$y_{\text{Hg}} = \frac{0.046}{0.046 + 1250} = 3.68 \times 10^{-5}$$

The partial pressure of the Hg in the gas is $y p_{\text{total}}$

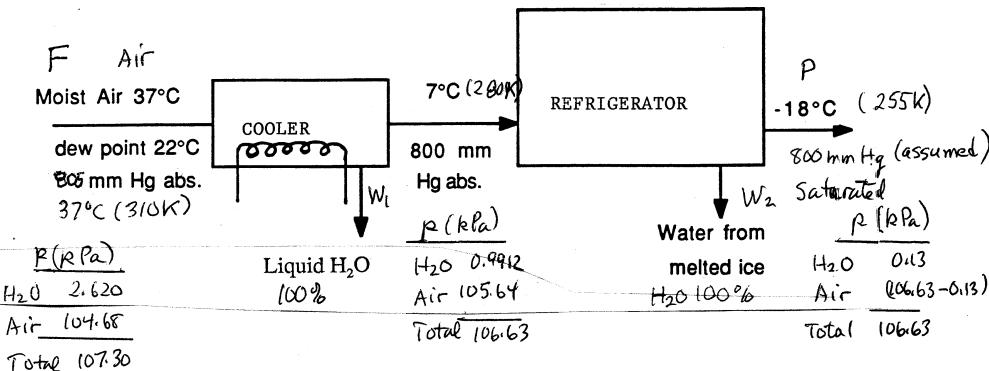
$$(3.68 \times 10^{-5})(14.7) = 5.4 \times 10^{-4} \text{ psia}$$

The Hg will remain a vapor and not condense.

Solutions Chapter 8

8.4.18

Basis: 20,000 ft³ moist air at entering conditions in 1 day



$$\frac{20,000 \text{ ft}^3}{280} \left| \frac{273}{280} \right| \left| \frac{800}{760} \right| \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3 \text{ at SC}} \right| = 57.18 \text{ lb mol total}$$

(0.532 lb mol H₂O)

System: Refrigerator is system

Steps 6 and 7: Unknowns: W₂ and P; balance: H₂O and air

Steps 8 and 9:

$$\left. \begin{aligned} \text{H}_2\text{O: } 57.18 \left(\frac{0.9912}{106.63} \right) &= W_2(1) + P \left(\frac{0.13}{106.63} \right) \\ \text{Air: } 57.18 \left(\frac{105.64}{106.63} \right) &= W_2(0) + P \left(\frac{106.5}{106.63} \right) \text{ not accurate} \end{aligned} \right\} \begin{aligned} &\text{lb mol} \\ &P = 56.72 \\ &W_2 = 0.4613 \end{aligned}$$

$$\text{Total: } 57.18 = W_2 + P$$

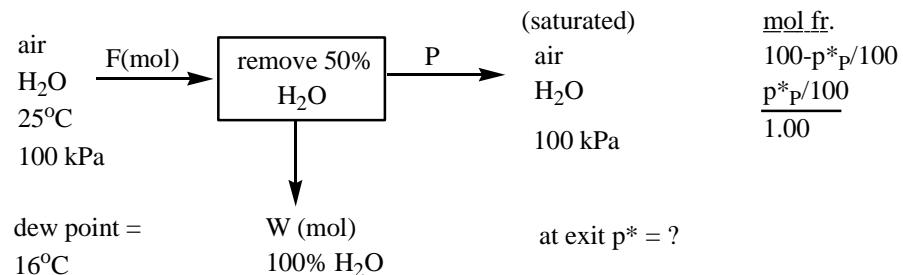
Basis: 30 days

$$30 (0.4613) (18) = \boxed{249 \text{ lb H}_2\text{O}/30 \text{ days}}$$

Solutions Chapter 8

8.4.19

Steps 1-4:



At 16°C 0.57 in Hg
 0.28 psia

$$p_{\text{H}_2\text{O}}^* \approx 13.6 \text{ mm Hg} = 1.81 \text{ kPa} \quad \text{From steam tables } p^* = 1.92 \text{ kPa}$$

Thus $p_{\text{air}} = 100 - 1.81 = 98.18 \text{ kPa}$ $p_{\text{air}} = 100 - 1.92 = 98.08$

Step 5: Basis is 100 Mol F

Step 6: Unknowns: W, P

Step 7: Balances: H₂O, air

Steps 8 & 9: Balances around process in mol

Air $100 \left(\frac{98.08}{100} \right) = W(0) + P \left(\frac{100 - p_{\text{H}_2\text{O}}^*}{100} \right) \text{ in P}$

H₂O $100 \left(\frac{1.92}{100} \right) = W(1) + P \left(\frac{p_{\text{H}_2\text{O}}^* \text{ in P}}{100} \right)$

Total $100 = W + P$

Also, $p^* = f(T)$ vapor pressure relation

- The exit gas has one-half the entering H₂O, or $\frac{1}{2}(1.92) = 0.96$ mol thus $W = \frac{1}{2}(1.92) = 0.96$ mol H₂O.
- The exit air has 98.08 mol dry air.
- At the exit $p_{\text{H}_2\text{O}} = p_{\text{H}_2\text{O}}^* = y_{\text{H}_2\text{O}}(100) = \frac{0.96}{0.96 + 98.08} 100 \approx 0.97 \text{ kPa}$

Solutions Chapter 8

- From the steam tables, this corresponds to about $\boxed{280 \text{ K}}_{(7^\circ\text{C})}$, or use Antoine Eq.

Note: Taking $\frac{1}{2}$ of (1.92) = 0.96 and dividing by 100 instead of $(p_{\text{H}_2\text{O}} + p_{\text{air}})$ is wrong. The answer is close to correct because of the very small amount of water.

8.4.20

Basis: 1000 m³ sat. air at 99 kPa and 30°C

$$p^*_{\text{H}_2\text{O}} \text{ at } 30^\circ\text{C} = 0.6155 \text{ psia} = 31.8 \text{ mm Hg} = 4.24 \text{ kPa}$$

$$\frac{1000 \text{ m}^3}{22.415 \text{ m}^3 \text{ a tSC}} \left| \frac{1 \text{ kg mol}}{101.3 \text{ kPa}} \right| \frac{99 \text{ kPa}}{303 \text{ K}} = 39.3 \text{ kg mol}$$

$$\text{or } n = \frac{99 \text{ kPa}}{303 \text{ K}} \left| \frac{1000 \text{ m}^3}{8.314 \text{ (kPa)(m}^3\text{)}} \right| \frac{(\text{kg mol})(\text{K})}{= 39.3 \text{ kg mol}}$$

Initial:

$$\text{Initial mol H}_2\text{O} = 39.3 \left(\frac{4.24}{99} \right) = 1.68 \text{ kg mol H}_2\text{O}$$

$$\text{Initial mol air} = 39.3 \left(\frac{99 - 4.24}{99} \right) = 39.3 - 1.68 = 37.62 \text{ kg mol air}$$

Final:

At 14°C and 133 kPa, the air is still saturated, and $n_{\text{air}} = 37.62 \text{ kg mol}$

$$p^*_{14^\circ\text{C H}_2\text{O}} = 0.2302 \text{ psia} = 11.9 \text{ mm Hg} = 1.59 \text{ kPa} = p_{\text{H}_2\text{O}} @ 14^\circ\text{C}$$

$$\frac{p_{\text{H}_2\text{O}}}{p_{\text{air}}} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{air}}} \text{ so } \frac{1.59}{(133 - 1.59)} = \frac{n_{\text{H}_2\text{O}}}{37.62} \left. \begin{array}{l} \text{There is the same as} \\ \text{an H}_2\text{O material balance} \end{array} \right\}$$

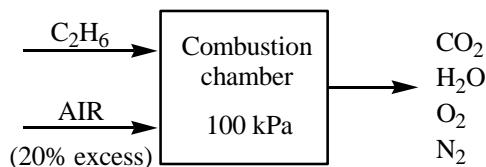
$$n_{\text{H}_2\text{O}} = 0.46 \text{ kg mol}$$

$$1.68 - 0.46 = 1.22 \text{ kg mol or } \boxed{22 \text{ kg}}$$

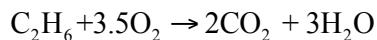
Solutions Chapter 8

8.4.21

Steps 2, 3, and 4:



Assume combustion is complete and the gases are ideal. The process is open, steady state with reaction. The first objective is to make material balances.



Step 5: Basis: 100 mol C₂H₆

Step 4: The entering O₂ is 350 mol
 The excess O₂ is (0.20)(3.50) = 70 mol
 Total O₂ is 420 mol
 The N₂ is 420 $\left(\frac{0.79}{0.21}\right)$ = 1580 mol

Steps 6 and 7:

Unknowns: 4 (The components of the flue gas)

Balances: C, H, O, N, total of 4

Degrees of freedom = 0

Steps 8 and 9 (balances in moles, in = out):

C:	$2(100) = n_{\text{CO}_2}$	$n_{\text{CO}_2} = 200 \text{ mol}$
2N:	$1580 = n_{\text{N}_2}$	$n_{\text{N}_2} = 1580 \text{ mol}$
H:	$6(100) = 2n_{\text{H}_2\text{O}}$	$n_{\text{H}_2\text{O}} = 300 \text{ mol}$
O:	$420(2) = 2n_{\text{CO}_2} + n_{\text{H}_2\text{O}} + 2n_{\text{O}_2}$	$n_{\text{O}_2} = 700 \text{ mol}$
	Total	2150 mol

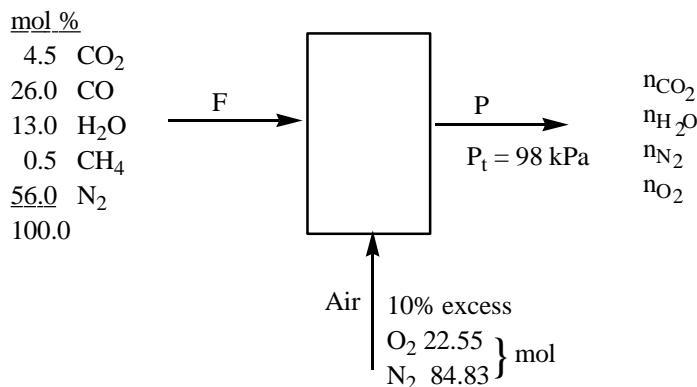
The dewpoint is the temperature at which the flue gas is saturated

$$p_{\text{H}_2\text{O}}^* = y_{\text{H}_2\text{O}} p_{\text{Total}} = \frac{300}{2150} (100 \text{ kPa}) = 14.0 \text{ kPa}$$

This pressure of H₂O corresponds (from the steam tables) to [325.7 K] (52.6°C)

Solutions Chapter 8

8.4.22



Step 4: Calculate the xs air and add total air to the diagram

Step 5: Basis: 100 mol synthesis gas

Step 6: Unknowns: n_{O₂}, N_{CO₂}, n_{H₂O}, n_{N₂}, P (5 total)

Step 7: Balances C, O, H, N, $\sum n_i = P$ (5 independent equations)

Steps 8, 9: Use element balances

	<u>In</u>	<u>out</u>	
C:	4.5	+ 26.0 + 0.5	= n _{CO₂} n _{CO₂} = 31.0
H:	0.5 (4)	+ 13 (2)	= n _{H₂O} (2) n _{H₂O} = $\frac{28}{2}$
O ₂ :	4.5	+ $\frac{26.0}{2}$ + 22.55 =	n _{CO₂} + $\frac{n_{H_2O}}{2}$ n _{O₂} = 2.05
N ₂ :	56.0	+ 84.83	= n _{N₂} n _{N₂} = $\frac{140.8}{187.9}$

$$y_{H_2O} = \frac{28/2}{187.9} = \frac{14}{187.9}$$

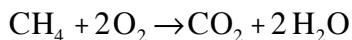
$$p^*_{H_2O} = p_{H_2O} = 98 \left(\frac{14}{187.9} \right) = 7.3 \text{ kPa} \text{ (or 1.06 psia)}$$

This is equivalent to a temperature of 104°F from the steam tables (40°C)

Solutions Chapter 8

8.4.23

Basis: 100 mol gases leaving absorber



$$\frac{0.8335 \text{ mol N}_2}{0.79 \text{ mol N}_2} \left| \frac{0.21 \text{ mol O}_2}{2 \text{ mol O}_2} \right| \frac{1 \text{ mol CO}_2}{1 \text{ mol CO}_2} = 0.1108 \text{ mol CO}_2$$

$$1 - 0.8335 - 0.1108 = 0.0557 \text{ mol H}_2\text{O}; 0.00557 (20) = 1.114 \text{ psia}$$

Dew point \approx 105 °F at 1.114 psia

- b) At constant temperature of 130 °F, the gas must be compressed until the partial pressure increases and becomes equal to the vapor pressure in order to reach the point of condensation.

From Steam tables, the vapor pressure of water at 130 °F is 2.223 psia.

The total pressure at which the partial pressure of water (mol fraction = 0.0557) will be 2.223 psia is

$$\frac{2.223}{0.0557} = \boxed{40.1 \text{ psia}}$$

$$P_{\text{H}_2\text{O}} = P_t y_{\text{H}_2\text{O}}$$

8.4.24

Basis: 1 lb mol of benzene free air

$$\begin{array}{lcl} \text{Barometric Pressure} & = & \underline{\text{mm Hg}} \\ & & 742 \end{array}$$

$$\begin{array}{lcl} p^* \text{ benzene at } 40^\circ\text{C} & = & \underline{181} \end{array}$$

$$\begin{array}{lcl} \text{Partial pressure of air} & = & \underline{561} \end{array}$$

$$\begin{array}{lcl} \text{Partial pressure of benzene} & = & \underline{181} \Rightarrow 0.323 \text{ lb mol benzene} \end{array}$$

$$\begin{array}{lcl} \text{At 25 psig total pressure or} & & 2052 \end{array}$$

$$\begin{array}{lcl} p^* \text{ benzene at } 10^\circ\text{C} & = & \underline{45.4} \end{array}$$

$$\begin{array}{lcl} \text{Partial pressure of air} & & \underline{2006.6} \end{array}$$

$$\begin{array}{lcl} \text{Final partial pressure of benzene in air} & = & \underline{45.4} \Rightarrow 0.023 \text{ lb mol benzene} \end{array}$$

Solutions Chapter 8

$$0.323 - 0.023 = 0.3 \text{ lb mol C}_6\text{H}_6 \text{ recovered}$$

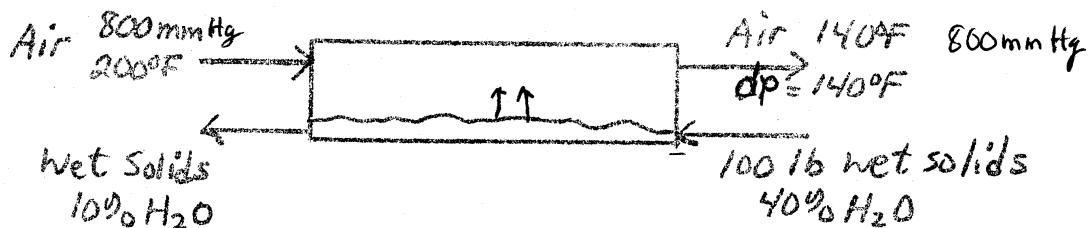
a. $\frac{(0.3)(100)}{(0.323)} = 92.9\% \text{ recovery}$

b. 2 psig is $103 + 742 = 845 \text{ mm Hg}$

$$\frac{(0.023)(845)}{(1.023)} = 18.9 \text{ mm Hg} \text{ partial pressure of benzene in the recycled air.}$$

8.4.25

Steps 2, 3, and 4:



The dewpoint of 140°F gives $p_{\text{H}_2\text{O}}^* = 149.3 \text{ mm Hg}$

Step 5:

Basis: 100 lb wet solids in (BDS is bone dry solids)

Steps 8 and 9:

BDS balance: 60 lb BDS = 0.90 (wet solids out)

$$\text{wet solids out} = 66.7 \text{ lb}$$

From a total balance $100 - 66.7 = 33.3 \text{ lb H}_2\text{O evaporated} = 1.85 \text{ lb mol H}_2\text{O evaporated}$

For the air,

Assume the air exits at 1.0 atm

$$\text{Composition in: H}_2\text{O is } \frac{10}{800}(100) = 1.25\%$$

Solutions Chapter 8

	Air is $\frac{790}{800}(100)$	=	98.75%
Composition out:	H_2O is $\frac{149.3}{800}(100)$	=	18.7%
	Air	=	81.3%

Overall balance (mol) on the gas phase

$$A_{in} + 1.85 = A_{out}$$

Air balance (mol) on the gas phase

$$0.9875 A_{in} = 0.813 A_{out}$$

$$A_{in} = 8.619 \text{ lb moles wet air in}$$

$$\frac{8.619 \text{ lb mol}}{\text{lb mol}} \left| \frac{359 \text{ ft}^3}{492^\circ R} \right| \left| \frac{660^\circ R}{800} \right| \left| \frac{760}{3940 \text{ ft}^3} \right| \text{ of wet air @ 800 mm Hg and } 200^\circ F$$

8.4.26

Basis: 1 hr

Calculate the amounts of the various components in the gas phase:

Water

H_2O in = 0 (by specification)

H_2O out (saturated):

$$p^* \text{ at } 300 \text{ K} = 3.51 \text{ kPa} = p_{H_2O}$$

$$y_{H_2O} = \frac{3.51 \text{ kPa}}{110 \text{ kPa}} = 0.0319$$

CO_2

CO_2 in: $y_{CO_2} = 0.00055$

CO_2 out: $y_{CO_2} = 0.125$

O_2

O_2 in: $y_{O_2} = 0.21$

Solutions Chapter 8

$$O_2 \text{ out: } y_{O_2} = 0.0804$$

Assume the other gas in and out is N₂.

The entering gas is

$$\frac{600 \text{ m}^3}{\text{kg mol}} \left| \frac{120 \text{ kPa}}{300 \text{ K}} \right| \left| \frac{(\text{kg mol})(\text{K})}{8.314(\text{kPa})(\text{m}^3)} \right| = 28.87 \text{ kg mol}$$

The exit gas can be obtained from a N₂ balance

$$28.87(1 - 0 - 0.00055 - 0.21) = n_{\text{out}}(1 - 0.0319 - 0.125 - 0.0804)$$

$$n_{\text{out}} = 29.89 \text{ kg mol}$$

In one hour in the steady state the moles of CO₂ produced were

$$29.89(0.125) - 28.87(0.00055) = 3.72 \text{ kg mol}$$

The mole of O₂ consumed were

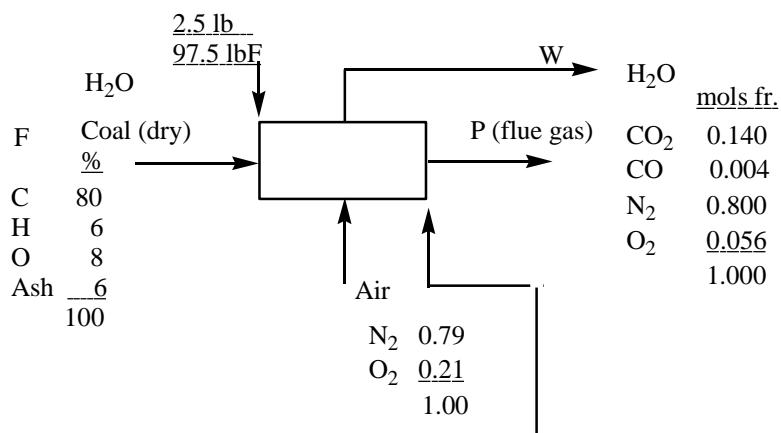
$$28.87(0.21) - 30.14(0.0804) = 3.64 \text{ kg mol}$$

$$RQ = \frac{3.72}{3.64} = \boxed{1.02}$$

8.4.27

Step 5: Basis: 100 lb mol flue gas

Steps 2, 3, and 4:



H₂O, dew point 50°F; p*_{H₂O} = 0.3624 in Hg

Solutions Chapter 8

Steps 6 and 7:

Unknowns: F, A, W

Equations: Material balances: C, H, O (the ash is ignored)

Steps 8 and 9 (balances are in moles; in = out)

To get F:

$$C: (0.80F)(1/12) = (0.140 + 0.004) 100 \quad F = 216 \text{ lb or } 18.0 \text{ lb mol}$$

To get A:

$$N_2: 80 = A(0.79) \quad A = 101.27 \text{ lb mol}$$

H: Hydrogen from the dry coal plus the water in the coal is (MW H = 1.008):

$$\left[\frac{216(0.06)}{1.008} + \frac{2.5}{97.5} \left| \frac{216}{18.016} \right| \frac{1}{2} \right] \frac{1}{2} = 1 \quad 6.74 \text{ lb mol H}_2\text{O}$$

$$\text{In A: } p_{H_2O}^* = 0.3624 = y_{H_2O}^A \quad p_{\text{total}} = y_{H_2O}^A (29.90)$$

$$y_{H_2O}^A = 0.0121$$

$$\text{The water in A is } (0.0121) (101.27) = \underline{1.23 \text{ lb mol}}$$

$$\text{Total H}_2\text{O in P: } W = \underline{7.97 \text{ lb mol}}$$

The dew point is

$$\frac{7.97}{107.97} (29.92) = 2.21 \text{ in. Hg equivalent to } \boxed{105^\circ\text{F}}$$

8.5.1

- (a) F; (b) F; (c) F; (d) T; (e) T; (f) T

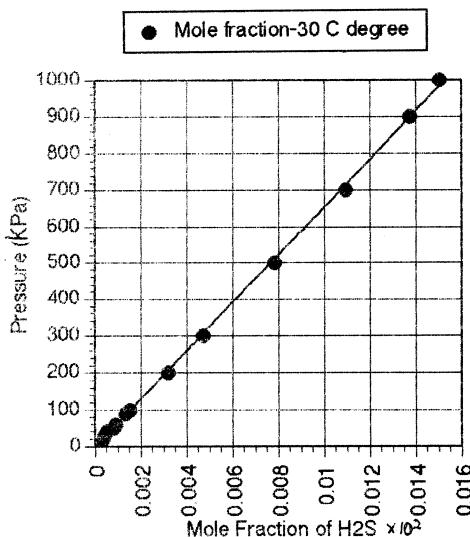
8.5.2

For multiple components, the vapor pressure varies with composition as well as with temperature, and to be precise the composition should be stated.

Solutions Chapter 8

8.5.3

Henry's Law is $p = Hx$, a straight line with no intercept. A plot of the data indicates Henry's law fits the data well.



8.5.4

Use Henry's law $p = Hx$. The MW of CHCl₃ is 119.4. The total pressure is 1 atm.

$$x = \frac{p}{H} = \frac{0.024(1)}{170} = 1.41 \times 10^{-4} \text{ mol fraction}$$

The concentration in mg/L is

$$\text{Water: } \frac{1000}{18} = 55.6 \text{ g mol/L}$$

The number of moles of CHCl₃ is

$$\frac{(55.6)(1.41 \times 10^{-4})}{1 - 1.41 \times 10^{-4}} = 7.84 \times 10^{-3} \text{ g mol/L}$$

$$\text{Concentration} = \frac{119.4 \text{ g}}{\text{g mol}} \left| \frac{7.84 \times 10^{-3} \text{ g mol}}{1 \text{ L}} \right| \left| \frac{1000 \text{ mg}}{1 \text{ g}} \right| = 940 \text{ mg/L}$$

Solutions Chapter 8

8.5.5

$p = Hx$ where p is in kPa and x is mol fraction

The mole fraction of O₂ in the gas phase is y_{O_2}

$$y_{O_2} = \frac{p_{O_2}}{p_{\text{Total}}} = \frac{Hx_{O_2}}{p_{\text{Total}}}$$

The moles of O₂ and H₂O are:

$$O_2: \frac{6 \text{ mg}}{L} \left| \frac{1 \text{ g}}{1000 \text{ mg}} \right| \frac{10^3 \text{ L}}{1 \text{ m}^3} \left| \frac{1 \text{ g mol } O_2}{32 \text{ g } O_2} \right| = 0.1875 \text{ g mol/m}^3 \text{ in water}$$

$$H_2O: \frac{10^3 \times 10^3}{18} = 55.6 \times 10^3 \text{ g mol/m}^3$$

$$x_{O_2} = \frac{0.1875}{55.6 \times 10^3 + 0.1875} = 3.37 \times 10^{-6}$$

$$p_{\text{Total}} = 1 \text{ atm} \quad y_{O_2} = \frac{4.02 \times 10^6 \text{ kPa}}{\text{mol fr.}} \left| \frac{1}{101.3 \text{ kPa}} \right| \frac{3.37 \times 10^{-6} \text{ mol fr.}}{} = 0.134$$

Basis: 1 L gas

$$n_{O_2} = \frac{p_{O_2}}{RT} V = \frac{(101.3 \text{ kPa})(0.134)}{101.3 \text{ kPa}} \left| \frac{1 \text{ atm}}{0.08206(L)(atm)} \right| \left| \frac{1 \text{ L}}{290 \text{ K}} \right| \left| \frac{(g \text{ mol})(K)}{18 \text{ g}} \right| \left| \frac{1000 \text{ mg}}{1 \text{ g mol}} \right| \left| \frac{0.101 \text{ mg}}{1 \text{ g}} \right| = \boxed{0.101 \text{ mg per L}}$$

Solutions Chapter 8

8.5.6

Steps 2, 3, and 4

$p_{\text{Total}} = 1 \text{ atm}$ and at 60°F the vapor pressures are:

$$p^*_{\text{Toluene}} = 16 \text{ mm Hg} \quad p^*_{\text{Benzene}} = 60 \text{ mm Hg}$$

Assume the mixture to be ideal so that Raoult's Law applies

Step 5: Basis: 1 mol liquid

Steps 6-9:

$$y_i = \frac{p_i}{p_{\text{Total}}} = \frac{p^*_i x_i}{p_{\text{Total}}}$$

For toluene:

$$y_{\text{Tol}} = \frac{(16)(0.60)}{760} = \boxed{0.0126}$$

For benzene:

$$y_{\text{Bz}} = \frac{(60)(0.40)}{760} = \boxed{0.0316}$$

The balance is air.

0.0126	Toluene
<u>0.0316</u>	Benzene
0.0442	Total

The vapor is flammable.

8.5.7

Use Raoult's Law. $p_{\text{Total}} = p_p^*(1 - x_B) + p_B^* x_B$

From Perry the vapor pressures are:

$$p^*_{\text{Propane}} = 16.8 \text{ atm} \quad p^*_{\text{Butane}} = 4.8 \text{ atm}$$

$$p_{\text{Total}} = (100/14.7) \text{ atm} = 6.80 \text{ atm}$$

$$6.80 = 16.8(1 - x_B) + 4.8x_B$$

$x_{\text{Butane}} = \boxed{0.83}$ assuming the liquid phase is essentially all of the mixture.

Solutions Chapter 8

8.5.8

Mole fraction in the liquid phase is given by solving the following equations for x_{Bz} :

$$y_{Bz} = p^*_{Bz} x_{Bz} / p_{\text{Total}} \quad \text{and} \quad y_{\text{Tol}} = p^*_{\text{Tol}} x_{\text{Tol}} / p_{\text{Total}} \quad \text{to get} \quad x_{Bz} = (p_{\text{Total}} - p^*_{\text{Tol}}) / (p^*_{Bz} - p^*_{\text{Tol}})$$

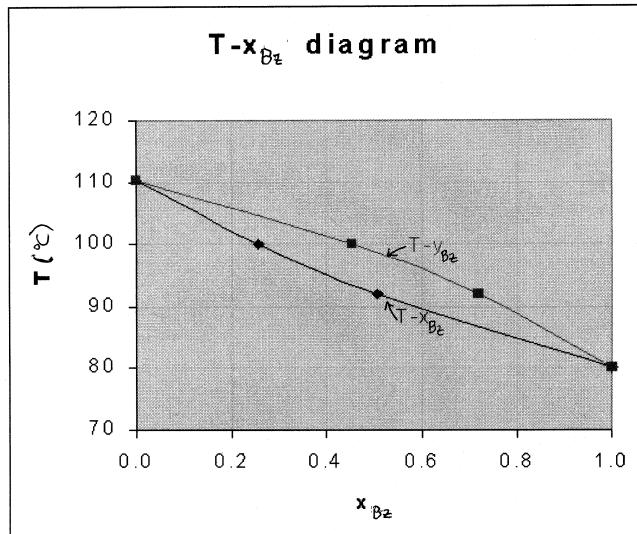
The corresponding equilibrium mole fraction in vapor phase (y) is,

$$y_i = p^*_i x_i / p_{\text{Total}}$$

Using these equations for the various temperatures given, the following data for x and y are obtained for the total pressure of 1 atm

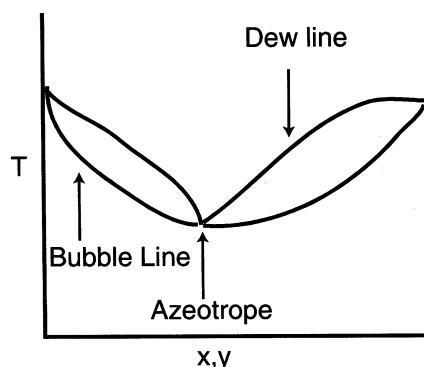
T(°C)	x_{Bz}	y_{Bz}
80	1.000	1.000
92	0.508	0.720
100	0.256	0.453
110.4	0.000	0.000

From the above-calculated data, the following T-x diagram can be drawn.



Solutions Chapter 8

8.5.9



8.5.10

The mole fractions of each component are needed to apply Raoult's law. Assuming a basis of 100 g of solution, we can construct the following:

	g	Molecular weight	Mol	Mol fraction
Water	25	18	1.39	0.37
Methanol	75	32	2.34	0.63
			3.73	1.00

Raoult's law is used to compute the vapor pressure (p^*) of pure methanol based on the partial pressure required to flash:

$$p = xp^*$$
$$p^* = p/x = 62/0.63 = 98.4 \text{ mm Hg.}$$

Use the Antoine equation to get T

$$\ln(p^*) = 18.5875 - \frac{3626.55}{-34.29 + T} \quad T = \boxed{293 \text{ K}} (20^\circ\text{C})$$

Solutions Chapter 8

8.5.11

Basis: $p_{\text{Nap}}^* @ 180^\circ\text{F} = 460 \text{ mm Hg}$

$p_{\text{H}_2\text{O}}^* @ 180^\circ\text{F} = 388 \text{ mm Hg}$

$$p_{\text{Max}} = p_{\text{H}_2\text{O}} + p_{\text{Naptha}} = 460 + 388 = \boxed{848 \text{ mm Hg}} \quad (\text{a})$$

$p_{\text{Naptha}}^* @ 160^\circ\text{F} = 318 \text{ mm Hg}$

$p_{\text{H}_2\text{O}}^* @ 160^\circ\text{F} = 245 \text{ mm Hg}$

Basis: 6000 lb feed $(5000)(0.928) = 4640 \text{ lb pure Naptha}$

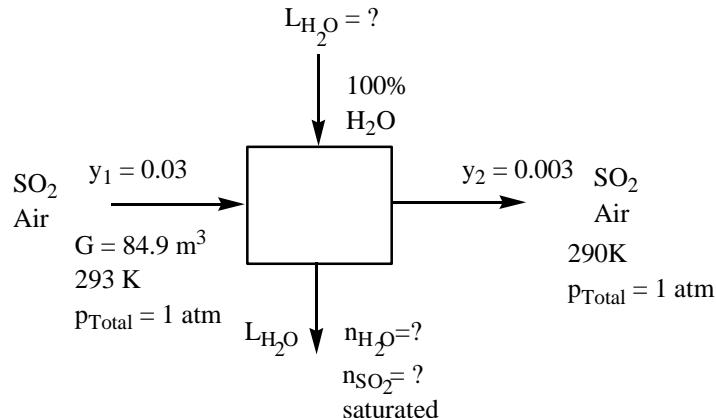
$$\frac{\text{lb mol H}_2\text{O}}{\text{lb mol Nap}} = \frac{245}{318} = 0.77$$

$$\frac{W_1}{W_2} = \frac{n_1 M_1}{n_2 M_2}; \quad W_1 = 4640 \left(\frac{18}{107} \right) (0.77) = 600 \text{ lb H}_2\text{O Distilled}$$

$$1000 - 600 = \boxed{400 \text{ lb H}_2\text{O left}} \quad (\text{b})$$

8.5.12

Steps 2, 3, and 4:



Step 5: Basis: 1 min (85 m^3 entering gas)

Solutions Chapter 8

Steps 6 and 7:

Unknowns: $n_{H_2O}^L, n_{SO_2}^L, \text{Air}$

Equations. Material balances: H_2O, SO_2, Air
 $y_i > Hx_i$

Steps 8 and 9:

The liquid and vapor are assumed to be in equilibrium at the exit, and the water is saturated with SO_2 so that

$$y_1 = Hx_1$$

$$0.03 = (43) x_{SO_2} \text{ so that } x_{SO_2} = 0.00070 \text{ mol fraction}$$

Material balance SO_2 (moles):

$$G (0.03 - 0.003) = L (0.00070 - 0)$$

b.
$$\frac{L}{G} = \boxed{38.6 \frac{\text{g mol } H_2O}{\text{g mol air}}}$$

The respective flow rates are

$$G = \frac{85 \text{ m}^3}{0.024 \text{ m}^3} \left| \frac{1 \text{ g mol gas}}{0.024 \text{ m}^3} \right. = 3540 \text{ g mol gas}$$

$$L = (3540) (38.4) = 137 \times 10^3 \text{ g mol water}$$

In terms of kg

a. $L = (136) (18) = \boxed{2450 \text{ kg/min}}$

Solutions Chapter 8

8.5.13

Use the Antoine equation or the physical property package on the CD to get the vapor pressure of pentane (P) and heptane (H). Assume ideal liquid and vapor.

Basis: Data given in problem statement

$$\ln p^*_P(\text{mm}) = 15.8333 - \frac{2477.07}{T-39.94} \quad p^*_P = 283.6 \text{ mm Hg (5.48 psia)}$$

$$\ln p^*_H(\text{mm}) = 15.8737 - \frac{2911.32}{T-56.51} \quad p^*_H = 20.6 \text{ mm Hg (0.40 psia)}$$

Convert mass fractions to mole fractions:

Basis: 100 g liquid

	<u>g</u>	<u>MW</u>	<u>g mol</u>	<u>mol. fr.</u>
P	20	72.15	0.28	0.23
H	80	86.17	0.93	0.77
	100		1.21	1.00

Equations to use, $i = P$ and H

$$\sum y_i = 1 \quad y_i = \frac{p^*_i x_i}{p_{\text{Total}}}$$

a. $\frac{p^*_P}{p_{\text{Total}}} x_P + \frac{p^*_H}{p_{\text{Total}}} x_H = 1 \quad p_{\text{Total}} = (283.6)(0.23) + 20.6(0.77) = \boxed{80.95 \text{ mm Hg}}$

3.19 in Hg
10.8 kPa
1.57 psia

b. $y_i = \frac{p^*_i x_i}{p_{\text{Total}}} \quad y_P = \frac{16}{4.07}(0.23) = \boxed{0.90}$
 $y_H = \frac{0.5}{4.07}(0.77) = \boxed{0.10}$
 $\overline{1.00}$

Solutions Chapter 8

8.5.14

Data:

	<u>MW</u>	<u>p* at 60°C</u>
Benzene (B)	78.1	51.3 kPa
Toluene (T)	92.1	18.5 kPa

Assume ideal gas and liquid. Apply Raoult's Law. Calculate mole fractions in the liquid.

b.
$$x_B = \frac{1}{\frac{1}{78.1} + \frac{1}{92.1}} = \boxed{0.541}$$

$$x_T = \frac{1}{\frac{1}{92.1} + \frac{1}{78.1}} = \boxed{0.459}$$

a. The equations to use are

$$x_B p_{\text{tot}} = x_B p_B^*$$

$$y_T p_{\text{tot}} = x_T p_T^*$$

$$y_B + y_T = 1$$

$$y_B + x_T = 1$$

$$(1 - y_B) p_{\text{tot}} = x_T p_T^*$$

$$\left(1 - \frac{x_B p_B^*}{p_{\text{tot}}}\right) p_{\text{tot}} = x_T p_T^*$$

$$p_{\text{tot}} = x_B p_B^* + x_T p_T^* = (0.541)(51.3) + (0.459)(18.5) = \boxed{36.2 \text{ kPa}}$$

(b) What will be the composition of this first bubble?

$$y_B = \frac{x_B p_B^*}{p_{\text{tot}}} = \frac{(0.541)(51.3)}{36.2} = \boxed{0.766}$$

$$y_T = 1 - y_B = \boxed{0.234}$$

Solutions Chapter 8

8.5.15

Data:

<u>p^* at -31.2°C (kPa)</u>	
Propane (P)	160.0
n-butane (B)	27.6

Assume ideal solution and vapor. Use Raoult's law

$$(a) \quad y_P p_{\text{total}} = x_P p_P^* \quad y_P + y_B = 1$$

$$y_B p_{\text{total}} = x_B p_B^* \quad y_P + y_B = 1$$

$$y_P = \frac{x_P p_P^*}{p_{\text{total}}} \quad (1 - y_P) p_{\text{total}} = (1 - x_P) p_B^*$$

More manipulations give

$$x_P = \frac{p_{\text{total}} - p_B^*}{p_P^* - p_B^*} = \frac{101.3 - 26.7}{160.0 - 26.7} = \boxed{0.56}$$

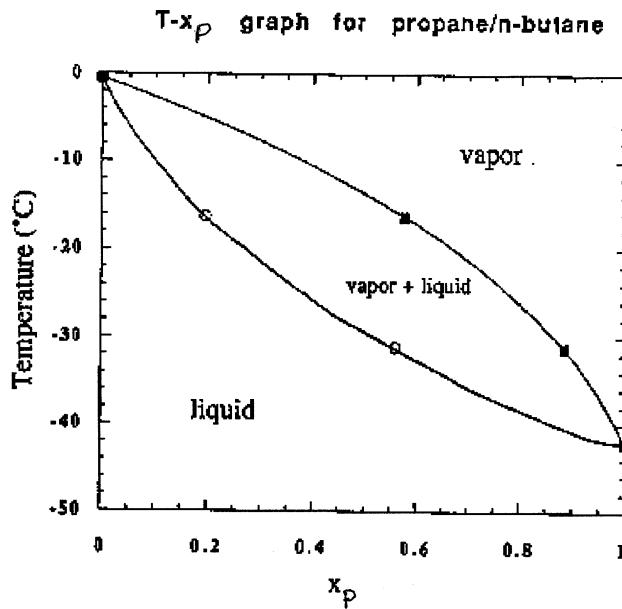
$$x_B = 1 - 0.56 = 0.44$$

$$(b) \quad y_P = \frac{(0.56)(160.0)}{101.3} = \boxed{0.884} \quad y_B = 1 - 0.884 = \boxed{0.116}$$

(c) For propane

<u>$T^\circ\text{C}$</u>	<u>x</u>	<u>y</u>
-0.5	0.0	0.0
-16.3	0.196	0.577
-31.2	0.560	0.884
-42.1	1.0	1.0

Solutions Chapter 8



8.5.16

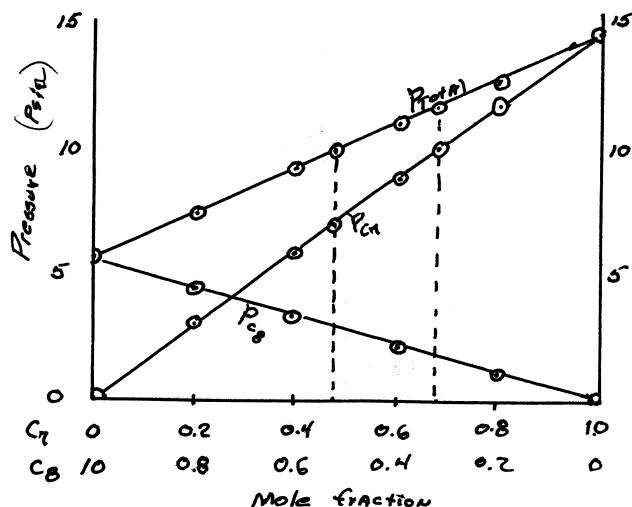
Basis: 1.0 lb mol of mixture @ 200°C

Data:

$$p^*_{C_7} \text{ @ } 200^\circ\text{F} = 14.7 \text{ psia}$$

$$p^*_{C_8} \text{ @ } 200^\circ\text{F} = 5.5 \text{ psia}$$

Mole fraction C ₇	0	0.2	0.4	0.6	0.8	1.0
Partial Press C ₇	0	2.94	5.88	8.82	11.75	14.7
Partial Press C ₈	<u>5.5</u>	<u>4.40</u>	<u>3.30</u>	<u>2.20</u>	<u>1.10</u>	<u>0</u>
	5.5	7.34	9.18	11.02	12.75	14.7



Solutions Chapter 8

$C_7 = 0.47$: $p_{\text{Tot}} = 11.7 \text{ psia}$
For $p_{C_7} = 10.0 \text{ psia}$
 $p_{C_8} = 1.7 \text{ psia}$

8.5.17

Assume ideal solution.

For the bubblepoint

$$p_{\text{Total}} = p^*_1(T)x_1 + p^*_2(T)x_2 \quad (1)$$

$$p_{\text{Total}} = 200 \text{ psia or } 10,342 \text{ mm Hg}$$

x_i (mol fr.)

0.20 n-pentane $p^*_1 = \exp \left[15.8333 - \frac{2477.07}{(-39.94 + T)} \right] \quad (2)$

0.80 n-hexane $p^*_2 = \exp \left[15.8366 - \frac{2697.55}{(-48.78 + T)} \right] \quad (3)$

p^*_i is mm Hg and T is in K

Solve Equation (1) to get from Polymath T = 447 K

Solutions Chapter 8

8.5.18

Assume ideal solution

For the dewpoint

$$\frac{1}{p_{\text{Total}}} = \frac{y_1}{p_1^*} + \frac{y_2}{p_2^*} \quad (1)$$

$$p_{\text{Total}} = 100 \text{ psia or } 5,171 \text{ mm Hg}$$

y_i (mol fr.)

$$0.20 \quad \text{n-pentane} \quad p_1^* = \exp \left[15.8333 - \frac{2477.07}{(-39.94 + T)} \right] \quad (2)$$

$$0.80 \quad \text{n-hexane} \quad p_2^* = \exp \left[15.8366 - \frac{2697.55}{(-48.78 + T)} \right] \quad (3)$$

p_i^* is mm Hg and T is in K

Solve Equation (1) to get from Polymath $T = 413 \text{ K}$

8.5.19

Calculate the bubble point and dew point temperatures at 39.36 in. Hg = 1000 mm Hg. Use the Antoine equations to get p^* based on the assumption the solution is ideal.

$$\ln p^* = A - \frac{B}{C+T} \quad 1 = \text{Benzene}$$

2 = Toluene

$$K_1 = \frac{p_1^*}{p_t} \quad \ln(K_1) = \ln(p_1^*) - \ln(p_t) = \ln(p_1^*) - 6.9078$$

Calculate $\ln K_1$ and $\ln K_2$. Solve the bubble point equation and the dew point equation by a computer code (or Newton's method) starting with $T = 365 \text{ K}$ (slightly above p^* for benzene).

a. Bubble point temperature

$$\sum y_i = 1 = \sum x_i$$

Solutions Chapter 8

If solution is ideal $K_i x_i = \frac{p_i^* x_i}{p_t}$ and $0.5 \frac{p_1^*}{p_t} + 0.5 \frac{p_2^*}{p_t} - 1 = 0$ (1)

Use the Antoine equation to get p_i^*

$$\text{Benzene } p_1^* = 15.9008 - \frac{2788.51}{-52.36 + T}$$

$$\text{Toluene } p_2^* = 16.0137 - \frac{3096.52}{-53.67 + T}$$

Solution of Equation (1) using Polymath: Bubble point temperature is [375 K]

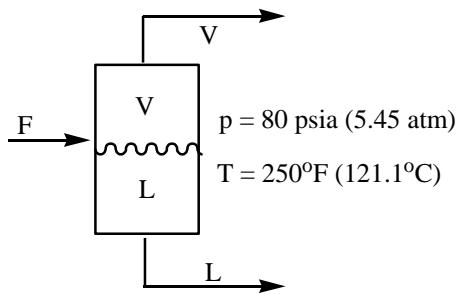
b. Dew point temperature

$$\sum x_i = 1 = \frac{\sum x_i}{K_i} = \frac{0.5}{K_1} + \frac{0.5}{K_2} \quad (2)$$

Solution of Equation (2): Dewpoint temperature is [381.5 K]

Solutions Chapter 8

8.5.20



Assume ideal liquid and vapor exist.

Vapor pressure data at 121°C from the Antoine equation (refer to problem P19.23 for the equations)

	<u>p^* (atm)</u>
Pentane (P)	9.07
Hexane (H)	4.03

$$p_p = p^*_p x_p = 9.07 x_p$$

$$p_h = p^*_h (1 - x_p) = 4.03(1 - x_p)$$

$$p_{\text{Total}} = 5.45 = p_p + p_h = 9.07 x_p + 4.03(1 - x_p)$$

b. $x_p = \boxed{0.282}$ (0.718 hexane)

$$y_p = \frac{p_p}{p_{\text{Total}}} = \frac{p^*_p x_p}{p_{\text{Total}}} = \frac{(9.07)(0.282)}{5.45} = \boxed{0.469} \text{ (0.531 hexane)}$$

a. Basis: $\boxed{F = 1 \text{ mol}}$

$$F = L + V \quad L = 1 - V$$

$$F(x_F) = Lx + Vy \quad 1(0.40) = (1-V)(0.282) + V(0.469)$$

$$L = \boxed{0.37 \text{ mol}} \quad V = \boxed{0.63 \text{ mol}}$$

Solutions Chapter 8

8.5.21

Assume pentane is the major contributor to the gas-phase composition.

$$y_i = \frac{p_i}{p_{\text{tot}}}$$

For Raoult's law,

$$p_i = p_i^* x_i \quad \text{so} \quad p_i^* = \frac{y_i p_{\text{tot}}}{x_i} = \frac{(0.018)(100)}{0.05} = 36 \text{ kPa}$$

Using the Antoine equation,

$$\ln(36) = 15.8333 - \frac{2477.07}{-39.94 + T}$$

$$T = 242 \text{ K}$$

8.5.22

Assume that the pressure at the bottom of the lake = p_{CO_2}

$$p = \rho gh \text{ varies with height}$$

$$\text{Avg. depth} = 225 \text{ m}$$

$$p_{\text{CO}_2} = \frac{1000 \text{ kg}}{\text{m}^3} \left| \frac{9.8 \text{ m}}{\text{s}^2} \right| \frac{225 \text{ m}}{} = 2.21 \times 10^3 \text{ kPa} + 1.01 \times 10^2 \text{ kPa} \\ = 23 \text{ Atm}$$

$$p_{\text{CO}_2} = H x_{\text{CO}_2} \Rightarrow x_{\text{CO}_2} = \frac{23 \text{ atm}}{1.7 \times 10^3 \text{ atm/mol f}} = 0.0134$$

If the entire 200,000 tons were saturated at p_{CO} but not supersaturated

$$\frac{200,000 \text{ ton H}_2\text{O}}{} \left| \frac{1000 \text{ kg}}{\text{ton}} \right| \frac{1 \text{ kg mol}}{18 \text{ kg}} = 1.11 \times 10^7 \text{ kg mol}$$

$$0.0134 = \frac{n_{\text{CO}_2}}{1.11 \times 10^7 + n_{\text{CO}_2}} \quad n_{\text{CO}_2} \text{ is mol of CO}_2$$

Solutions Chapter 8

$$n_{CO_2} = 1.51 \times 10^5 \text{ kg mol}$$

$$\frac{nRT}{p} = V_{CO_2} = \frac{(1.5 \times 10^5)(8.314)(273)}{101.3 \text{ kPa}} = [3.39 \times 10^6 \text{ m}^3]$$

Above would be the worst case. The CO₂ would be less; p_{CO₂} average might be a better choice to use in which case V_{CO₂} would be, say ½ the calculated amount.

8.5.23

- a. Apply Henry's law to solve the problem.

$$p = Hx \quad \text{or} \quad x = \frac{p}{H}$$

From the internet, H = 43,600 where x is the mole fraction in the liquid and p is in bars.

Enriched gas

$$x_{O_2} = \frac{\frac{(110)(0.397) \text{ kPa}}{43,600 \text{ bar}} \left| \begin{array}{l} 1 \text{ bar} \\ 100 \text{ kPa} \end{array} \right.}{\text{mol fr.}} = 1.00 \times 10^{-5} \text{ mol fr.}$$

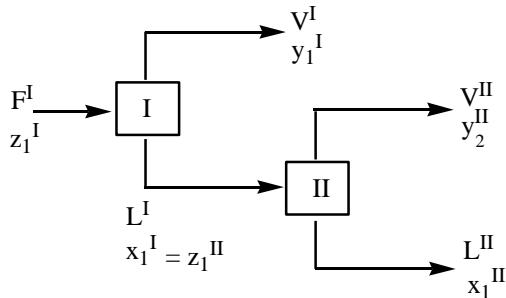
- b. To compare enriched gas with nonenriched gas

$$\frac{x_{\text{enriched}}}{x_{\text{nonenriched}}} = \frac{\left(\frac{p}{H} \right)_{\text{enriched}}}{\left(\frac{p}{H} \right)_{\text{nonenriched}}} = \frac{(110)(0.397)}{(110)(0.21)} = 1.89$$

$$\text{percent excess is: } \frac{1.89 - 1}{1} (100) = [89\%]$$

Solutions Chapter 8

8.5.24

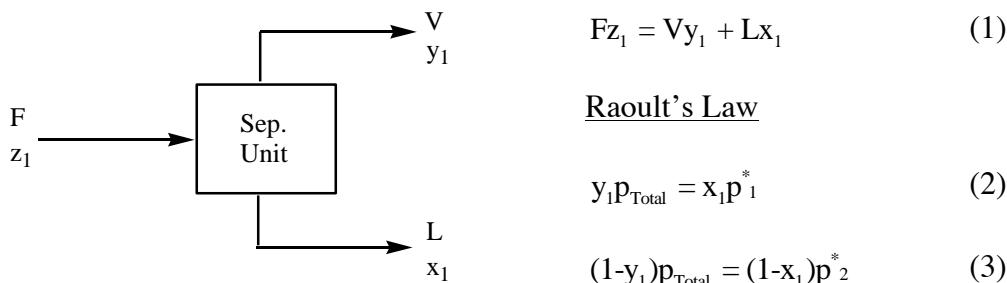


1 designates component A

2 designates component B

For each of the separation units we can write a mass balance and an equilibrium relationship, e.g., Raoult's Law.

Material balance on Comp. 1



Solve for y₁ in (1):

$$y_1 = \left(\frac{Fz_1}{V} \right) - \left(\frac{L}{V} \right) x_1 \quad (4)$$

Introduce in (2):

$$\left[\left(\frac{Fz_1}{V} \right) - \left(\frac{L}{V} \right) x_1 \right] p_{Total} = x_1 p_1^*$$

Basis: 1 minute

Introduce the given values

$$p_1^* = 10 \text{ kPa} \quad p_2^* = 100 \text{ kPa}$$

$$F^I = 100 \text{ mol} \quad L^I = 50 \text{ mol}$$

Solutions Chapter 8

$$V^I = 50 \text{ mol} \quad V^{II} = 25 \text{ mol}$$

$$L^I = 25 \text{ mol}$$

$$z_1 = 0.50$$

The solution is

$$p_{\text{1}}^* = 10 \text{ kPa}$$

$$p_{\text{2}}^* = 100 \text{ kPa}$$

$$p_{\text{1}}^* = 10 \text{ kPa}$$

$$p_{\text{2}}^* = 100 \text{ kPa}$$

Unit I

$$F^I = 100 \text{ mol/s}$$

$$L^I = 50 \text{ mol/s}$$

$$V^I = 50 \text{ mol/s}$$

$$z_1^I = 0.5$$

Unit II

$$F^{II} = 50 \text{ mol/s}$$

$$L^{II} = 25 \text{ mol/s}$$

$$V^{II} = 25 \text{ mol/s}$$

$$z_1^{II} = 0.75975$$

$x_1^I = 0.75975 = z_1^{II}$
$x_2^I = 0.24025 = z_2^{II}$
$y_1^I = 0.24025$
$y_2^I = 0.75975$
$p_{\text{Total}}^I = 31.62 \text{ kPa}$

$x_1^{II} = 0.93391$
$x_2^{II} = 0.06609$
$y_1^{II} = 0.58559$
$y_2^{II} = 0.41441$
$p_{\text{Total}}^{II} = 15.95 \text{ kPa}$

8.6.1

Apply K values to solve the problem. Get the mole fraction of the compound in the liquid phase.

Basis: 100 g water (5.555 g/mol)

	<u>g</u>	<u>MW</u>	<u>g/mol</u>	<u>g/mol</u>	<u>liquid</u> <u>H₂O</u>	<u>K</u>	<u>vapor</u> <u>y (mol fr.)</u>
Glycerol	5.5	92.08	0.0597	5.555	0.0106	1.2×10^{-7}	1.27×10^{-9}
MEK	1.1	72.10	0.0153	5.555	0.00275	3.065	0.00843
Phenol	2.1	94.11	0.0223	5.555	0.00400	0.00485	1.94×10^{-5}

The mole fractions in the gas phase are in the far right hand column. Glycerol and phenol have the lowest concentrations. If volatilization is proportional to the vapor phase concentration, only MEK might be a problem.

Solutions Chapter 9

9.1.1

Basis: 1 lb_m

a.
$$\frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \begin{array}{c} 252 \text{ cal} \\ 1 \text{ Btu} \end{array} \right| \left| \begin{array}{c} 1 \text{ lb}_m \\ 0.454 \text{ kg} \end{array} \right| = \boxed{2.5 \times 10^4 \text{ cal / kg}}$$

b.
$$\frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \begin{array}{c} 1.055 \times 10^3 \text{ J} \\ 1 \text{ Btu} \end{array} \right| \left| \begin{array}{c} 1 \text{ lb}_m \\ 0.454 \text{ kg} \end{array} \right| = \boxed{1.048 \times 10^5 \text{ J / kg}}$$

c.
$$\frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \begin{array}{c} 2.930 \times 10^{-4} (\text{kW})(\text{hr}) \\ 1 \text{ Btu} \end{array} \right| \left| \begin{array}{c} 1 \text{ lb}_m \\ 0.454 \text{ kg} \end{array} \right| = \boxed{2.91 \times 10^{-2} \frac{(\text{kW})(\text{hr})}{\text{kg}}}$$

d.
$$\frac{45.0 \text{ Btu}}{\text{lb}_m} \left| \begin{array}{c} 7.7816 \times 10^2 (\text{ft})(\text{lb}_f) \\ 1 \text{ Btu} \end{array} \right| = \boxed{3.5 \times 10^4 (\text{ft})(\text{lb}_f) / \text{lb}_m}$$

9.1.2

a.
$$\frac{4.184 \text{ J}}{(\text{g})(\text{°C})} \left| \begin{array}{c} 9.484 \times 10^{-4} \text{ Btu} \\ \text{J} \end{array} \right| \left| \begin{array}{c} 1 \text{ g} \\ 2.2 \times 10^{-3} \text{ lb}_m \end{array} \right| \left| \begin{array}{c} 1 \text{ °C} \\ 1.8 \text{ °F} \end{array} \right| = \boxed{\frac{1.00}{(\text{lb}_m)(\text{°F})}}$$

b.
$$\frac{-41.6 \text{ J}}{\text{kg}} \left| \begin{array}{c} 9.484 \times 10^{-4} \text{ Btu} \\ \text{J} \end{array} \right| \left| \begin{array}{c} \text{kg} \\ 1000 \text{ g} \end{array} \right| \left| \begin{array}{c} 1 \text{ g} \\ 2.20 \times 10^{-3} \text{ lb}_m \end{array} \right| = \boxed{-0.0179 \frac{\text{Btu}}{\text{lb}_m}}$$

c.
$$\frac{0.59 (\text{kg})(\text{m})}{(\text{s}^3)(\text{K})} \left| \begin{array}{c} 1 \text{ N} \\ (\text{kg})(\text{m})(\text{s}^{-2}) \end{array} \right| \left| \begin{array}{c} (\text{J})(\text{m}^{-1}) \\ 1 \text{ N} \end{array} \right| \left| \begin{array}{c} 9.484 \times 10^{-4} \text{ Btu} \\ \text{J} \end{array} \right| \left| \begin{array}{c} 1 \text{ m} \\ 3.2808 \text{ ft} \end{array} \right| \left| \begin{array}{c} 3600 \text{ s} \\ \text{hr} \end{array} \right| \left| \begin{array}{c} 1 \text{ K} \\ 1.8 \text{ °F} \end{array} \right|$$

$$= \boxed{0.341 \frac{\text{Btu}}{(\text{ft})(\text{hr})(\text{°F})}}$$

9.1.3

a.
$$\frac{6000 \text{ Btu}}{(\text{hr})(\text{ft}^2)} \left| \begin{array}{c} 252 \text{ cal} \\ \text{Btu} \end{array} \right| \left| \begin{array}{c} \text{hr} \\ 3600 \text{ s} \end{array} \right| \left| \begin{array}{c} \text{ft}^2 \\ 30.48^2 \text{ cm}^2 \end{array} \right| = \boxed{0.4521 \frac{\text{cal}}{(\text{s})(\text{cm}^2)}}$$

b.
$$\frac{2.3 \text{ Btu}}{(\text{lb})(\text{°F})} \left| \begin{array}{c} 252 \text{ cal} \\ \text{Btu} \end{array} \right| \left| \begin{array}{c} \text{lb} \\ 453.6 \text{ g} \end{array} \right| \left| \begin{array}{c} (\Delta) 1.8 \text{ °F} \\ (\Delta) \text{°C} \end{array} \right| = \boxed{2.3 \frac{\text{cal}}{(\text{g})(\text{°C})}}$$

Solutions Chapter 9

c.
$$\frac{200 \text{ Btu}}{(\text{hr})(\text{ft})(^{\circ}\text{F})} \left| \begin{array}{c} 1,055 \text{ J} \\ \text{Btu} \end{array} \right| \left| \begin{array}{c} \text{hr} \\ 3600 \end{array} \right| \left| \begin{array}{c} \text{ft} \\ 30.45 \text{ cm} \end{array} \right| \left| \begin{array}{c} (\Delta) 1.8^{\circ}\text{F} \\ (\Delta)^{\circ}\text{C} \end{array} \right| = \boxed{3.46 \frac{\text{J}}{(\text{s})(\text{cm})(^{\circ}\text{C})}}$$

d.
$$\frac{10.73 (\text{lb}_f)(\text{ft}^3)}{(\text{in.}^2)(\text{lb mol})(^{\circ}\text{R})} \left| \begin{array}{c} 144 \text{ in.}^2 \\ \text{ft}^2 \end{array} \right| \left| \begin{array}{c} \text{Btu} \\ 778 (\text{ft})(\text{lb}_f) \end{array} \right| \left| \begin{array}{c} \text{lb mol} \\ 453.6 \text{ g mol} \end{array} \right| \left| \begin{array}{c} 1.055 \times 10^3 \text{ J} \\ \text{Btu} \end{array} \right| \left| \begin{array}{c} (\Delta) 1.8^{\circ}\text{R} \\ (\Delta)^{\circ}\text{K} \end{array} \right| = \boxed{8.31 \frac{\text{J}}{(\text{g mol})(^{\circ}\text{K})}}$$

9.1.4

Basis: 10^{11} watts

$$\frac{10^8 \text{ W}}{10^3 (\text{W})(\text{hr})} \left| \begin{array}{c} 8.6057 \times 10^5 \text{ cal} \\ \text{hr} \end{array} \right| \left| \begin{array}{c} 1 \text{ hr} \\ 60 \text{ min} \end{array} \right| \left| \begin{array}{c} 1 \\ 0.10 \end{array} \right| \left| \begin{array}{c} (\text{min})(\text{cm}^2) \\ 32.0 \text{ cal} \end{array} \right| \left| \begin{array}{c} 1 \text{ m}^2 \\ (100 \text{ cm})^2 \end{array} \right| = 4.5 \times 10^4 \text{ m}^2 \quad \boxed{\text{large}}$$

9.1.5

- (a) T; (b) T; (c) F; (d) F; (e) T

9.1.6

- (a) T; (b) T; (c) T; (d) T; (e) T; (f) F; (g) F

9.1.7

partial pressure	intensive
volume	extensive
specific gravity	intensive
potential energy	extensive
relative saturation	intensive
specific volume	intensive
surface tension	intensive
refractive index	intensive

Solutions Chapter 9

9.1.8

- a. Intensive
- b. Intensive
- c. Intensive
- d. Extensive

9.1.9

To convert to $J/(min) (cm^2) ({}^\circ C)$, we set up the dimensional equation as follows

$$h = \frac{0.026 G^{0.6} \text{ Btu}}{D^{0.4} (\text{hr}) (\text{ft}^2) ({}^\circ F)} \left| \frac{1055 \text{ J}}{1 \text{ Btu}} \right| \left| \frac{1 \text{ hr}}{60 \text{ min}} \right| \left(\frac{1 \text{ ft}}{12 \text{ in.}} \right)^2 \left(\frac{1 \text{ in.}}{2.54 \text{ cm}} \right)^2 \left| \frac{1.8 {}^\circ F}{1 {}^\circ C} \right.$$
$$= 8.86 \times 10^{-4} \frac{G^{0.6} \text{ J}}{D^{0.4} (\text{min})(\text{cm}^2)({}^\circ C)}$$

9.1.10

a. $\frac{1 \text{ lb fat}}{2.2 \text{ lb}} \left| \frac{1 \text{ kg}}{\text{kg}} \right| \left| \frac{7,700 \text{ k cal}}{500 \text{ k cal}} \right| \left| \frac{\text{day}}{4.184 \text{ k J}} \right| = [7 \text{ days}]$

b. $\frac{1 \text{ lb fat}}{2.2 \text{ lb}} \left| \frac{1 \text{ kg}}{\text{kg}} \right| \left| \frac{7,700 \text{ k cal}}{1 \text{ k cal}} \right| \left| \frac{4.184 \text{ k J}}{400 \text{ k J}} \right| \left| \frac{\text{km}}{0.6214 \text{ mi}} \right| = [22.75 \text{ mi}]$

- c. Total energy consumed is the same. The higher power consumption is compensated for in the shorter travel time.

Solutions Chapter 9

9.1.11

a.

$$\frac{975 \text{ W}}{\text{m}^2} \left| \begin{array}{l} \text{A m}^2 \\ \hline 1 \end{array} \right| \left| \begin{array}{l} 320 \text{ days} \\ | \\ 24 \text{ hr} \\ | \\ 5 \text{ } \end{array} \right| \left| \begin{array}{l} 0.21 \\ | \\ 25 \end{array} \right| \left| \begin{array}{l} 3.6 \times 10^6 \text{ J} \\ | \\ 1(\text{kW})(\text{hr}) \end{array} \right|$$

$$= 3 \times 10^{20} \text{ J}$$

$$A = 2.5 \times 10^{11} \text{ m}^2 \quad (2.5 \times 10^5 \text{ km}^2)$$

The capital cost is probably too great and the maintenance too high relative to other power sources. Also, the location would have to be in the far western united so power would have to be transmitted over long distances.

b.

$$3 \times 10^{20} \text{ J} = \frac{10,000 \text{ Btu}}{\text{lb}} \left| \begin{array}{l} 2,000 \text{ lb} \\ | \\ \text{ton} \end{array} \right| \left| \begin{array}{l} T \text{ tons} \\ | \\ 1055 \text{ J} \\ | \\ 1 \text{ Btu} \end{array} \right| \left| \begin{array}{l} 0.70 \\ | \end{array} \right|$$

$$T = 2.0 \times 10^{10} \text{ tons}$$

$$\frac{2.0 \times 10^{10}}{1.7 \times 10^{12}} = \boxed{0.012}$$

9.1.12

First substitute for $T_{\circ F}$

$$T_{\circ F} = T_{\circ C}(1.8) + 32$$

Next change units

$$k = \frac{\{a + b[T_{\circ C}(1.8) + 32]\}\text{Btu}}{(\text{hr})(\text{ft})(^{\circ}\text{F})} \left| \begin{array}{l} 1055 \text{ J} \\ | \\ 1 \text{ Btu} \end{array} \right| \left| \begin{array}{l} 1 \text{ ft} \\ | \\ 12 \text{ in} \\ | \\ 2.54 \text{ cm} \end{array} \right| \left| \begin{array}{l} 1 \text{ in} \\ | \\ 60 \text{ min} \end{array} \right| \left| \begin{array}{l} 1 \text{ hr} \\ | \\ 10 \text{ K} \end{array} \right| 1.80^{\circ}\text{F}$$

$$= 1.05 [a + b(T_{\circ C}(1.8) + 32)] \frac{\text{J}}{(\text{min})(\text{cm})(\text{K})} \quad \text{or } k = 1.05 a + 1.8 b T_{\circ C} + 33.2$$

Solutions Chapter 9

9.1.13

$$\frac{900,000 \text{ J}}{9 \times 10^{-3} \text{ s}} \left| \frac{(s)(10^{-3}) \text{ kW}}{1 \text{ J}} \right. = 10^5 \text{ kW or } 100 \text{ MW}$$

The answer is yes.

9.1.14

- (a) Some examples are:

How far would you have to run to lose 1 kg of fat?

$$\frac{32,000 \text{ kJ}}{400 \text{ kJ}} \left| \frac{1 \text{ km}}{1000 \text{ k cal}} \right. = 80 \text{ km}$$

about the distance of 2 marathons!

- (b) How many days would you have to reduce your diet from 2400 calories to 1400 calories to lose one kg of fat?

$$\frac{7700 \text{ k cal}}{1 \text{ kg fat}} \left| \frac{1 \text{ day}}{1000 \text{ k cal}} \right. = 8 \text{ days}$$

9.1.15

A main meal is equivalent to about 4000 kJ. A $\frac{1}{4}$ hour is 900 seconds, so that $(700 \text{ J/s})(900 \text{ s}) / 1000 = 630 \text{ kJ}$, an insufficient amount of time.

9.1.16

A closed system because no mass exchange occurs with the surroundings.

9.1.17

Yes. Watts are power, and if the energy is transferred for a very short period to time, the power can be quite large. For example, 1J (a very small amount of energy) transferred in 10^{-6}s is 1 MW!

Solutions Chapter 9

9.1.18

The trend is to advertise in a way that makes people select a product. And sometimes that just creates confusion.

What the manufacturer is doing is basing the advertisement on the *weight* of the hot dog. A hot dog weights about 43 grams and has 8 grams of fat in it. They divided 8 by 43 and get 19 percent fat. They can round it off to 20 and say it's 80 percent fat free.

But you are concerned with the percentage of fat in the *calories*. You want 30 percent or less to come from fat.

Your figures are right.

9.2.1

Basis: $40.0 \text{ Newtons} \times 6.00 \text{ m} = 240(\text{N})(\text{m})$

$$(a) \frac{240(\text{N})(\text{m})}{1(\text{N})(\text{m})} \left| \frac{1 \text{ J}}{1 \text{ N} \cdot \text{m}} \right| = \boxed{240 \text{ J}}$$

$$(b) \frac{240(\text{N})(\text{m})}{1(\text{N})(\text{m})} \left| \frac{0.738(\text{ft})(\text{lb}_f)}{1 \text{ N} \cdot \text{m}} \right| = \boxed{177.0(\text{ft})(\text{lb}_f)}$$

$$(c) \frac{240(\text{N})(\text{m})}{1(\text{N})(\text{m})} \left| \frac{1 \text{ J}}{1 \text{ N} \cdot \text{m}} \right| \left| \frac{0.239 \text{ cal}}{1 \text{ J}} \right| = \boxed{57.4 \text{ cal}}$$

$$(d) \frac{240(\text{N})(\text{m})}{1(\text{N})(\text{m})} \left| \frac{1 \text{ J}}{1 \text{ N} \cdot \text{m}} \right| \left| \frac{9.478 \times 10^{-4} \text{ Btu}}{1 \text{ J}} \right| = \boxed{0.226 \text{ Btu}}$$

9.2.2

The work done by the cylinder-piston system is $W = -p(V_2 - V_1)$

$$= - \frac{350 \text{ kPa}}{(1 \text{ kPa})(1 \text{ m}^3)} \left| 0.15 - 0.02 \text{ m}^3 \right| \left| \frac{1 \text{ kJ}}{1 \text{ N} \cdot \text{m}} \right| = \boxed{45.5 \text{ kJ}}$$

Solutions Chapter 9

9.2.3

No work is done because the boundary of the system remains fixed.

9.2.4

Basis: 2 kg mass

$$PE = mgh = \frac{12 \text{ kg}}{\text{s}^2} \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{25 \text{ m}}{1(\text{kg})(\text{m}^2)} \right| = \boxed{2940 \text{ J}}$$

9.2.5

Any correct examples will be satisfactory for (b), (c), and (d). But for (a), liquid to solid, there are probably no examples. If any, they would be pathological cases.

9.2.6

(1) Solid melting.

9.2.7

Basis: 10 lb water (5 lb vaporized)

The work done by the piston is caused by the water vapor expanding at constant temperature and pressure. Ignore the volume of the liquid water at the initial conditions, and assume the initial amount of vapor is also negligible. From state to state 2

$\Delta \hat{V}_{\text{vapor}} = 4.897 \text{ ft}^3/\text{lb}$ from the steam tables. For the 5 lb

$$V_2 = (5 \text{ lb})(4.897 \text{ ft}^3/\text{lb}) = 24.49 \text{ ft}^3$$

$$W = -\frac{89.65 \text{ lb}_f}{\text{in}^2} \left| \frac{144 \text{ in}^2}{1 \text{ ft}^2} \right| \left| \frac{(24.49 \text{ ft}^3)}{1(\text{lb}_f)(\text{ft})} \right| = \boxed{-3.16 \times 10^5 (\text{lb}_f)(\text{ft})}$$

9.2.8

- (a) T; (b) F; (c) T; (d) F; (e) F; (f) F; (g) T

Solutions Chapter 9

9.2.9

The comment is not a correct use of the term heat, which is a transfer of energy.

9.2.10

Conservation is confused with balancing. Heat is energy transferred from one system to another, and from the viewpoint of either system (for which an energy balance is made), heat is not conserved. Thus (a) is wrong, heat is part of a balance; (b) same as (a); (c) heat is not conserved—it is transferred and is part of the energy balance; (d) the answer should be no with the explanation offered.

9.2.11

- (a) Wrong. Heat is energy, not material.
- (b) Wrong. Heat is energy by definition.
- (c) Wrong. Heat is energy; cold is related to temperature.
- (d) Wrong. See (c).
- (e) Wrong. Heat is a transfer of energy.
- (f) Heat can be measured, but indirectly via temperature, mass, etc.
- (g) Wrong. See (a).
- (h) OK except for “or can be stored,” which is wrong.
- (i) Burning produces a change in the state of the reactants and products, but the change is not heat. Heat transfer can result from the change in state.
- (j) Heat cannot be stored and hence destroyed. Heat transfer can be terminated.

9.2.12

A better use of words than “absorbing heat” would be “to transfer heat.” Heat is really not “concentrated.” The internal energy of the medium increases.

Solutions Chapter 9

9.2.13

- (a) F; (b) F; (c) T; (d) F; (e) T; (f) T but debatable; (g) F; (h) F

9.2.14

Heat transfer rate is $\dot{Q}=hA\Delta T=h(\pi DL)\Delta T$

$$\dot{Q} = \frac{5 \text{ J}}{(\text{s})(\text{m}^2)(^\circ\text{C})} \left| \frac{5 \text{ cm}}{100 \text{ cm}} \right| \left| \frac{1 \text{ m}}{100 \text{ cm}} \right| \left| \frac{100\pi \text{ m}}{(120-20)^\circ\text{C}} \right| [7854 \text{ J/s}]$$

9.2.15

Basis: 1 minute

$$KE = \left(\frac{1}{2} \right) mv^2$$

$$v = \frac{500,000 \text{ g}}{\text{min}} \left| \frac{1 \text{ cm}^3}{1.15 \text{ g}} \right| \left| \frac{4}{\pi(5)^2 \text{ cm}^2} \right| = 22,143 \text{ cm/min}$$

$$KE = \frac{1}{2} \left| \frac{500 \text{ kg}}{\text{min}} \right| \left(\frac{22,143 \text{ cm}}{\text{min}} \right)^2 \left| \frac{1(\text{J})(\text{s}^2)}{1(\text{kg})(\text{m}^2)} \right| \left(\frac{1 \text{ min}}{60 \text{ s}} \right)^2 \left(\frac{1 \text{ m}}{100 \text{ cm}} \right)^2 = [6810 \text{ J}]$$

9.2.16

Basis: 1 lb_m H₂O KE = 1/2 mv²

$$KE = \frac{1}{2} \left| \frac{1 \text{ lb}_m}{\text{s}} \right| \left(\frac{10 \text{ ft}^2}{\text{s}} \right) \left| \frac{(\text{lb}_f)(\text{s}^2)}{32.2 (\text{lb}_m)(\text{ft})} \right| = [1.55 (\text{ft}) (\text{lb}_f)]$$

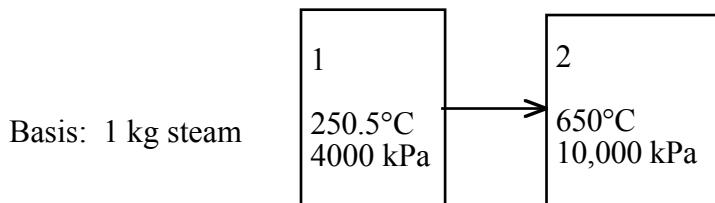
Solutions Chapter 9

9.2.17

Relative to the reference values in the steam tables and the CD:

- (a) $U = 3528 \text{ kJ/kg}$ (from the steam tables)
- (b) The quality is 0.13% and $U = 1213 \text{ kJ/kg}$ from the steam tables
- (c) At 100°C and 1000 kPa, U of the liquid is about $U \approx 532 \text{ kJ/kg}$ from the steam table

9.2.18



$\Delta U = \Delta H - \Delta pV$ or use U values directly from SI tables or computer code.

Data here taken from the steam tables.

	State 1 (assumed saturated)	State 2 (superheated)
T	250.5°C (523.5 K)	650°C (923 K)
	482°F	1202°F
p	4000 kPa abs.	10,000 kPa abs.
\hat{V}	580 psia	1450 psia
ΔU	0.498 m ³ /kg	0.04117 m ³ /kg
ΔH (ref. satd liquid at 0°C)	2602 kJ/kg	3338 kJ/kg
	2801 kJ/kg	3742 kJ/kg

Solutions Chapter 9

9.2.19

Internal energy is the energy contained in the material of a system because of its molecular arrangement. Heat is energy that flows between the system and the surroundings because of a temperature gradient. Therefore they are not the same class of energy.

9.2.20

$$\Delta H = \Delta U + \Delta(pV)$$

When a liquid vaporizes $\Delta(pV)$ adds to ΔU .

9.2.21

ΔH and ΔU are zero because ΔH and ΔU are point (state) functions (variables).

9.2.22

None. The initial and final states for U and H are the same.

9.2.23

The energy balance is $\Delta E = \Delta U + \Delta PE + \Delta KE = Q + W$

	Q	W	ΔE	ΔU
(a)	>0	0	>0	>0
(b ₁)	0	>0	>0	>0
(b ₂)	0	>0	>0	>0
(c)	0	>0	>0	>0

9.2.24

- | | | | |
|-----|---|-----|---|
| (a) | T | (f) | F |
| (b) | F | (g) | F |
| (c) | F | (h) | F |
| (d) | T | (i) | T |
| (e) | F | (j) | T |

Solutions Chapter 9

9.2.25

- | | | | | | |
|-----|---|-----|---|-----|---|
| (a) | F | (f) | T | (k) | T |
| (b) | F | (g) | F | (l) | F |
| (c) | F | (h) | T | (m) | T |
| (d) | T | (i) | F | (n) | T |
| (e) | T | (j) | F | | |

9.2.26

- (a) 1; (b) 3; (c) 5; (d) 2; (e) 4

The boiling temperature is at 4 reading to the left scale (100°C)

The freezing temperature is at 1 reading to the left scale (0°C)

9.2.27

$$T_c = 540.2 \text{ K} \quad p_c = 27 \text{ atm}$$

$$\Delta H_v = T_b \frac{\frac{0.0331}{T_c} - 0.0327 + 0.0297 \log(p_c)}{1.07 - \left(\frac{T_b}{T_c}\right)} \frac{\text{kJ}}{(\text{g mol})(\text{K})}$$

$$\Delta H_v = 31.679 \frac{\text{kJ}}{\text{g mol}}$$

The percent error is negligible in view of the precision of the data.

9.2.28

Below log is \log_{10} . The critical temperature = 408.1 K

$$C_p = A + B \log T_r$$

Basis: 1 g mol

$$B = \frac{C_{p_1} - C_{p_2}}{\log T_{r_1} - \log T_{r_2}} \quad ; \quad A = C_{p_1} - B \log T_{r_1}$$

Solutions Chapter 9

$$C_{p_1} = 97.3 \quad T_{r_1} = 300 / 408.1 = 0.735 \quad \log T_{r_1} = 0.134$$

$$C_{p_2} = 149.0 \quad T_{r_2} = 500 / 408.1 = 1.225 \quad \log T_{r_2} = 0.088$$

$$A = 128.5 \quad B = 232.6$$

$$\text{at } 1000 \text{ K: } T_{r_{1000}} = 1000 / 408.1 = 2.45 \quad \log T_{r_{1000}} = 0.389$$

$$C_p = 128.5 + 232.6(0.389) = \boxed{219.0 \text{ J/(g mol)(K)}}$$

$$(100) \frac{227.6 - 219.0}{227.6} = \boxed{3.8\%}$$

9.2.29

$$\Delta H = 2 \int_{50+273}^{250+273} (27.32 + 0.6226 \times 10^{-2}T - 0.0950 \times 10^{-5}T^2) dT$$

$$\boxed{\Delta H = 11,980 \text{ J}} \quad (\text{The CD gives } 11,784 \text{ J})$$

9.2.30

Integrate the heat capacity equation, use Table D3 in the Appendix, or use CD

From the CD $\Delta H = 2580 \text{ J/g mol}$

9.2.31

The volume of the wire is $\left(\frac{\pi D^2}{4}\right)5.5 = \pi \frac{(0.25)^2}{4}(5.5) = 0.27 \text{ cm}^3$. The density of Al is 19.35 g/cm³, so $19.35(0.27) = 5.22 \text{ g}$ or 0.194 g mol Al . From Perry, $C_p = 20.0 + 0.0135T$ (T in K, C_p in J/(g mol)(°C) and $\Delta H_{\text{fusion}} = 10,670 \text{ J/g mol}$ at 660°C.

$$\Delta H = 0.194 \left[\int_{25+273}^{660+273} (20.0 + 0.0135T) dT + 10,670 \right] = 5560 \text{ J}$$

$$5560(2.773 \times 10^{-7}) = 1.54 \times 10^{-3} \text{ kWh}$$

Solutions Chapter 9

9.2.32

Basis: 5 ft³ vessel Vapor = 4 ft³, Liquid = 1 ft³

Steam tables: Sat'd steam at 1000 psia

$$\hat{V}_v = 0.44596 \frac{\text{ft}^3}{\text{lb}}$$

$$\hat{V}_l = 0.02159 \frac{\text{ft}^3}{\text{lb}}$$

lb mass fr.

$$m_l = \frac{1 \text{ ft}^3}{0.02159 \text{ ft}^3} \left| \begin{array}{c} \text{lb} \\ \hline 0.02159 \text{ ft}^3 \end{array} \right. = 46.32 \quad 0.838$$

$$m_v = \frac{4 \text{ ft}^3}{0.44596 \text{ ft}^3} \left| \begin{array}{c} \text{lb} \\ \hline 0.44596 \text{ ft}^3 \end{array} \right. = \underline{8.97} \quad \underline{0.162}$$

$$m_t = \quad \quad \quad 55.29 \quad \quad \quad 1.000$$

Quality = 0.162

9.2.33

We will use the steam tables for this problem.

Basis: 1 lb of H₂O at 60°F

From steam tables (ref. temp. = 32°F):

$$\hat{H} = 28.07 \text{ Btu/lb} \quad \text{at } 60^\circ\text{F}$$

$$\hat{H} = 1604.5 \text{ Btu/lb} \quad \text{at } 1150^\circ\text{F and 240 psig (254.7 psia)}$$

$$\Delta \hat{H} = (1604.5 - 28.07) = 1576.4 \text{ Btu/lb}$$

$$\Delta H = 1576(8.345) = 13.150 \text{ Btu/gal}$$

Note: The enthalpy value that has been used for liquid was taken from the steam tables for the saturated liquid under its own vapor pressure. Since the enthalpy of liquid water changes negligibly with pressure, no loss of accuracy is encountered for engineering purposes if the initial pressure on the water is not stated.

Solutions Chapter 9

9.2.34

Basis: 3 kg H₂O

The initial conditions are obtained from the SI steam tables for saturated liquid. Enthalpy is a function of the temperature and pressure, but the effect of pressure on liquid water under these conditions is negligible. Therefore the enthalpy of water at 300K and 101.3 kPa can be approximated by the enthalpy of saturated water at the same temperature but at the vapor pressure of 3.536 kPa.

The final conditions are presumably a state in which water is all vapor. A check of the steam tables shows this assumption to be true.

At

T(K)	p(kPa)	$\hat{\Delta H}$ (kJ/kg)
300	3.536	111.7
800	1500	3384.3

The enthalpy change is

$$\Delta H = \frac{3 \text{ kg}}{\text{kg}} \left| \frac{(3384.3 - 111.7) \text{ kJ}}{\text{kg}} \right| = 9817.8 \text{ kJ}$$

9.2.35

The amount of energy that the water gives up in cooling to 0°C is not enough to melt all the ice, since each gram of water will give up 209 J in cooling, while heating 1 g of ice to 0° and melting it requires that $2 \times 40 + 335 = 415$ J be expended (the heat capacity of ice is 2 J/(g) (°C)).

9.2.36

Yes. 40°F and saturated liquid is an arbitrary reference state for enthalpy that can be assigned a value of zero. Only enthalpy changes can be computed using the chart; the enthalpy itself cannot be determined.

Solutions Chapter 9

9.2.37

Basis: 1.2 ft³ gas at 7.3 atm

$$p \text{ of 1 atm} = 15,450 \text{ lb}_f/\text{ft}^2$$

$$pV^{1.3} = \text{const.}$$

$$V_1^{1.3} = (1.2)^{1.3} = 1.27$$

$$p_1 V_1^{1.3} = (15450)(1.27) = 19,620$$

$$W = - \int p dV = - \int_{V_1}^{19,620} \frac{1}{V^{1.3}} dV = 19,620 \int \frac{dV}{V^{1.3}} = - \left[\frac{19,620}{-0.3V^{0.3}} \right] V_1$$

$$V_2^{1.3} = \frac{(V_1^{1.3})(p_1)}{p_2} = \frac{(1.27)(7.3)}{(1.0)} = 9.27$$

$$V_2 = 5.54 \text{ ft}^3$$

$$V_1^{0.3} = (1.2)^{0.3} = 1.06$$

$$V_2^{0.3} = (5.54)^{0.3} = 1.67$$

$$W = \frac{19,620}{0.3} \left[\frac{1}{1.67} - \frac{1}{1.06} \right] = - \frac{(19,620)(0.344)}{0.3} = \boxed{-22,500(\text{ft})(\text{lb}_f)}$$

9.2.38

The density of air at 27°C and 1 atm is $\rho = \frac{(p)(MW)}{(RT)}$

$$\rho = \frac{101.3 \text{ kPa}}{1 \text{ kg mol air}} \left| \frac{29 \text{ kg air}}{1 \text{ kg mol air}} \right| \left| \frac{(\text{kg mol})(\text{K})}{8.314(\text{kPa})(\text{m}^3)} \right| \left| \frac{}{300 \text{ K}} \right| = 1.18 \text{ kg/m}^3$$

$$\text{Power} = \frac{1}{2} \text{ mv}^2 = \frac{1}{2} (\rho A v) v^2 = \frac{1}{2} \rho A v^3$$

Solutions Chapter 9

Assume air flow through the windmill is equivalent to the average flow in a pipe of diameter 15m.

$$v = \frac{20 \text{ mi}}{\text{hr}} \left| \frac{1.61 \times 10^3 \text{ m}}{1 \text{ mi}} \right| \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| = 8.94 \text{ m/s}$$

$$\text{Power} = \left(\frac{1}{2} \right) \frac{1.18 \text{ kg}}{\text{m}^3} \left| \frac{\pi \left(\frac{15}{2} \text{ m} \right)^2}{\left(\frac{8.94 \text{ m}}{\text{s}} \right)^3} \right| \left| \frac{1(\text{s}^2)\text{J}}{1(\text{kg})(\text{m}^2)} \right| \left| \frac{(\text{s})(\text{W})}{1 \text{ J}} \right| \left| \frac{1 \text{ kW}}{1000 \text{ W}} \right| = [74.46 \text{ kW}]$$

$$\text{Electrical energy} = (74.46)(0.30) = [22.3 \text{ kW}]$$

9.2.39

Basis: 1 lb_m of vehicle

a. $\frac{25,000 \text{ mi}}{\text{hr}} \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| \left| \frac{5280 \text{ ft}}{1 \text{ mi}} \right| = 36,600 \text{ ft/s}$

$$\text{K.E.} = \frac{1}{2} \left| \frac{1.34 \times 10^9 \text{ ft}^2}{\text{s}^2} \right| \left| \frac{1 \text{ lb}_m}{g_c} \right| = 2.08 \times 10^7 \frac{(\text{ft})(\text{lb}_f)}{\text{lb}_m}$$

$$\text{K.E.} = \frac{2.08 \times 10^7 (\text{ft})(\text{lb}_f)}{\text{lb}_m} \left| \frac{1 \text{ Btu}}{778 (\text{ft})(\text{lb}_f)} \right| = [2.68 \times 10^4 \text{ Btu / lb}_m]$$

- b. Heat capacity of, say, 1 Btu/(lb) (°F) gives

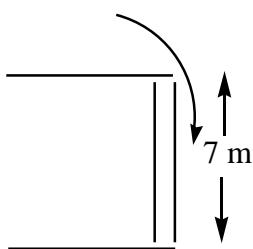
$$\frac{1 \text{ Btu}}{(\text{lb})(\text{°F})} \left| \frac{20 \text{ °F}}{} \right| = 20 \text{ Btu/lb}_m.$$

Essentially all the energy must be transferred to the surroundings

Solutions Chapter 9

9.2.40

Filled reservoir



Assume 7 meters is a constant level difference hence $h = 7\text{m}$

For one-half of the complete cycle (6 hours):

$$m = \rho Ah = \frac{10^3 \text{ kg}}{\text{m}^3} \left| \frac{23 \text{ km}^2}{\text{s}^2} \right| \left| \frac{7 \text{ m}}{\text{s}^2} \right| \left(\frac{10^3 \text{ m}}{1 \text{ km}} \right)^2 = 1.61 \times 10^{11} \text{ kg}$$

$$\Delta(\text{PE}) = \frac{1.61 \times 10^{11} \text{ kg}}{\text{s}^2} \left| \frac{9.80 \text{ m}}{\text{s}^2} \right| \left| \frac{7 \text{ m}}{\text{s}^2} \right| \left| \frac{1 \text{ J}}{(1 \text{ kg})(\text{m}^2)} \right| = 1.10 \times 10^{13} \text{ J}$$

For a complete cycle:

$$\frac{2 \left| 1.10 \times 10^{13} \text{ J} \right| 0.85}{370 \text{ min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right| = 4.23 \times 10^8 \text{ J/s}$$

or $5.06 \times 10^8 \text{ W}$

Solutions Chapter 9

9.2.41

The heat capacity of a monoatomic ideal gas is $\frac{5}{2}R$, and the heat capacity at constant volume is: $\frac{5}{2}R - R = \frac{3}{2}R$

You can show that $C_p = C_v + R$

$$C_p = \left(\frac{\partial \hat{H}}{\partial T} \right)_p = \left[\frac{\partial \hat{U} + \partial(p\hat{V})}{\partial T} \right]_p = \left(\frac{\partial U}{\partial T} \right)_p + p \left(\frac{\partial V}{\partial T} \right)_p$$

For the ideal gas \hat{U} is a function of T only (not of p or \hat{V}) so that

$$\left(\frac{\partial U}{\partial T} \right)_p = \left(\frac{\partial U}{\partial T} \right)_{\hat{V}} = C_v$$

$$p \left(\frac{\partial \hat{V}}{\partial T} \right)_p = p \left(\frac{R}{p} \right) = R$$

$$\Delta U = \int C_v dT = (3/2 R)(50) = \boxed{624 \text{ J}}$$

9.2.42

Use the same reference state, so that

$$\Delta \hat{H} = \Delta \hat{U} + \Delta(p\hat{V})$$

For one mole of an ideal gas: $p\hat{V} = RT$

$$\begin{aligned} \Delta \hat{U} &= \Delta \hat{H} - \Delta RT \\ &= 6.05 \times 10^5 \frac{\text{J}}{\text{kg mol}} - \frac{8.314 \text{ J}}{(\text{g mol})(\text{K})} \left| \frac{10^3 \text{ g mol}}{1 \text{ kg mol}} \right| \frac{[(100 + 273) - (273)] \text{ K}}{} \\ &= 6.05 \times 10^5 - 8.314 \times 10^5 \\ &= \boxed{-2.26 \times 10^5 \text{ J/kg mol}} \end{aligned}$$

Solutions Chapter 9

9.2.43

Basis: 100 mol gas

<u>Comp.</u>	<u>mol</u>
CO	68
H ₂	30
CO ₂	2
	100

$\hat{\Delta H}$ (J/g mol) relative to 0°C and 1 atm

	CO	H ₂	CO ₂
--	----	----------------	-----------------

25°C =	298 K	728	718	912
	1500 K	39,576	36,994	62,676
1400°C =	1673 K	45,723	42,724	72,896
	1750 K	48,459	45,275	77,445

Basis: 1000 m³ at 101 kPa and 1673 K

$$\frac{1000 \text{ m}^3}{1673 \text{ K}} \left| \frac{273 \text{ K}}{1673 \text{ K}} \right| \left| \frac{1 \text{ kg mol}}{22.4 \text{ m}^3} \right| = 7.28 \text{ kg mol}$$

Calculation of ΔH:

	<u>kg mol</u>	<u>$\hat{\Delta H}$ (kJ/kg mol)</u>	<u>ΔH(kJ)</u>
CO	7.28 (.68)	-44,995	-222,743
H ₂	7.28 (.30)	-42,010	-91,750
CO ₂	7.28 (.02)	-71,984	-10,481

Solutions Chapter 9

9.2.44

<u>K</u>	<u>°C</u>	<u>°F</u>	
423	150.0	302	vapor
353.3	80.1	176	↓ satd vapor
278.7	5.5	42	→ satd liquid
253.0	-20.0	-4	↓ Satd liquid
			→ satd solid
			↓ solid

Basis: 1 g mol

From Table D.1 in the Appendix.

Benzene properties:

Mol. wt.	78.11	Boiling point	353.26 K
Melting point	278.69 K	$\Delta H_{\text{vaporization}}$	30.76 kJ/g mol
ΔH_{fusion}	984 kJ/g mol		

<u>K</u>	<u>°C</u>
423	150
353.26	80.11
278.69	5.54
253	-20

Heat Capacity Equation Coefficients:

	<u>a</u>	<u>b</u>	<u>c</u>	<u>d</u>	<u>T</u>
Benzene(g)	74.06	32.95×10^{-2}	-25.20×10^{-5}	77.57×10^{-9}	$^{\circ}\text{C}$
Benzene(l)	62.55	23.9×10^{-2}	-	-	K

The C_p equation is in $^{\circ}\text{C}$ hence the limits on integration should be in $^{\circ}\text{C}$. $\Delta H_1 =$

$$\int_{423}^{353} (74.06 + 32.95 \times 10^{-2}T - 25.20 \times 10^{-5}T^2 + 77.57 \times 10^{-9}T^3) dT = -11,790 \text{ J/g mol}$$

Solutions Chapter 9

Condensation

$$\Delta H_2 = -3.076 \times 10^4 \text{ J/g mol}$$

Liquid

$$\Delta H_3 = \int_{353.26}^{278.69} (62.55 + 23.4 \times 10^{-2} T) dT = 10,180 \text{ J/g mol}$$

Fusion

$$\Delta H_4 = -9.84 \times 10^3 \text{ J/g mol}$$

Solid

From Perry, 5 th edition:	$C_p(\text{cal}/(\text{g})(^\circ\text{C}))$	$C_p(\text{J}/(\text{g mol})(^\circ\text{C}))$
	0°C 0.375	12.3
	-50°C 0.299	97.7

If a linear relationship exists between C_p and T,

$$C_{p,\text{av}} = 119 \text{ J}/(\text{g mol}) (^\circ\text{C}) \quad -11,790$$

$$\Delta H_s = \int_{5.5}^{-20.0} (119) dT = 3034 \text{ J/g mol} \quad -30,760$$

$$-10,180$$

$$\text{Overall, } \Delta H = \sum_{i=1}^5 \Delta H_i = 65,604 \text{ J/g mol} \quad -9,840$$

$$\frac{-3,034}{-65,604}$$

$$\frac{-65,604}{\text{g mol}} \left| \frac{\text{g mol}}{78.11} \right| \left| \frac{1000 \text{ g}}{\text{kg}} \right| = \boxed{-8.40 \times 10^5 \text{ J/kg}}$$

Solutions Chapter 9

9.2.45

Basis: liquid water at 32°F and 1 atm

a. $\Delta\hat{H} = 3(\hat{H}_{300^\circ\text{F}, 1 \text{ atm}} - \hat{H}_{32^\circ\text{F}, 1 \text{ atm}}) = 3(1192 - 0) = \boxed{3576 \text{ Btu}}$

b. Basis: liquid water at 40°F and 60 psia

$$\hat{H}_{32^\circ\text{F}, 60 \text{ psia}} = 0 \quad \Delta\hat{H} = 3(11192 - 0) = \boxed{3576 \text{ Btu}}$$

c. Basis: liquid water 40°F and 60 psia

$$\begin{aligned} \Delta\hat{H} &= (\hat{H}_{300^\circ\text{F}, 60 \text{ psia}} - \hat{H}_{40^\circ\text{F}, 60 \text{ psia}}) = (1181.4 - 8.05) \\ &= \boxed{1173.4 \text{ Btu}} \end{aligned}$$

d. Basis: water-steam mixture of 60% quality

State	$\Delta\hat{H}$, Btu/lb
1 60% steam - 40% water at 300°F; sat'd steam	1179.7
2 80% steam - 20% water at 300°F; water	269.6

$$\Delta\hat{H} = \hat{H}_2 - \hat{H}_1$$

$$\hat{H}_2 = (0.80)(1179.7) + (0.20)(269.6) = 998 \text{ Btu/lb}$$

$$\hat{H}_1 = (0.60)(1179.7) + (0.40)(269.6) = 816 \text{ Btu/lb}$$

Enthalpy change needed = $\Delta\hat{H}$

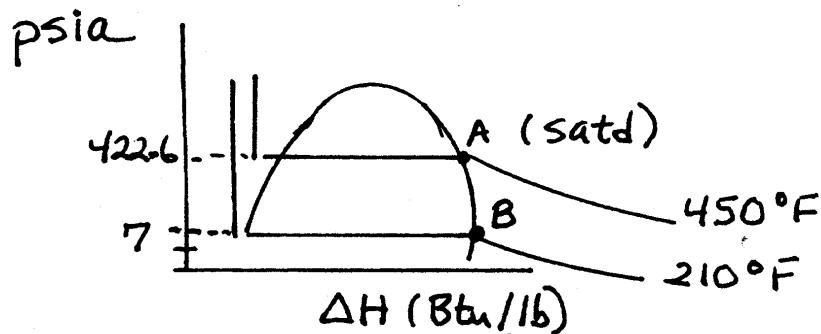
$$\Delta\hat{H} = \hat{H}_2 - \hat{H}_1 = \boxed{182 \text{ Btu / lb}}$$

e. Basis: steam at 500°F and 120 psia

$$\Delta\hat{H} = \hat{H}_2 - \hat{H}_1 = 312.5 - 1276.7 = \boxed{-964.2 \text{ Btu / lb}}$$

f. $\Delta\hat{H} = \hat{H}_2 - \hat{H}_1 = 487.8 - 1276.7 = \boxed{788.9 \text{ Btu / lb}}$

Solutions Chapter 9



Data from text

$$\Delta H_A = 1205.0$$

ΔH_B use tables in pocket

	210°F		
5 psia	<u>200°F</u>	1148.3	<u>250°F</u>
			1171.1
			a. Enthalpy decrease
7 psia	1146.7		1170.2
\hat{V}_A	1.0451 ft ³ /lb		
V_B	78.17	84.24	b. volume goes up
	38.88	41.96	
(h)	<u>40 psia and 267.24°F</u> sat steam/sat liquid	<u>70 psia/302°F</u> liquid	<u>70 psia/304°F</u> superheated steam

depending on heat supply

(i) 2.5 ft³ tank of water @ 160 psia and 363.5°F. @ 160 psia 6363.5 total volume is occupied by sat steam

$$\hat{V}_{\text{steam}} = 2.834 \text{ ft}^3/\text{lb} \Rightarrow m_{\text{steam}} = \frac{2.5}{2.834} = 0.88 \text{ lb}$$

$$\hat{V}_{\text{Liq/water}} = 0.0182 \text{ ft}^3/\text{lb} \Rightarrow \dot{m}_{\text{water}} = (1 - m_{\text{steam}})$$

$$V_{\text{water}} = \frac{2.5}{2.834} \times 0.0182 = [0.016 \text{ ft}^3]$$

Solutions Chapter 9

$$V_{\text{steam}} = 2.5 - 0.016 = 2.49 \text{ ft}^3$$

Of 5 lb H₂O assume x lb is sat steam $(5 - x)$ lb is sat. water

$$x(2.834) + (5 - x)(0.0182) = 2.5$$

$$\Rightarrow x(2.834 - 0.0182) = 2.5 - 5(0.0182)$$

$$\Rightarrow x = \frac{2.5 - 0.0910}{2.816} = 0.86 \text{ lb}$$

Yes, it is possible

(k) Enthalpy of 10 lb steam @ 100 psia = 9000 Btu

Enthalpy/lb steam @ 100 psia = 900 Btu

$\hat{\Delta H}_{\text{steam}}$ @ 100 psia = 1187.3 Btu

$\hat{\Delta H}_{\text{water}}$ @ 100 psia = 298.43 Btu

Let x be fraction of steam

(1-x) is fraction of water

$$(1187.3)x + (1-x) 298.43 = 900$$

$$x(1187.3 - 298.43) = 900 - 298.43 \quad x = \frac{601.57}{888.87} = 0.68$$

or 68%

9.2.46

State 1

$$T = 400 \text{ K}$$

$$p = 100 \text{ kPa}$$

State 2

$$T = 900 \text{ K}$$

$$p = 100 \text{ kPa}$$

a. From the steam tables in SI units (interpolation required):

$$(1) \hat{\Delta H}_1 = 2729.8 \text{ kJ/kg}$$

$$(2) \hat{\Delta H}_2 = 3763.6 \text{ kJ/kg}$$

Solutions Chapter 9

$$\hat{\Delta H} = 3763.6 - 2729.8 = 1033.8 \text{ kJ/kg}$$

$$\frac{1033.8 \text{ kJ}}{\text{kg}} \left| \frac{18 \text{ kg}}{\text{kg mol}} \right| \frac{2 \text{ kg mol}}{} = \boxed{3.7217 \times 10^4 \text{ kJ/2 kg mol}}$$

- b. Using the table for the enthalpies of combustion gases:

$$(1) \quad \hat{\Delta H} = 4284 \text{ J/g mol}$$

$$(2) \quad \hat{\Delta H} = 22,760 \text{ J/g mol}$$

$$\Delta H = 22760 - 4284 = 1.848 \times 10^4 \text{ J/g mol} = 1.848 \times 10^4 \text{ J/kg mol}$$

$$\frac{1.1848 \text{ kJ}}{\text{kg mol}} \left| \frac{2 \text{ kg mol}}{} \right. = \boxed{3.695 \times 10^4 \text{ kJ/2 kg mol}}$$

- c. Using the heat capacity equation for steam:

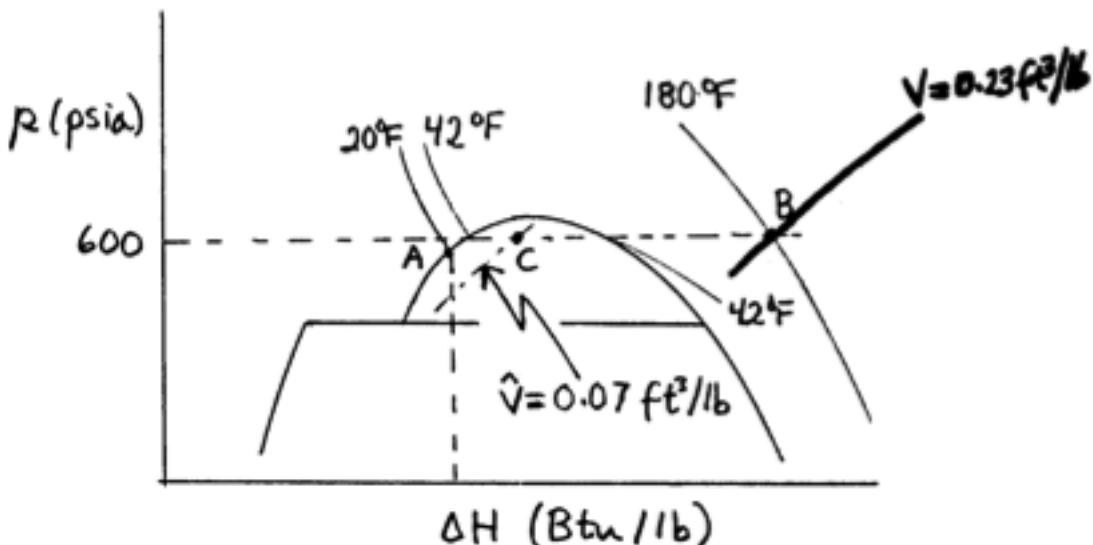
$$\begin{aligned} \Delta H &= \int_{127^\circ + 273}^{627^\circ C + 273} C_p dT = \int_{400}^{900} (33.46 + 0.6880 \times 10^{-2} T + 0.7604 \times 10^{-5} T^2 \\ &\quad - 3.593 \times 10^{-9} T^3) dT \\ &= 33.46 (900 - 400) + \frac{0.6880 \times 10^{-2}}{2} (-900^2 - 400^2) \\ &\quad + \frac{0.7604 \times 10^{-5}}{3} (900^3 - 400^3) - \frac{3.593 \times 10^{-9}}{4} (900^4 - 400^4) \\ &= 20,085 \text{ J/g mol} = 20,085 \text{ kJ/kg mol} \end{aligned}$$

$$\frac{20,085 \times 10^4 \text{ kJ}}{\text{kg mol}} \left| \frac{2 \text{ kg mol}}{} \right. = \boxed{4.017 \times 10^4 \text{ kJ/2 kg mol}}$$

The steam tables are the most accurate value.

Solutions Chapter 9

9.2.47



a-1: $\hat{V} \approx 0.23 \text{ ft}^3/\text{lb}$

a-2: gas

b-1: 42°F

b-2: mixture of liquid and vapor

9.2.48

Basis: 1 g mol CO₂

$$\Delta H = m \int_{50^\circ\text{C}}^{100^\circ\text{C}} (a + bT + cT^2 + dT^3) dT$$

$$\Delta H = m \left[a(100 - 50) + \frac{b}{2} (100^2 - 50^2) + \frac{c}{3} (100^3 - 50^3) + \frac{d}{4} (100^4 - 50^4) \right]$$

$$\Delta H = 1 \text{ g mol} \left[\begin{aligned} & 36.11(100 - 50) + \frac{4.233 \times 10^{-2}}{2} (100^2 - 50^2) - \frac{2.887 \times 10^{-5}}{3} (100^3 - 50^3) + \\ & \frac{7.464 \times 10^{-9}}{4} (100^4 - 50^4) \end{aligned} \right]$$

$\boxed{\Delta H = 1956 \text{ J}}$

From the CO₂ chart $\Delta H \approx 198 - 178 = 20 \text{ Btu/lb}$ or 2040 J/g mol . From the enthalpy tables (interpolating) $\Delta H = 1957 \text{ J/g mol}$. The CD gives 2038 J/g mol .

Solutions Chapter 9

9.2.49

$$\Delta H = 10(\hat{\Delta H}_2 - \hat{\Delta H}_1) = 10(86 - 288) = \boxed{2020 \text{ Btu}}. \text{ The CD gives } -1962 \text{ J.}$$

9.2.50

Assume the temperature is 80°F, and the propane is saturated liquid and vapor. The corresponding pressure is the saturation pressure, namely about 2.3 atm. Another temperature would correspond to another pressure. After 80% of the propane is used, the conditions are still saturated liquid-vapor mixture at 80°F and 2.3 atm.

9.2.51

Basis: 10 lb mol ideal gas

(a) Use $pV = nRT$

$$\Delta(p\hat{V}) = \Delta(RT)$$

$$(1) \frac{10 \text{ lb mol}}{\text{lb mol}} \left| \frac{359 (\text{ft})^3}{100 \text{ atm}} \right| \frac{1 \text{ atm}}{492^\circ\text{R}} \left| \frac{500^\circ\text{R}}{100 \text{ atm}} \right| = \boxed{36.5 (\text{ft})^3 @ 100 \text{ atm, } 40^\circ\text{F}}$$

$$(2) \frac{100 \text{ atm}}{500^\circ\text{R}} = \boxed{180 \text{ atm}}$$

$$(3) \Delta H = (\hat{H}_2 - \hat{H}_1) 10 = 10 [300 + 8.0 (440) - (300 + 8.0 (40))] = \boxed{32,000 \text{ Btu}}$$

(b) The equation for H is based on the reference conditions where $\hat{H} = 0$.

$\hat{H} = 0$ when $300 = -8T$ or $T_{\text{ref}} = -37.5^\circ\text{F} = -38.5^\circ\text{C}$. U should have the same reference temperature.

$$\Delta \hat{U} = \Delta \hat{H} - \Delta(p\hat{V}) = \Delta \hat{H} - \Delta RT \text{ for an ideal gas}$$

Change units for \hat{H} :

$$\text{First term: } \frac{300 \text{ Btu}}{\text{lb mol}} \left| \frac{1 \text{ lb mol}}{454 \text{ g mol}} \right| \left| \frac{1055 \text{ J}}{\text{Btu}} \right| = \frac{697 \text{ J}}{\text{g mol}} \quad T_{\circ\text{F}} = 1.8T_{\circ\text{C}} + 32$$

Solutions Chapter 9

Second term: $\frac{8.0 \text{ Btu}}{(\text{lb mol})(^{\circ}\text{F})} \left| \frac{1055 \text{ J}}{\text{Btu}} \right| \left| \frac{\text{lb mol}}{454 \text{ g mol}} \right| \left| \frac{(1.8T_{^{\circ}\text{C}} + 32)^{\circ}\text{F}}{} \right| = (33.5T_{^{\circ}\text{C}} + 595) \frac{\text{J}}{\text{g mol}}$

$$\hat{H}_{\text{ref T}} = 0$$

$$\Delta H = H_T - H_{\text{ref T}} = H_T \quad \Delta RT = (RT)_T - (RT)_{\text{ref T}} \quad (\text{T is absolute})$$

$$\Delta U = 697 + 595 + 33.5 T_{^{\circ}\text{C}} - R(T_{\text{ABS}} - T_{\text{ABS}_{\text{REF T}}})$$

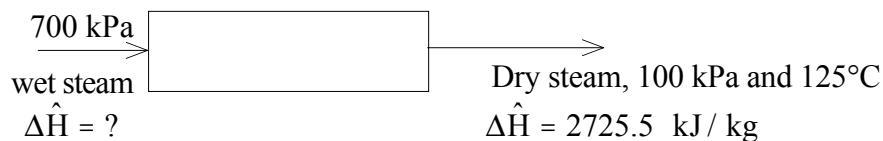
$$T_{\text{ABS}} = T_{^{\circ}\text{C}} + 273$$

$$T_{\text{ASS}_{\text{REF T}}} = -38.5 + 273$$

$$\Delta U = 1292 + 33.5 T_{^{\circ}\text{C}} - 1.987 (T_{^{\circ}\text{C}} + 38.5) = 1215 + 31.5 T_{^{\circ}\text{C}}$$

9.2.52

Steady state flow process, no reaction



The energy balances reduces to $\Delta H=0$ for this process. At 700 kPa saturated (438.1K)

$$\Delta \hat{H}_L = 696.7 \text{ kJ/kg}$$

$$\Delta \hat{H}_V = 2763.1 \text{ kJ/kg}$$

Let x = vapor fraction

$$(1-x)(696.7) + x(2763.1) = 2725.4$$

$$x = 0.98$$

9.3.1

All of them.

Solutions Chapter 9

9.3.2

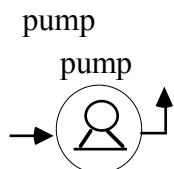
Closed unsteady state system

$$Q + W = \Delta U$$

$$60 + W = 220 \quad W = 160 \text{ Btu} \quad (\text{work done on the system})$$

9.3.3

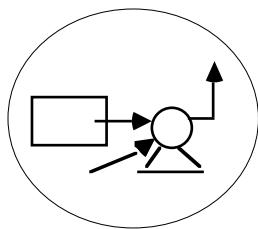
(a)



system is the pump. Open, steady state.

$\frac{Q}{\Delta U}$	$\frac{W}{\Delta H}$	$\frac{\Delta U}{\Delta H}$	$\frac{\Delta H}{\Delta P_E}$	$\frac{\Delta P_E}{\Delta K_E}$
Very little	Yes	No	Yes (flow)	No

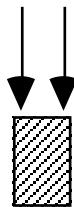
(b)



system is the pump and motor. Open, steady state

A little	Yes	No	Yes	No	No
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(c)

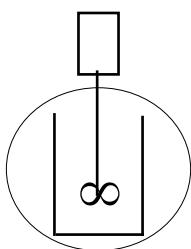


System is the ice. Closed, unsteady state.

Yes	No	Yes	Yes	No	No
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Solutions Chapter 9

(d)



system is the mixer and solution. The process is closed, unsteady state.

Possibly Yes

Yes

Yes

Yes

No

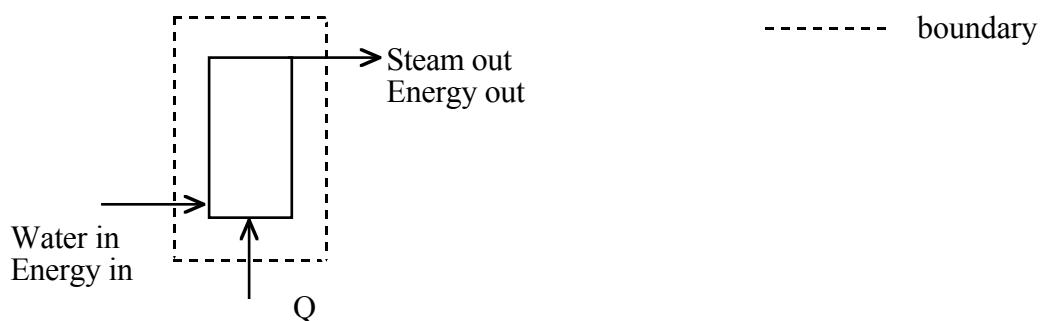
No

9.3.4

- a. System: can and liquid $Q = 0, W \neq 0$
- b. System: motor $Q = 0, W \neq 0$ But motor may get hot.
- c. System: pipe and water $Q = 0, W \neq 0$

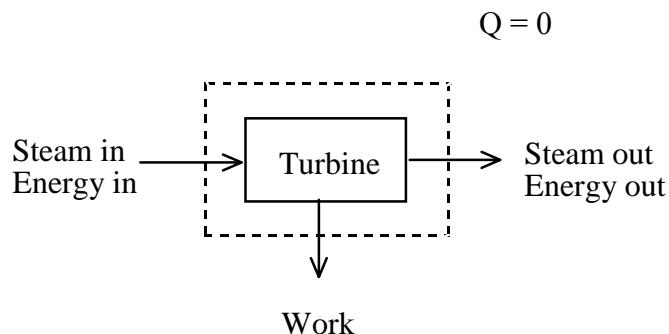
9.3.5

a.

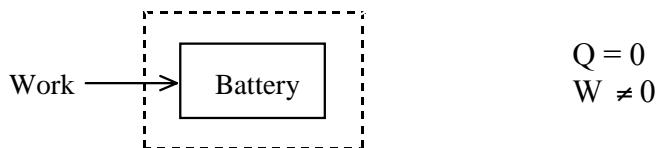


Solutions Chapter 9

b.



c.



9.3.6

No. The energy balance is $Q + W = \Delta U$, and for $Q = 0$ and since $\Delta U = 0$ for an isothermal process $[W = 0]$.

9.3.7

Closed unsteady state system

$$Q + W = \Delta U$$

$$\text{In kJ: } (30-5) + 0.5 = U_f - 10$$

$$U_f = 35.5 \text{ kJ}$$

Solutions Chapter 9

9.3.8

Closed unsteady state system

$$Q + W = \Delta U \quad Q = 0$$

$$W = \Delta U = C_v \Delta T$$

$$W = \frac{(100 \text{ W})(5 \text{ hr})}{1000 \text{ W}} \left| \frac{1 \text{ kW}}{3.6 \times 10^3 \text{ kJ}} \right| \frac{3.6 \times 10^3 \text{ kJ}}{1 \text{ kW}} = 1.8 \times 10^3 \text{ kJ}$$

$$\text{mols of air} = n = \frac{pV}{RT} = \frac{(100 \text{ kPa})(100 \text{ m}^3)}{303 \text{ K}} \left| \frac{(\text{kg mol})(\text{K})}{(8.314)(\text{kPa})(\text{m}^3)} \right| = 3.97 \text{ kg mol}$$

$$1.8 \times 10^3 = 30(3.97)(T - 30) \quad \boxed{T = 45^\circ\text{C}}$$

9.3.9

Closed unsteady state process

$$Q + W = \Delta U + \Delta(\text{PE})$$

Ignore change in center of mass of the air

$Q = 0$ assumed

$\Delta U = 0$ assumed (to get maximum elevation)

$$W = 100 \text{ J}$$

$$100 = \Delta(\text{PE}) = mg\Delta h = (0.990 \text{ kg})(9.80 \text{ m/s}^2) \Delta h (\text{m})$$

$$\boxed{\Delta h = 10.3 \text{ m}}$$

Solutions Chapter 9

9.3.10

Closed, unsteady state process

Initial conditions

$V = 1 \text{ ft}$ saturated dry satd. steam (the basis)

Look up

$$\hat{V} = 33.610 \text{ ft}^3/\text{lb}$$

$$\hat{H} = 1145.72 \text{ Btu/lb}$$

$$\hat{U} = 1073.96 \text{ Btu/lb}$$

$$p = 11.548 \text{ psia}$$

Calculate the lb of steam

$$m = \frac{1 \text{ lb}}{33.610 \text{ ft}^3} \left| \frac{1 \text{ ft}^3}{\hat{V}} \right| = 0.02975 \text{ lb}$$

$$Q + W = \Delta U$$

a. $[W = 0]$ (fixed boundary)

$$Q = \Delta U$$

b&c. $\Delta U = U_2 - U_1 = (1077.48) (0.02975) - (1073.96) (0.02975) = [0.105 \text{ Btu}] = Q$

d. The volume of the second tank is $V_{\text{final}} = (392.713) (0.02975) = 11.68$
 $V_2 = 11.68 - 1 = 10.68 \text{ ft}^3$

9.3.11

No. For each path $Q + W = \Delta U$, and for the cycle 1 to 2 and back $\Delta U = 0$. Addition gives

$$(Q_A + W_A) + (Q_B + W_B) = \Delta U_{1-2} + \Delta U_{2-1} = 0$$

$$(Q_A + Q_B) = -(W_A + W_B)$$

Note: The equations in the problem used a different sign for W . A similar analysis applies to the second equation in the problem.

9.3.12

A closed steady-state system.

The cooling at the maximum efficiency is

$$\frac{0.695 \text{ kW}}{(1 \text{ kW})(\text{s})} \left| \frac{0.948 \text{ Btu}}{1 \text{ hr}} \right| \left| \frac{3600 \text{ s}}{1 \text{ hr}} \right| = 2372 \text{ Btu/hr}$$

not 5500 Btu/hr.

The main question with the advertisement is: where does the energy go that is removed from the room if the unit does not require outside venting?

9.3.13

A closed steady-state system

$$\dot{Q} + \dot{W} = \Delta \dot{U} = 0$$

$$\dot{Q} = -\dot{W} \quad Q \text{ is negative (heat loss)}$$

$$\dot{Q} = -\frac{2050 \times 10^3 \text{ J}}{\text{hr}} \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| \left| \frac{10^{-3} \text{ kW}}{1(\text{J})(\text{s})} \right| = -0.57 \text{ kW}$$

$\dot{W} = 0.57 \text{ kW}$

9.3.14

A closed steady-state system

$$\dot{Q} + \dot{W} = \Delta \dot{U} = 0 \quad \dot{Q} = -\dot{W}$$

$$\dot{W} = \frac{0.25 \text{ hp}}{1 \text{ hp}} \left| 0.7068 \left(\frac{\text{Btu}}{\text{s}} \right) \right| \left| \frac{60 \text{ s}}{1 \text{ min}} \right| = 10.6 \text{ Btu/min}$$

$\dot{Q} = -10.6 \text{ Btu/min}$

Solutions Chapter 9

9.3.15

Open system, unsteady-state. The system is the volume containing 1 lb of H₂O at 27°C (liquid). At the end of the process the system contains nothing. The water leaving is at 100°C because the atmospheric pressure is 760 mm Hg.

$$Q + W = \Delta H \quad W = 0$$

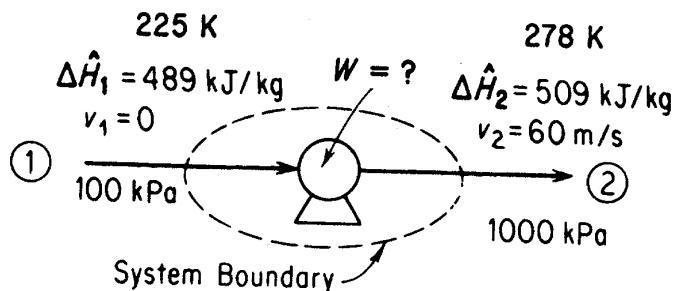
$$Q = \Delta H = \hat{H}_{\text{out}}(1) - \hat{H}_{\text{in}}(0)$$

The reference temperature for enthalpy is 0°C but the water is at

$$27^\circ\text{C}, \hat{H}_{\text{out}} = \hat{H}_{100^\circ\text{C}} - \hat{H}_{27^\circ\text{C}}$$

$$Q = (1 \text{ kg}) (2675.6 - 111.7) \text{ kJ/kg} = \boxed{2558 \text{ kJ}}$$

9.3.16



Steps 1, 2, 3, and 4:

Figure P22.27 shows the known quantities. No reaction occurs. The process is clearly a flow process (open system). Assume that the entering velocity of the air is zero.

Step 5:

Basis: 100 kg of air = 1 hr

Steps 6 and 7:

Simplify the energy balance (only one component exists):

$$\Delta E = Q + W - \Delta[\hat{H} + \hat{K}E + \hat{P}E]m$$

- (1) The process is in the steady state, hence $\Delta E = 0$.

Solutions Chapter 9

- (2) $m_1 = m_2 = m$.
- (3) $\Delta(\hat{P}E)(m) = 0$.
- (4) $Q = 0$ by assumption (Q would be small even if the system were not insulated).
- (5) $v_1 = 0$ (value is not known but would be small).

The result is

$$W = \Delta[\hat{H} + \hat{KE}]m = \Delta H + \Delta KE$$

We have one equation and one unknown, W . ΔKE and ΔH can be calculated, hence the problem has a unique solution.

Steps 7, 8, and 9

$$\Delta H = \frac{(509 - 489)\text{kJ}}{\text{kg}} \left| \frac{100 \text{ kg}}{} \right. = 2000 \text{ kJ}$$

$$\begin{aligned}\Delta KE &= \frac{1}{2}m(v_2^2 - v_1^2) \\ &= \left(\frac{1}{2} \right) \frac{100 \text{ kg}}{\text{s}^2} \left| \frac{(60 \text{ m}^3)}{} \right. \left| \frac{1 \text{ kJ}}{1000(\text{kg})(\text{m}^2)} \right. \\ &\quad \left. \left. \frac{}{(s)^2} \right| \right. = 180 \text{ kJ}\end{aligned}$$

$$W = (2000 + 180) = 2180 \text{ kJ}$$

(Note: The positive sign indicates work is done on the air.)

To convert to power (work/time),

$$\text{kW} = \frac{2180 \text{ kJ}}{1 \text{ hr}} \left| \frac{1 \text{ kW}}{1 \text{ kJ}} \right. \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right. = \boxed{0.61 \text{ kW}}$$

Solutions Chapter 9

9.3.17

(a) Steady state process assumed.

$$\Delta E = -\Delta \left[(\hat{H} + \hat{KE} + \hat{PE})m \right] + Q + W$$

1. Ignore \hat{PE} ; $\Delta \hat{PE} = 0$
2. $\Delta \hat{KE}$ is small so $\Delta \hat{KE} = 0$
3. No reaction
4. $W = 0$
5. $(E_2 - E_1) = 0$, steady state

$$\boxed{\Delta H = Q}$$

(b) $\Delta E = -[(\hat{H} + \hat{KE} + \hat{PE})m] + Q + W$

1. Ignore \hat{PE} ; $\Delta \hat{PE} = 0$
2. No reaction
3. $(E_2 - E_1) = 0$; steady state
4. $Q = 0$ – assumed
5. $W = 0$
6. $\Delta \hat{KE} = 0$

$$\boxed{\Delta H = 0}$$

9.3.18

System: gas

$$E_{t_2} - E_{t_1} = -\Delta \left[(\hat{H} + \hat{KE} + \hat{PE})m \right] + Q + W$$

- a. no reaction

$$-\Delta \left[(\hat{H} + \hat{KE} + \hat{PE})m \right] = 0, \text{ no flow}$$

ΔKE and ΔPE of gas = 0

$$\boxed{U_{t_2} - U_{t_1} = Q + W}$$

Solutions Chapter 9

b. Here $W = 0$

$$\boxed{U_{t_2} - U_{t_1} = Q}$$

c. Here $Q = 0$,

$$\boxed{U_{t_2} - U_{t_1} = W}$$

d. $\boxed{U_{t_2} - U_{t_1} = Q + W}$

e. Here, the system is the gas $Q = 0$, $W = 0$

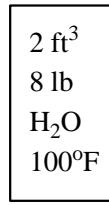
$$\boxed{U_{t_2} - U_{t_1} = 0}$$

9.3.19

(a) System is the tank

(c)

(b) Closed, unsteady state process



The 8 lb H₂O occupy
0.129 ft³ hence the rest
of space is vapor.
We will ignore the
initial vapor (see note
at end of solution) } (d1)

Basis: 8 lb H₂O

(d) { Initial data for H₂O are (satd liquid)
 $T = 100^\circ\text{F}$ $\hat{V} = 0.01613 \text{ ft}^3/\text{lb}$
 $p = 0.9487 \text{ psia}$ $\Delta\hat{H} = 67.97 \text{ Btu/lb}$ if neglect vapor

Basis: 1 hr

(e) { The energy balance is
 $\Delta E = [\Delta U + \Delta PE + \Delta KE]_{\text{inside}} = Q + W - \Delta H - \Delta PE - \Delta KE$
no change in PE or KE inside no mass transfer
 $\Delta U = W = \Delta H - \Delta(pV) = \Delta H - V\Delta p$

(f) $W = \frac{0.25 \text{ hp}}{1(\text{hp}) (\text{s})} \left| \frac{0.7068 \text{ Btu}}{1 \text{ hr}} \right| \frac{3600 \text{ s}}{1 \text{ hr}} = + 636 \text{ Btu}$

Solutions Chapter 9

This proves to be negligible quantity



$$(g1) \quad 636 = \Delta\hat{H}_{\text{final}}(8) - \frac{2 \text{ ft}^3}{\text{in}^2} \left| \frac{(p_{\text{final}} - 0.9487) \text{ lb}_f}{1 \text{ ft}^2} \right| \left| \frac{144 \text{ in}^2}{1 \text{ ft}^2} \right| \left| \frac{1 \text{ Btu}}{748(\text{ft})(\text{lb}_f)} \right|$$

(h) { Since p_{final} , \hat{V}_{final} , and $\Delta\hat{H}_{\text{final}}$ are in the tables, you have to get a $\Delta\hat{H}_{\text{final}}$, and \hat{V}_{final} vapor given an assumed p_{final} that satisfy the equation. $\Delta\hat{H}_{\text{final}}$ will be composed of saturated liquid and vapor. $\Delta\hat{H}_L(8-m) + \Delta\hat{H}_v(m) = \Delta\hat{H}_{\text{final}}$. $m = \text{lb vapor}$. (g3)

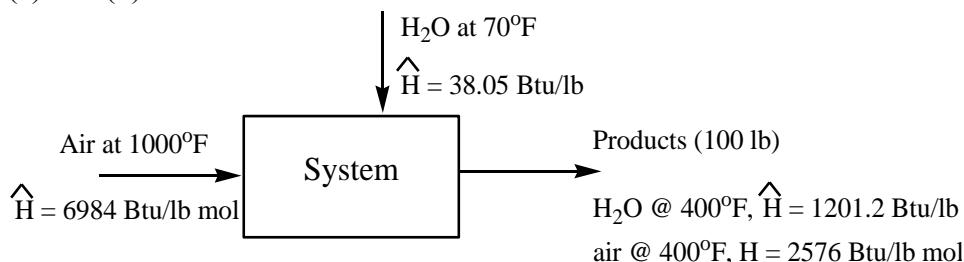
$$(g2) \quad 2 \text{ ft}^3 = \hat{V}_L(8-m) + \hat{V}_v(m).$$

\hat{V}_L , \hat{V}_v , $\Delta\hat{H}_L$, $\Delta\hat{H}_v$, and p_{final} are all related in the steam tables.

* \hat{V} of saturated vapor = $350.8 \text{ ft}^3/\text{lb}$ so that 1.87 ft^3 represents 0.0053 lb , a negligible amount relative to 2 lb .

9.3.20

- (a) The system is the mixing point of the 1000°F “air” and water at 70°F
- (b) Open system
- (c) and (d)



The enthalpies of water come from the steam tables. The properties of air come from the tables in Appendix D7 (with interpolation). The reference temperature for the enthalpy is 32°F .

Solutions Chapter 9

(e)
$$\underbrace{\Delta E = [\Delta U + \Delta PE + \Delta KE]}_{\text{inside}} = Q + W - \Delta H - \Delta PE - \Delta KE$$

- 0 because steady state
- Q is assumed to be 0 because time is short in transit
- W = 0 (none specified)
- $\Delta KE = \Delta PE = 0$ none with mass flow

Thus $\Delta H = 0$ or $\Delta H_{\text{out}} = \Delta H_{\text{in}}$

(f) The units in the balance will be Btu and lb

$$(n_{\text{air}})\Delta \hat{H}_{\text{air}} + (n_{\text{H}_2\text{O}})\Delta \hat{H}_{\text{H}_2\text{O}}(g) = (n_{\text{air}})\Delta \hat{H}_{\text{air}} + (n_{\text{H}_2\text{O}})\Delta \hat{H}_{\text{H}_2\text{O}} \quad (\text{e})$$

@ 400°F @ 400°F @ 1000°F (a) 70°F

$$\frac{(100)(2576)}{29} + (m_{\text{H}_2\text{O}})(1238.9) = (100)\frac{(6984)}{29} + m_{\text{H}_2\text{O}}(38.05)$$

9.3.21

a. $(E_2 - E_1) = -\Delta[\hat{H} + \hat{KE} + \hat{PE}]m + Q + W$ for all parts of this problem

1. Ignore \hat{PE} ; $\Delta \hat{PE} = 0$
2. $\Delta \hat{KE}$ is small so $\Delta \hat{KE} = 0$ (or it can be included)
3. No reaction
4. $W = 0$
5. $(E_2 - E_1) = 0$; steady state

$\boxed{\Delta H = Q}$

- b.
1. Ignore \hat{PE} ; $\Delta \hat{PE} = 0$
 2. No reaction
 3. $W = 0$
 4. $(E_2 - E_1) = 0$; steady state
 5. $Q = 0$

Solutions Chapter 9

$$-\Delta[\hat{H} + \widehat{\text{KE}}]m = 0$$

- c.
1. Ignore $\widehat{\text{PE}}$; $\Delta\widehat{\text{PE}} = 0$
 2. $\Delta\widehat{\text{KE}} = 0$
 3. No reaction
 4. $(E_2 - E_1) = 0$; steady state
 5. $Q = 0$ (assume)

$$\boxed{\Delta H = W}$$

- d.
1. Ignore $\widehat{\text{PE}}$; $\Delta\widehat{\text{PE}} = 0$
 2. No reaction
 3. $(E_2 - E_1) = 0$; steady state (may be not the $\widehat{\text{KE}}$)
 4. $Q = 0$ (assumed)

$$\boxed{\Delta[\hat{H} + \widehat{\text{KE}}]m = W}$$

Solutions Chapter 9

9.3.22

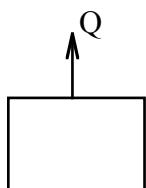
General balance is

$$\Delta E = [\Delta U + \Delta KE + \Delta PE]_{\text{inside}} = -\Delta[(\hat{H} + \hat{KE} + \hat{PE})m] + Q + W$$

(1) (2) (3) (4) (5) (6) (7) (8)

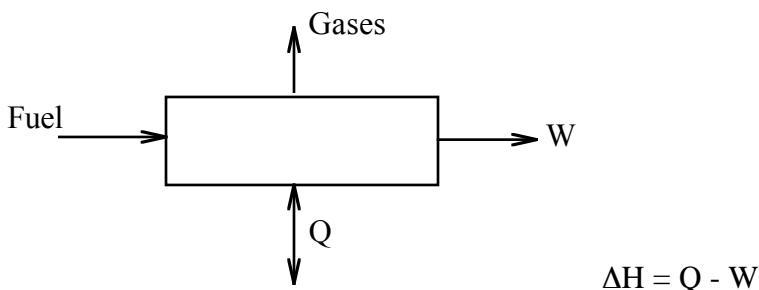
Assume all reactants are in bomb at start of reaction.

a.



- | | | | |
|---|--|---|---------------------------|
| 1 | ΔU retain because changes | 7 | Q retain |
| 2 | ΔKE delete - no change | 8 | W delete (fixed boundary) |
| 3 | ΔPE delete - no change | | |
| 4 | $\left. \begin{array}{l} \Delta H \\ \Delta KE \text{ delete as no mass flow in or out} \\ \Delta PE \end{array} \right\}$ | | |
| 5 | | | |
| 6 | | | |
- Result: $\Delta U = Q$

b.



- | | | | |
|---|-------------------------------------|---|------------------------|
| 1 | delete as negligible | 5 | delete as negligible |
| 2 | $\Delta E = 0$ because steady state | 6 | delete not a factor |
| 3 | | 7 | Q keep |
| 4 | ΔH keep | 8 | W keep (electric work) |

Result: $\Delta H = Q + W$

Solutions Chapter 9

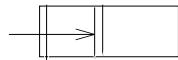
c.

- | | | | |
|---|-----------------------------|---|-----------------------------------|
| 1 | | 5 | ΔKE delete negligible |
| 2 | $\Delta U = 0$ steady state | 6 | ΔPE delete not applicable |
| 3 | | 7 | $Q = 0$ insulated applicable |
| 4 | ΔH is kept | 8 | $W = 0$ no work done |
- Result: $\Delta H = 0$

9.3.23

Unsteady state, closed, isothermal process at 25°C

Basis: 1 kg CO₂



$$\begin{aligned} p_1 &= 550 \text{ kPa} & p_2 &= 3500 \text{ kPa} \\ T_1 &= 25^\circ\text{C} & T_2 &= 25^\circ\text{C} \end{aligned}$$

$$\begin{aligned} \text{From CO}_2 \text{ chart} \quad \left\{ \begin{aligned} \hat{V}_1 &= 0.10 \text{ m}^3/\text{kg} \\ \Delta \hat{H} &= 205 \text{ kJ/kg} \end{aligned} \right. & \quad \left. \begin{aligned} \hat{V}_2 &= 0.0125 \text{ m}^3/\text{kg} \\ \Delta \hat{H}_2 &= 170 \text{ kJ/kg} \end{aligned} \right. \end{aligned}$$

(converted to SI units)

Energy balance

$$\Delta E = \Delta(U + PE + KE)_{\text{inside}} = Q + W - \Delta(H + PE + KE)$$

$$\Delta U = Q + W = \Delta H - \Delta(pV) \text{ so } Q = \Delta H - \Delta(pV) - W$$

$$\Delta H = (170 - 205)(1) = -35 \text{ kJ}$$

$$W = 4.106 \text{ kJ}$$

$$\Delta(pV) = \left[\frac{3500 \text{ kPa}}{\text{kg}} \middle| \frac{0.0125 \text{ m}^3}{\text{kg}} \right] - \left[\frac{550 \text{ kPa}}{\text{kg}} \middle| \frac{0.10 \text{ m}^3}{\text{kg}} \right] \left[\frac{10^3 \frac{\text{N}}{\text{m}^2}}{1 \text{ kPa}} \middle| \frac{1 \text{ J}}{1(\text{N})(\text{m})} \right] = -11.25 \text{ kJ}$$

$$Q = (-35) - (-11.25) - 4.106 \quad \boxed{-27.86 \text{ kJ/kg CO}_2 \text{ (removed)}}$$

Solutions Chapter 9

9.3.24

Pick the room as the system. The simplified form of the energy balance is (for no mass flow):

$$\Delta E = \Delta U = Q + W = \Delta U$$

where $Q = 0$ (room is insulated)

W = the electrical energy provided by the freezer through the system boundary and is positive. (No volume change occurs). Hence $\Delta U = C_v \Delta T$ is positive and ΔT is positive; i.e. the temperature increases.

9.3.25

This is an unsteady state closed process

Basis: 1 lb water

Data from the CD

Initial Conditions

$$T = 327.8^\circ\text{F}$$

$$p = 100 \text{ psia}$$

$$\hat{V} = 0.018 \text{ ft}^3/\text{lb} \text{ for liquid and } 4.435 \text{ for vapor}$$

Final Conditions

$$T = 327.8^\circ\text{F}$$

$$\hat{V} = 4.435$$

Solutions Chapter 9

$$\hat{H} = 298.475 \text{ Btu/lb}$$

$$\hat{U} = 298.146 \text{ Btu/lb}$$

$$V = 4.435 \text{ ft}^3$$

$$V = 4.435 \text{ ft}^3$$

At the final conditions the water is saturated vapor

$$H = 1187.48 \text{ Btu/lb}$$

$$U = 1105.46 \text{ Btu/lb}$$

$$T = 327.75 \text{ }^{\circ}\text{F}$$

$$p = 100 \text{ psia still}$$

$$\Delta H = 1187.48 - 298.475 = \boxed{889.0 \text{ Btu/lb}}$$

$$\Delta U = 1105.46 - 298.146 = \boxed{807.3 \text{ Btu/lb}}$$

The energy balance is

$$\Delta U = Q + W$$

$W = 0$ (fixed container)

$$Q = \Delta U = \boxed{807.3 \text{ Btu/lb}}$$

9.3.26

Closed unsteady state system

Use the CD to get data

Basis: 4 kg steam

Initial Conditions

Given: $T = 500\text{K}$
 $p = 700 \text{ kPa}$

Final Conditions

Given: $T = 400\text{K}$
Known: $\hat{V} = 0.320 \text{ m}^3/\text{kg}$

Look up: $\hat{V} = 0.320 \text{ m}^3/\text{kg}$
 $\hat{H} = 2903.94 \text{ kJ/kg}$
 $\hat{U} = 2680.51 \text{ kJ/kg}$

Look up (2 phase system) the
quality (trial and error on the CD): $x = 0.437$
 $\hat{H} = 1486.81 \text{ kJ/kg}$

Solutions Chapter 9

Calculate $V = 0.320(4) = 1.280 \text{ m}^3/\text{kg}$	$\hat{U} = 1408.23 \text{ kJ/kg}$
	$p = 245.77 \text{ kPa}$

$$\hat{Q} + \hat{W} = \Delta \hat{U} \quad \hat{W} = 0$$
$$Q = (1408.23 - 2680.51)(4) = (-1272.3)(4) = \boxed{-5,089 \text{ kJ}}$$

If you do not use the CD, $\Delta \hat{U} = \Delta \hat{H} - (\Delta p \hat{V})$.

9.3.27

A closed, unsteady state system comprised of 2 tanks. Get the steam properties from the CD.
Basis: 1 lb steam.

State 1

$m = 1 \text{ lb}$	$m = 1 \text{ lb}^*$
$p = 600 \text{ psia}$	$p = 330.45 \text{ psia}$
$\hat{V} = 0.795 \text{ ft}^3/\text{lb}$	$\hat{V} = 1.590 \text{ ft}^3/\text{lb}$
$T = 500^\circ\text{F} (960^\circ\text{R})$	$T = 500^\circ\text{F} (960^\circ\text{R})^*$
$\hat{U} = 1128.19 \text{ Btu/lb}$	$\hat{U} = 1157.03 \text{ Btu/lb}$
$\hat{H} = 1215.97 \text{ Btu/lb}$	$\hat{H} = 1253.98 \text{ Btu/lb}$
$V_1 = 0.795 \text{ ft}^3$	$V_2 = 2V_1 = 1590 \text{ ft}^3*$

State 2

* used to get state 2 properties

The closed system is $Q + W = \Delta U$

$$\Delta U = 1157.03 - 1128.19 = \boxed{28.84 \text{ Btu/lb}}$$

$W = 0$ (fixed boundary)

$$Q = \Delta U = \boxed{28.84 \text{ Btu/lb}}$$

$$\Delta H = 1253.98 - 1215.97 = \boxed{38.01 \text{ Btu/lb}}$$

Solutions Chapter 9

9.3.28

Basis: 1 lb H₂O at 212°F, 1 atm

Data from the CD

	<u>Initial (liquid)</u>		<u>Final (vapor)</u>	
\hat{U}	180.182	Btu/lb	1077.40	Btu/lb
\hat{H}	180.226	Btu/lb	1150.29	Btu/lb
\hat{V}	0.017	ft ³ /lb	26.773	ft ³ /lb

$$p = 1.00 \text{ atm}$$

Non-flow process (unsteady-state)

$$Q + W = \Delta U$$

$$\Delta U = (1 \text{ lb})(1077.40 - 180.182) \text{ Btu/lb} = 897.22 \text{ Btu}$$

$$W = -\int p dV = (1 \text{ atm})(26.773 - 0.017) \text{ ft}^3/\text{lb} (2.72) \text{ Btu}/(\text{atm})(\text{ft}^3)$$
$$= -72.78 \text{ Btu}$$

$$Q = 897.22 - (-72.78) = \boxed{970.0 \text{ Btu}}$$

$$\Delta H = 1150.29 - 180.226 = \boxed{970.0 \text{ Btu}}$$

Flow process (unsteady-state)

$$\Delta U = Q + W - \Delta H$$

Assume the volume of the system is fixed at $V = 0.017 \text{ ft}^3$ and that $W = 0$. Also assume that nothing is left in the system after the water evaporates.

$$\Delta U = \hat{U}_{\text{final}}(0) - \hat{U}_{\text{initial}}(1) = -180.182 \text{ Btu}$$

$$\Delta H = \hat{H}_{\text{out } 212^\circ\text{F}}(1) - \hat{H}_{\text{in}}(0) = 1150.29 \text{ Btu}$$

$$Q = \Delta U + \Delta H = -180.182 + 1150.29 = \boxed{970.1 \text{ Btu}}$$

Solutions Chapter 9

9.3.29

Treat the system (the cylinder) as an unsteady state flow system.

$$\Delta U = Q + W - \Delta H$$

$$W = 0 \quad Q = 0$$

$$U_{t_2} - U_{t_1} = -(H_{out} - H_{in})$$

$$\hat{U}_{t_2} = \hat{U}_{T_1, 40 \text{ atm}}$$

n_f = final moles in cylinder

$$\hat{U}_{t_1} = \hat{U}_{298K, 1 \text{ atm}}$$

n_i = initial moles in cylinder

$$\hat{H}_{out} = 0$$

$$\hat{H}_{in} = \hat{H}_{298 K, 50 \text{ atm}}$$

Let the reference temperature be T_R that makes $\hat{H}_R = 0$. Ignore the effect of pressure on the values of \hat{U} and \hat{H} .

$$\hat{H}_{in} = \hat{H}_R + C_p(T_{in} - T_R) \quad \hat{H}_R = 0$$

$$\underline{\Delta U} \quad \underline{\text{in}} \quad \underline{\text{out}}$$

$$U_{t_2} - U_{t_1} = n_f \hat{U}_{t_2} - n_i \hat{U}_{t_1} = (n_f - n_i) \hat{H}_{in} - 0$$

$$n_f [C_v(T - T_R) - RT_R] - n_i [C_v(T_{in} - T_R) - RT_R] = (n_f - n_i) [C_p(T_{in} - T_R)]$$

$$= (n_f - n_i) [(C_v + R)(T_{in} - T_R)]$$

Multiply all of the terms out to get (note terms with T_R cancel):

$$n_f C_v T = n_f C_v T_{in} + n_f RT_{in} - n_i RT_{in}$$

$$C_V = C_p - R$$

Insert $pV = nRT$ to get n_i and n_f

$$\frac{R}{C_V} = \frac{2}{5} \text{ for diatomic gas}$$

The equations reduce to

$$n_f C_v T = n_f C_v T_{in} + n_f RT_{in} - n_i RT_{in}$$

$$\frac{T}{T_{in}} = \left[1 + \frac{R}{C_v} \frac{p_i}{p_f} \frac{T}{T_i} \frac{R}{C_v} \right]$$

Solutions Chapter 9

$$\frac{T}{298} = \left[1 + \frac{2}{5} - \left(\frac{1}{40} \right) \left(\frac{T}{298} \right) \left(\frac{2}{5} \right) \right]$$

$T = 417 \text{ K}$

9.3.30

The tank is an open unsteady state system. f stands for final, i for initial, in for in, m for mass in lb.

Data:

at 291°F and 50 psia

at 14.7 psia saturated (212°F)

$$1179.39$$

$$\hat{H} \text{ Btu/lb}$$

$$1150.26$$

$$1099.60$$

$$\hat{U} \text{ Btu/lb}$$

$$1077.37$$

$$8.653$$

$$\hat{V} \text{ ft}^3/\text{lb}$$

$$26.818$$

$$\Delta U = Q + W - \Delta H \quad W = 0 \quad Q = 0 \quad H_{\text{out}} = 0$$

$$\Delta U = -\Delta H$$

$$n_f \hat{U}_f - m_i \hat{U}_i = (m_f - m_i) \hat{H}_{\text{in}} - 0$$

$$V = 50 \text{ ft}^3 \text{ so } m_f = \frac{50}{8.653} = 5.78 \text{ lb}$$

$$m_i = \frac{50}{26.818} = 1.86 \text{ lb}$$

$$5.78(\hat{U}_f) - 1.86(1077.37) = (5.78 - 1.86) 1179.39$$

$$\hat{U}_f = 1146.56 \text{ Btu/lb at 50 psia}$$

$T_f = 411^\circ\text{F}$ (superheated)

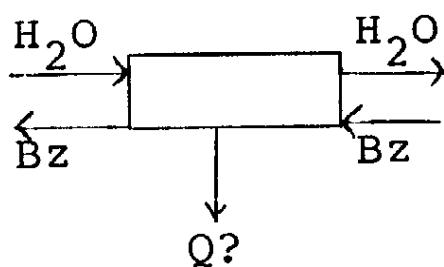
9.3.31

The general energy balance is

$$\Delta E = Q + W - \Delta[\hat{H} + \hat{KE} + \hat{PE}] m$$

- (1) (2) (3) (4) (5) (6)

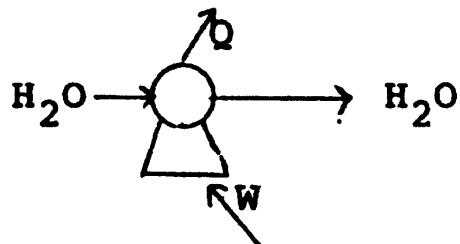
- (a) (1) $\Delta E = 0$ steady state flow process, one overall system (You can also pick two system, one the H_2O and one the benzene).



- (2) Q is the net overall heat transfer to and from the heat exchanger with the surroundings.

It is essentially 0 if exchanger is well insulated. If you pick 2 systems, Q is the heat transfer between the benzene and the H_2O , and is not 0.

- (3) $W = 0$ no mechanical work in the process
- (4) $\Delta H \neq 0$ for all streams
- (5) $\Delta KE = 0$ negligible KE change
- (6) $\Delta PE = 0$ level exchanger assumed. $Q = \Delta H$
- (b) (1) $\Delta E = 0$ steady state process
- (2) Q not zero as isothermal



Solutions Chapter 9

- | | | |
|-----|-------------------|---|
| (3) | W | retain |
| (4) | $\Delta H \neq 0$ | the pressure changes even if T is constant |
| (5) | $\Delta KE = 0$ | pipe diameter remains the same, and the flow rate is the same |
| (6) | $\Delta PE = 0$ | level pump lines |

$$Q + W = \Delta H$$

9.3.32

<u>Unknowns</u>	<u>Relationships (R)</u>
-----------------	--------------------------

\dot{F}	(1) $F = P + V$
\dot{P}	(2) $0.05F = x_p P$
\dot{V}	(3) $F\hat{H}_F + S\Delta H_s = VH_V + P\hat{H}_P$
\dot{S}	(4) $S\Delta H_s = \dot{Q}$
\dot{Q}	(5) $\dot{Q} = UA(T_s - T_v)$
T_v	
X_p	

Yes, two measurements must be made to balance the unknowns and the relationships. If x_p and T_v are measured: solve (R5) for \dot{Q} . (R4) for \dot{S} substitute (R2) and (R1) in (R3) and solve for F. Use (R2) to calculate P and (R1) to calculate \dot{V} . Note that measuring T_v and S is not satisfactory because this combination eliminates either (R4) or (R5) as an independent relationship. Also note that if you neglect the vapor pressure of the organic, you can set $T_v = 212^\circ F$.

Solutions Chapter 9

9.3.33

Basis: 1 hour

Input conditions:

$$\left. \begin{array}{l} 500^{\circ}\text{F} \\ 250 \text{ psi} \end{array} \right\} h_i = 1264.7 \text{ Btu/lb}$$

Exit conditions:

$$\left. \begin{array}{l} 14.7 \text{ psi} \\ 15\% \text{ liquid} \end{array} \right\} \begin{array}{l} h_{sv} = 1150.4 \text{ Btu/lb} \\ h_{sl} = 180.07 \text{ Btu/lb} \end{array}$$

$$\hat{H}_2 = 0.15(180.07) + 0.85(1150.4)$$

$$= 1004 \text{ Btu/lb}$$

The simplified energy balance is:

$$m\Delta\hat{H} = Q + W$$

$$\Delta\hat{H} = 1004 - 1265 = -261 \text{ Btu/lb}$$

$$m\Delta\hat{H} = -261,000 \text{ Btu}$$

$$W = -\frac{86.5 \text{ hp}}{} \left| \frac{1 \text{ hr}}{2.93 \times 10^4 (\text{hp})(\text{hr})} \right| \frac{1 \text{ Btu}}{} = -2.20 \times 10^5 \text{ Btu}$$

$$\text{Thus, } Q = m\Delta\hat{H} - W = -2.61 \times 10^5 + 2.2 \times 10^5 = -4.1 \times 10^4 \text{ Btu}$$

hence, not adiabatic.

Solutions Chapter 9

9.3.34

Basis: 1 lb air

The energy balance is in the steady state. The system is the valve.

$$\Delta[(\hat{H} + \hat{KE} + \hat{PE})m] = Q + W$$

$$\text{if } \Delta KE \approx 0 \quad W = 0$$

$$\Delta PE = 0 \quad Q ; 0$$

Hence $\Delta H = 0$

$$\Delta H = \int C_p dT = 0$$

$$(a) \quad \Delta T = 0 \quad \text{or} \quad T_2 = 250 \text{ K}$$

Since $\Delta H = 0$ (the kinetic energy term was negligible), the steady-state constraint requires that the mass flow rate be constant:

$$\dot{m} = \Delta v S = \text{Constant} \quad \begin{aligned} \text{where: } & \rho = \text{density} \\ & v = \text{velocity of the gas} \\ & S = \text{cross-sectional area of pipe} \end{aligned}$$

Since the diameter of the pipe does not change and density is a function of temperature and pressure, the gas velocity is also a function of temperature and pressure.

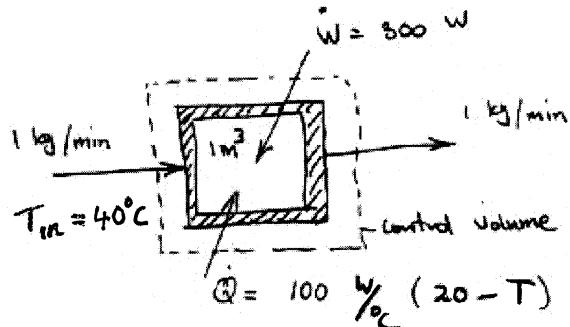
$$v_{STP} = \frac{100 \text{ lb Air}}{1 \text{ hr}} \left| \frac{1 \text{ lb mol}}{29 \text{ lb Air}} \right| \left| \frac{359 \text{ ft}^3}{1 \text{ lb mol}} \right| \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| \left| \frac{1}{\pi(1.5/12 \text{ ft})^2} \right| = 7.0 \text{ ft/s}$$

Therefore, the velocity downstream of the valve is:

$$v_{\text{Outlet}} = \frac{7.0 \text{ ft}}{\text{s}} \left| \frac{250 \text{ K}}{273 \text{ K}} \right| \left| \frac{1 \text{ atm}}{2 \text{ atm}} \right| = 3.2 \text{ ft/s}$$

Solutions Chapter 9

9.3.35



Steady-state process. Basis: 1 second

$$\dot{m}(\hat{H}_{out} - \hat{H}_{in}) = \dot{Q} + \dot{W}$$

To get \hat{H}_{in} use the steam tables or a C_p equation. Using constant C_p is not the most accurate method, but for liquids for small temperature changes, it is a good approximation.

$$(\dot{m})(C_p)(T_{out} - T_{in}) = \dot{Q} + \dot{W}$$

Because the tank is well-mixed, the outlet water temperature is the same as the temperature inside the tank T .

$$T = T_{out}$$

$$\dot{m}(C_p)(T - T_{in}) = 100(20 - T) + 300$$

$$\dot{m} = \frac{1 \text{ kg}}{\text{min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right. = \frac{1}{60} \frac{\text{kg}}{\text{s}}$$

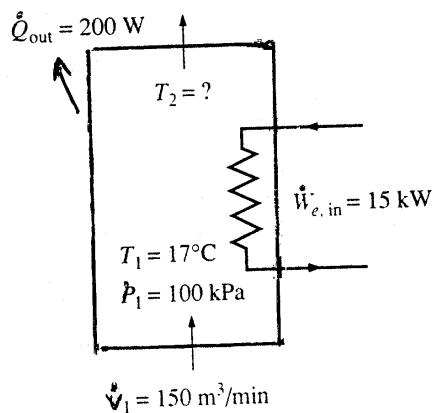
$$C_p = 4180 \text{ J/(kg)(K)}$$

$$\frac{4180}{60} (T - 40) = 100(20 - T) + 300$$

$T = 30.0^\circ\text{C}$

Solutions Chapter 9

9.3.36



Assumptions

1. This is a steady-flow process since there is no change with time at any point, hence $\Delta E = 0$.
2. Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point.
3. The kinetic and potential energy changes are negligible $\Delta KE \approx \Delta PE \approx 0$.
4. Constant specific heats at room temperature can be used for air.

The simplified energy balance is

$$\dot{Q} + \dot{W} = \Delta \dot{H} = m(\hat{H}_{\text{out}} - \hat{H}_{\text{in}})$$

$$\dot{Q} = -200 \text{ W}$$

$$\dot{W} = 15 \text{ kW}$$

Assume that with little error

$$\Delta H = C_p \Delta T \quad \text{with } C_p = 1.00 \text{ kJ/(kg)}^\circ\text{C}$$

Otherwise you will need tables or a data base for the properties of air.

The ideal gas law gives the specific volume of air at the inlet of the duct

$$\hat{V}_1 = \frac{RT_m}{p_{\text{in}}} = \frac{[(0.287 \text{ kPa})(m^3)/(kg)(K)](290 \text{ K})}{100 \text{ kPa}} = 0.832 \text{ m}^3/\text{kg}$$

Solutions Chapter 9

The mass flow rate of the air through the duct is determined from

$$\dot{m} = \frac{\dot{V}_1}{\hat{V}_1} = \frac{150 \text{ m}^3/\text{min}}{0.832 \text{ m}^3/\text{kg}} \left(\frac{1 \text{ min}}{60 \text{ s}} \right) = 3.0 \text{ kg/s}$$

Substituting the known quantities, the exit temperature of the air is determined to be

$$(15 \text{ kJ/s}) - (0.2 \text{ kJ/s}) = (3 \text{ kg/s})[1.00 \text{ kJ/(kg)}(\text{°C})](T_{\text{out}} - 17)\text{°C}$$

$$T_{\text{out}} = \boxed{21.9\text{°C}}$$

9.3.37

The procedure is correct only for an open, steady state system.

- (a) If the evaporation occurs from an open, unsteady-state system of fixed volume:

$$\Delta U = Q + W - \Delta H \quad W = 0$$

$$\Delta U = Q - \Delta H$$

Data:

$$\hat{U}_{\text{liquid}} = 419.5 \text{ kJ/kg} \quad \hat{U}_{\text{vapor}} = 2506.0 \text{ kJ/kg}$$

$$\hat{H}_{\text{liquid}} = 419.5 \text{ kJ/kg} \quad \hat{H}_{\text{vapor}} = 2675.6 \text{ kJ/kg}$$

Assume only 1 kg of water is in the system at $t = \text{initial}$. At $t = \text{final}$, 0 kg of water are in the system.

$$U_{\text{final}} = 0$$

$$U_{\text{initial}} = (1 \text{ kg})(419.5 \text{ kJ/kg}) = 419.5 \text{ kJ}$$

$$H_{\text{out}} = (1 \text{ kg})(2675.6 \text{ kJ/kg}) = 2675.6 \text{ kJ}$$

$$H_{\text{in}} = 0$$

$$-419.5 = Q - (2675.6 - 0)$$

$$Q = 2256.1 \text{ kJ}$$

- (b) If the evaporation occurs in a steady-state open system, m_{in} is in kg and $m_{\text{in}} - 1 = m_{\text{out}}$. The process is isothermal.

Solutions Chapter 9

$$W = 0 \quad \Delta U = 0$$

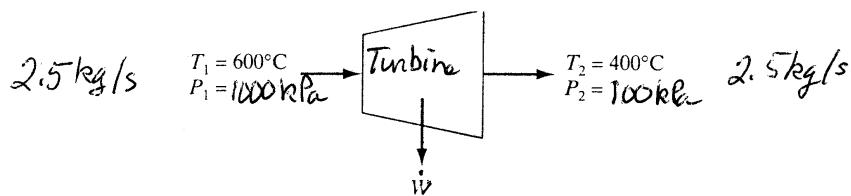
$$Q = \Delta H = [(m_1 - 1)\hat{H}_{\text{liquid}} + (1)\hat{H}_{\text{vapor}}] - m_1 \hat{H}_{\text{in}}$$

$$\hat{H}_{\text{in}} = \hat{H}_{\text{liquid}}$$

$$Q = (1)(2675.6 - 419.5) \quad 2256.1 \text{ kJ}$$

The answer in the solution is ok, but note that the equation $\Delta U = Q - p\Delta V$ refers to a closed system, not an open one, in which the vessel expands against the atmosphere. This viewpoint is ok, but an unlikely procedure.

9.3.38



Open, unsteady state system – the adiabatic turbine

$$\Delta \dot{U} = 0 \quad \dot{Q} = 0 \quad \Delta \dot{PE} = 0$$

$$\dot{W} = \dot{\Delta H} + \dot{\Delta KE}$$

Data from interpolating in the SI steam tables

At 600°C and 100 kPa

$$3697.9$$

$$\hat{H}(\text{kJ/kg})$$

$$0.4011$$

$$\hat{V}(\text{m}^3/\text{kg})$$

At 400°C and 100 kPa

$$3278.2$$

$$3.103$$

The velocities at the inlet and outlet to the turbine are calculated from the volumetric

flow rate = $\dot{m}\hat{V} = \frac{d^2}{4}v$ where d is the pipe diameter. Therefore,

$$v_1 = \frac{4\dot{m}_1 \hat{V}_1}{d_{\text{in}}^2} = \frac{(4)\left(2.5 \frac{\text{kg}}{\text{s}}\right)\left(0.4011 \frac{\text{m}^3}{\text{kg}}\right)}{(3.14159)(0.1 \text{ m})^2} = 127.7 \frac{\text{m}}{\text{s}},$$

Solutions Chapter 9

and $v_2 = \frac{4\dot{m}_2 \hat{V}_2}{d_{out}^2} = 158.0 \frac{\text{m}}{\text{s}}$

$$\Delta K\dot{E} = \left(\frac{1}{2}\right)(2.5) \left[158.0^2 - 127.7^2 \right] \left(\frac{1}{100} \right) \text{ kJ/s} = 10.82 \text{ kJ/s}$$

$$\Delta \dot{H} = (2.5)(3278.2 - 3697.9) \text{ kJ/s} = -1049.25 \text{ kJ/s}$$

$$\dot{W} = -1049.25 + 10.82 = \boxed{1038.4 \text{ kJ/s}} \\ \boxed{(1038.4 \text{ kW})}$$

9.3.39

This is an unsteady-state closed process. The energy balance reduces to

$$\Delta E = \Delta U + \Delta PE + \Delta KE = Q + W \quad \Delta PE = \Delta KE = 0$$

$$Q = \Delta U = U_2 - U_1 \quad \Delta H = \Delta(pV) = H_2 - (p_2 V_2 - p_1 V_1)$$

where 2 (327.8°F) is the final state and 1 (406°F) is the initial state

Get the data from the CD in the back of the book. The final state is saturated conditions. \hat{U} and \hat{H} are in Btu/lb and \hat{V} is ft³/lb.

$\hat{H}_{1,L} = 381.65$	$\hat{H}_{1,V} = 1202.2$	$\hat{H}_{2,L} = 298.5$	$\hat{H}_{2,V} = 1187.5$
$\hat{U}_{1,L} = 380.72$	$\hat{U}_{1,V} = 1116.7$	$\hat{U}_{2,L} = 298.2$	$\hat{U}_{2,V} = 1105.5$
$\hat{V}_{1,L} = 0.019$	$\hat{V}_{1,V} = 1.743$	$\hat{V}_{2,L} = 0.0177$	$\hat{V}_{2,V} = 4.433$

From the steam tables, get the initial amount of steam and use as the basis:

$100 \left(\frac{1}{1.743} \right) = 57.4$ lb ignoring the liquid volume. (If you do not, you have to get the average volume) and get the final state. Let y = the fraction of liquid at 100 psia

$$\hat{V}_{\text{liquid}} = 0.0177 \text{ ft}^3/\text{lb}, \hat{V}_{\text{vapor}} = 4.433 \text{ ft}^3/\text{lb}$$

Basis: 1 lb water

$$y(0.0177) + (1-y)(4.433) = 1.74 \quad y = 0.6095 \text{ lb (liquid)} \quad x = 0.3905 \text{ lb(vapor)}$$

Solutions Chapter 9

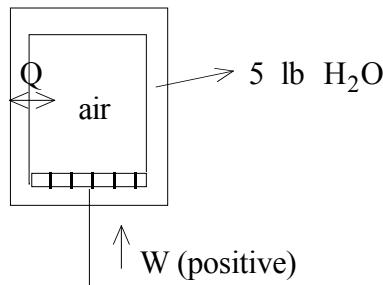
Use values of \hat{U} from the CD to calculate Q. Otherwise you have to calculate $\Delta(pV)$.

$$Q = [(0.6095)(298.2) + (0.3905)(1187.5)] - [(1116.7)(1)]$$

$$Q = -471 \frac{\text{Btu}}{\text{lb}} \text{ or } Q = -2.71 \times 10^4 \text{ Btu}$$

9.3.40

This is an unsteady state process in a closed system, or a closed system with air and surroundings with water. From the latter viewpoint the system is the air, and $\Delta U = Q + W$ where Q is the heat transfer to the water from the air.



For the system of the air

$$Q + W = \Delta E = \Delta U + \Delta P + \Delta K = \Delta H \Delta \quad (\text{pV})$$

For the water:

$Q = \Delta H - \Delta(pV)$ but $\Delta(pV)$ is negligible for liquid water so that

$$Q = \Delta H = 5 \int_T^{T+2.3} C_p dT = 5 C_p (T + 2.3 - T) \text{ for constant } C_p.$$

(or use the steam tables)

$$C_p = 8.0 \frac{\text{Btu}}{(\text{lb mol})(^\circ\text{F})}$$

$$Q = 8.0 \frac{\text{Btu}}{(\text{lb mol})} \left| \frac{2.3^\circ\text{F}}{18 \text{ lb H}_2\text{O}} \right| \left| \frac{1 \text{ lb mol H}_2\text{O}}{5 \text{ lb H}_2\text{O}} \right| = 5.11 \text{ Btu}$$

Q is removed from the air, so for the system comprised of the air, $Q = -5.11 \text{ Btu}$.

Solutions Chapter 9

For the system of the air

$$W = \frac{12,500(\text{ft})(\text{lb}_f)}{1(\text{ft})(\text{lb}_f)} \left| \frac{0.0012854 \text{ Btu}}{\text{Btu}} \right. = 16.07 \text{ Btu}$$

W is positive when the surroundings do work on the system of the air.

Basis: 3 ft³ air (not essential)

$$\Delta U = -5.11 \text{ Btu} + 16.07 \text{ Btu} = \boxed{10.96 \text{ Btu}}$$

9.3.41

Steps 1, 2, 3 and 4

Get the needed properties from the CO₂ chart or tables (Be sure to use the same reference value). Let m_{CO₂} be the mass of CO₂ in the cylinder at the final state, \hat{V} is the specific volume, \hat{U}_{final} is the specific internal energy of the CO₂ at the end of the filling, and \hat{H}_m is the specific enthalpy of the CO₂ in the pipeline.

At 200 psia, 40°F, $\hat{H} \approx 153 \text{ Btu/lb}$ and $V \approx 0.57 \text{ ft}^3/\text{lb}$

Step 5

Basis: 3 ft³ of CO₂ @ 200 psia (final conditions)

System: The cylinder (open system, unsteady state)

Steps 6 and 7:

Unknowns: $\hat{V}_{\text{CO}_2}, m_{\text{CO}_2}, T_{\text{CO}_2}$

Equations: energy balance, enthalpy chart

We need two points on the p– \hat{H} chart to fix the conditions in the cylinder. The energy balance reduces to (W = 0, Q assumed to be 0)

$$\Delta U = -\Delta H$$

which gives one point:

Solutions Chapter 9

$$m_{CO_2}(\hat{U}_{final}) - m_{initial}(\hat{U}_{initial}) = m_{in}(\hat{H}_{in}) - m_{out}(\hat{H}_{out})$$

$$m_{initial} = 0 \quad m_{out} = 0 \quad m_{CO_2} = m_{in}$$

$$\hat{U}_{final} = \hat{H}_{in} = 153 \text{ Btu/lb}$$

The other point is the pressure $p = 200 \text{ psia}$. Unfortunately the CO_2 chart is $p - \hat{H}$ and not $p - \hat{U}$, thus requiring a trial and error solution. Assume a T , lookup \hat{V} , and calculate $\hat{U} = \hat{H} - p\hat{V}$ (ignore $p\hat{V}$ at the reference state of $-40^\circ F$).

When $\hat{U} = 153 \text{ Btu/lb}$, then you have determined T . If you used tables of p vs \hat{U} in a handbook, the calculations would be easier.

	$\underline{\hat{H}}$	\underline{p}	$\underline{\hat{V}}$	$\underline{\hat{U}}$
Assume $T = 160^\circ F$.		Then $\hat{H} - p\hat{V} =$	$182 - (200)(0.68)(0.185) = 157$	
$T = 140^\circ F$.		Then $\hat{H} - p\hat{V} =$	$178 - (200)(0.70)(0.185) = 153$	

The calculations are quite approximate but

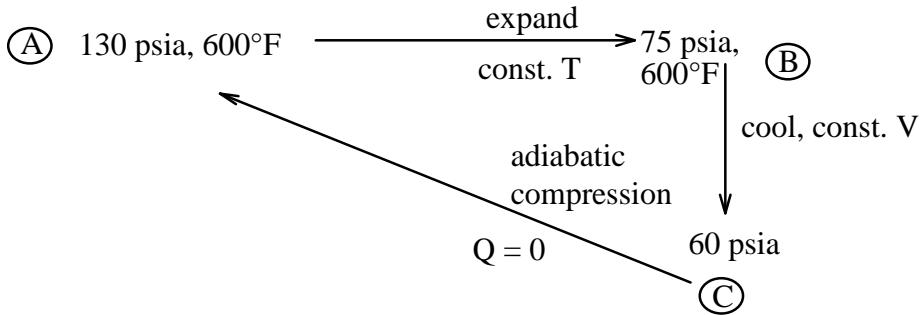
$$T = 140^\circ F \quad m_{CO_2} = \frac{3 \text{ ft}^3}{0.70 \text{ ft}^3/\text{lb}} = 4.3 \text{ lb}$$

Solutions Chapter 9

9.3.42

Basis: 1 lb steam

Closed system; hence $Q + W = \Delta E = \Delta U$



Basis: 1 lb steam

Note: The CD will result in slightly different values for $\hat{\Delta H}$.

$$\textcircled{A} \rightarrow \textcircled{B} : \hat{\Delta H} = 1329.6 - 1326.1 = \boxed{3.5 \text{ Btu / lb}}$$

Use the steam tables or the CD directly for U, or calculate

$$\hat{\Delta U} = \hat{\Delta H} \Delta (p\hat{V}) =$$

$$= 3.5 - \left[\frac{75 \text{ lb}_f}{\text{in}^2} \left| \frac{8.319 \text{ ft}^3}{\text{lb}} \right. - \frac{130 \text{ lb}_f}{\text{in}^2} \left| \frac{4.760 \text{ ft}^3}{\text{lb}} \right. \right] \left[\frac{144 \text{ in}^2}{\text{ft}^2} \left| \frac{1 \text{ Btu}}{778 (\text{ft})(\text{lb}_f)} \right. \right]$$

$$= 3.5 - .95 = \boxed{2.5 \text{ Btu / lb}} \quad \hat{Q} = ? \quad \hat{W} = ?$$

$\hat{W} = - \int p dV$ but pV relation is not known.

$$\textcircled{B} \rightarrow \textcircled{C} : \boxed{W = 0} \text{ (at constant volume)}$$

$$\hat{\Delta H} = 1232.7 - 1329.6 = \boxed{-96.9 \text{ Btu / lb}}$$

$$\hat{\Delta U} = -96.9 \left[\frac{60}{8.319} - \frac{75}{8.319} \right] \left[\frac{144 \text{ in}^2}{\text{ft}^2} \left| \frac{1 \text{ Btu}}{778 (\text{ft})(\text{lb}_f)} \right. \right] = -73.8 \text{ Btu/lb}$$

$$\hat{Q} = \hat{\Delta U} = \boxed{-73.8 \text{ Btu/lb}}$$

Solutions Chapter 9

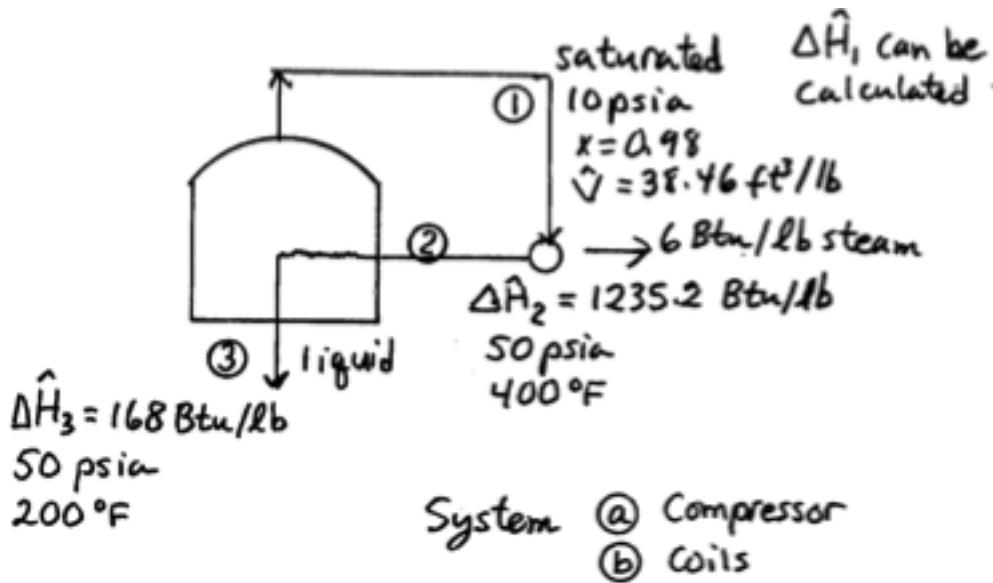
$$\textcircled{C} \rightarrow \textcircled{A}: \hat{Q} = 0 \text{ so } \hat{W} = \Delta \hat{U} = \Delta \hat{H} - \Delta(p\hat{V})$$

$$\Delta \hat{H} = 1326.1 - 1232.7 = 93.4 \text{ Btu/lb}$$

$$\Delta p\hat{V} = [130|4.760 - 60|8.319] \left[\frac{144}{778} \right] = 22.15 \text{ Btu/lb}$$

$$\hat{W} = 93.4 - 22.15 = \boxed{71.3 \text{ Btu/lb}} \quad \Delta U = 93.4 - 22.15 = \boxed{71.3 \text{ Btu/lb}}$$

9.3.43



To make the process a steady state open process from (1) to (3) assume the system is the coil plus the compressor. Then

$$\Delta \hat{E}^0 = -\Delta[(\hat{H} + \hat{P} + \hat{K})m + Q + W] \quad \text{or} \quad W = \Delta H - Q$$

Basis: 1 lb water evaporated

$$\text{Calculate } \Delta \hat{H} @ (1): (0.98)(1143.3) + (0.02)(161.17) = 1123.6 \text{ Btu/lb}$$

From (1) to (2): Balance on the compressor

$$\Delta \hat{H}_2 - \Delta \hat{H}_1 = 1235.2 - 1123.6 = 111.6 \text{ Btu/lb} \quad \hat{Q} = -6 \text{ Btu/lb}$$

Solutions Chapter 9

$$W = 111.6 - (-6) = \boxed{117.6 \text{ Btu/lb}}$$

From (2) to (3): Balance on the coil

$$\Delta \hat{H}_3 - \Delta \hat{H}_2 = 168 - 1235.2 = -1067.2 \text{ Btu/lb} \quad \hat{W} = 0 \text{ so } \hat{Q} = \Delta \hat{H} = -1067.2 \text{ Btu/lb}$$

a. $\frac{\hat{Q}}{\hat{W}} = \frac{1067.2}{117.6} = \boxed{9.1}$ (Note: the problem asks for the heat transfer out as a + value)

$$V_i = \left[\frac{38.46 \text{ ft}^3}{\text{lb}} \left| \frac{0.98}{\text{lb}} + \frac{(0.016)\text{ft}^3}{\text{lb}} \right| \frac{0.02}{\text{lb steam}} \right] \frac{\text{lb steam}}{1067.2 \text{ Btu}} = 37.69 \text{ ft}^3/\text{lb}$$

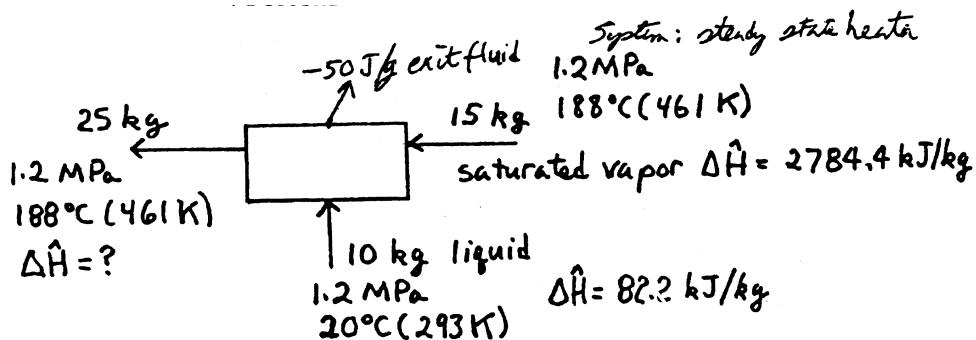
Basis: 1,000,000 Btu/hr

b. $\frac{10^6 \text{ Btu}}{\text{hr}} \left| \frac{1\text{hr}}{60 \text{ min}} \right| \frac{1 \text{ lb steam}}{1067.2 \text{ Btu}} \left| \frac{37.69 \text{ ft}^3}{\text{lb steam}} \right| = \boxed{589 \text{ ft}^3/\text{min}}$

Solutions Chapter 9

9.3.44

Basis: 25 kg exit fluid



$$Q + W = \Delta H \quad W = 0$$

$$Q = \Delta H = \Delta H_{25} - \Delta H_{15} - \Delta H_{10} = \Delta H_{25} - (2784.4)(15) - (82.2)(10)$$

$$Q = \frac{-50 \text{ J}}{\text{g exit}} \left| \frac{25 \times 10^3 \text{ g}}{} \right. = -1250 \text{ kJ} \quad (\text{note } \Delta \hat{K}E \sim 10^{-4} \text{ J})$$

$$\text{For the exit fluid} \begin{cases} \Delta \hat{H}_L = 798.5 \text{ kJ/kg} \\ \Delta \hat{H}_V = 2784.4 \text{ kJ/kg} \end{cases}$$

Let $x = \text{kg vapor}$, $25 - x = \text{kg liquid}$

$$-1250 = \frac{x \text{ kg} | 2784.4 \text{ kJ}}{\text{kg}} + \frac{(25-x) \text{ kg} | 798.5 \text{ kJ}}{\text{kg}} - \frac{15 \text{ kg} | 2784.4 \text{ kJ}}{\text{kg}} - \frac{10 \text{ kg} | 82.2 \text{ kJ}}{\text{kg}}$$

$$-1250 = 2784.4x + 19,963 - 798.5x - 41,766 - 822$$

$$x = 10.76 \quad \text{fraction vapor} = \frac{10.76}{25.0} = \boxed{0.43}$$

Solutions Chapter 9

9.3.45

Closed unsteady state process for each stage.

$$Q + W = \Delta U \text{ overall}$$

Calculate the moles of gas:

a. $n = \frac{pV}{RT} = \frac{(1 \text{ atm})(0.387 \text{ ft}^3)(\text{lb mol})(^{\circ}\text{R})}{(530^{\circ}\text{R})(0.7302)(\text{ft}^3)(\text{atm})} = [1 \times 10^{-3} \text{ lb mol}] \quad (\text{Basis})$

Known values	A	B	C	D
--------------	---	---	---	---

p (atm)	1	1	10	10
T (°F)	170 (630°R)	70 (530°R)	70 (530°R)	823 (1283°R)
n (lb mol)	1×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}
V	?	0.387	?	?

For an ideal gas, $C_v = 5/2 R$ (has to be looked up or calculated) and U and H are functions of T only

$$\text{Also, } \Delta(pV) = \Delta(nRT)$$

Calculate some of the missing values

$$V_A = \frac{(1 \times 10^{-3})(0.7302)(630)}{1} = 0.460 \text{ ft}^3$$

$$V_C = \frac{(1 \times 10^{-3})(0.7302)(530)}{10} = 0.0387 \text{ ft}^3$$

b. $V_D = \frac{(1 \times 10^{-3})(0.7302)(1283)}{10} = 0.0937 \text{ ft}^3$

The work for each stage will be assumed to be $\int pdV$ (ideal process)

W_{AB} (constant pressure process)

c. $W = -\int pdV = -p_{AB}(V_B - V_A)$

$$= -\frac{1 \text{ atm}}{} \left| \frac{(0.387 - 0.460)\text{ft}^3}{(1 \text{ atm})(0.7302)} \right| \frac{2.72 \text{ Btu}}{\text{ft}^3} = [0.199 \text{ Btu}]$$

Solutions Chapter 9

W_{BC} (isothermal process)

d.
$$W = -\int pdV = -\int_{0.387}^{0.0387} \frac{nRT}{V} dV = -nRT \int_{0.387}^{0.0387} \frac{dV}{V} = nRT [\ln V]_{0.387}^{0.0387}$$

$$= -(1 \times 10^{-3})(1.987)(530)(\ln 0.1) = \boxed{2.42 \text{ Btu}}$$

W_{CD} (constant pressure process)

e.
$$W = -\int pdV = -p_{CD}(V_D - V_c) = -(10)(0.0937 - 0.0387) = \boxed{-0.550 \text{ Btu}}$$

W_{DA} (ideal adiabatic process)

$$W = -\int pdV = -\int \frac{nRT}{V} dV$$
 However, both T and V vary.

Instead use

$$Q + W = \Delta U \quad Q = 0 \quad R = 1.987 \text{ Btu/(lb mol)} (\text{°R})$$

f.
$$W = \Delta U = nC_v\Delta T = (10^{-3})\left(\frac{5R}{2}\right)(630 - 1283) = \boxed{-3.243 \text{ Btu}}$$

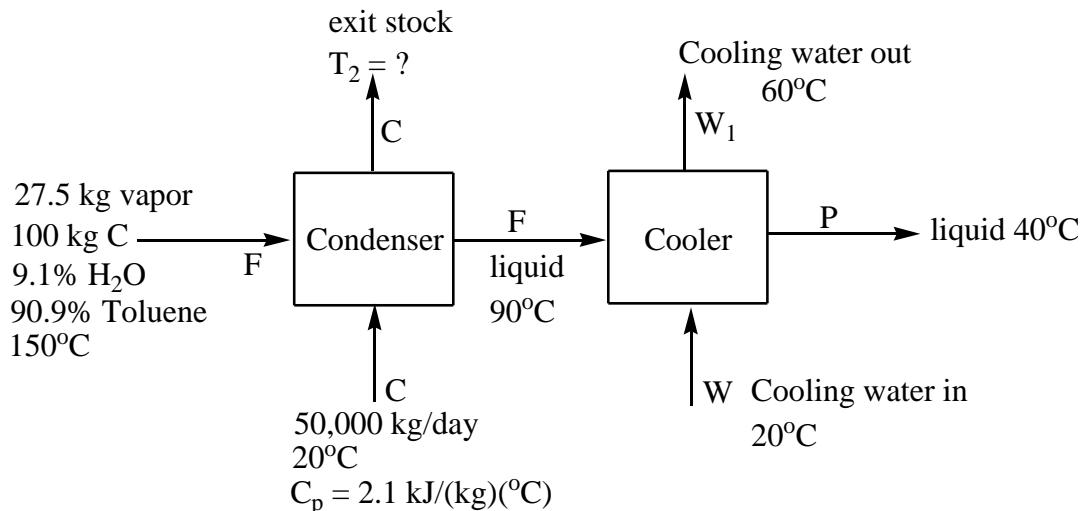
g.
$$W_{\text{overall}} = 0.199 + 0.891 - 0.550 - 3.243 = -1.74 \text{ Btu}$$

h.
$$\boxed{\Delta H = 0}$$
 (a cycle)

i. For the overall process $Q + W = \Delta U$. Because of the cycle, $\Delta U = 0$, and thus $Q = -W = \boxed{1.74 \text{ Btu}}$

Solutions Chapter 9

9.3.46



Basis: 1 day

$$\frac{27.5 \text{ kg F}}{100.0 \text{ kg C}} \left| \frac{50,000 \text{ kg C}}{\text{day}} \right| \left| \frac{1 \text{ day}}{\text{day}} \right| = 13,750 \text{ kg F}$$

$$\frac{13,750 \text{ kg F}}{100 \text{ kg F}} \left| \frac{9.1 \text{ kg } H_2O}{100 \text{ kg F}} \right| = 1,251.25 \text{ kg } H_2O$$

$$13,750 \text{ kg F} - 1,251.25 \text{ kg } H_2O = 12,498.75 \text{ kg toluene.}$$

Energy balance at condenser:

The energy balance reduces to $\Delta H = 0$

$$\Delta H_C + \Delta H_F = 0$$

$$m_C \int_{20}^{T_2} C_p dT + m_{H_2O} \left[\int_{150}^{100} C_p dT - \Delta H_{vap} \text{ at } 100^\circ\text{C} + \int_{100}^{90} C_p dT \right]$$

$$+ m_{tol} \left[\int_{150}^{111} C_p dT - \Delta H_{vap} \text{ at } 111^\circ\text{C} + \int_{111}^{90} C_p dT \right] = 0$$

$$\frac{50,000 \text{ kg}}{(\text{kg})(^\circ\text{C})} \left| \frac{2.1 \text{ kJ}}{(\text{kg})(^\circ\text{C})} \right| \left| \frac{T_2 - 20^\circ\text{C}}{^\circ\text{C}} \right|$$

Solutions Chapter 9

$$\begin{aligned}
 & + 1,251.25 \text{ kg H}_2\text{O} \left[\frac{2.1 \text{ kJ}}{(\text{kg})(\text{°C})} \right] \left(\frac{(100 - 150) \text{ °C}}{} - \frac{2260 \text{ kJ}}{\text{kg}} + \frac{4.2 \text{ kJ}}{(\text{kg})(\text{°C})} \right) \left(\frac{(90 - 100) \text{ °C}}{} \right) \\
 & + 12,498.75 \text{ kg tol} \left[\frac{1.3 \text{ kJ}}{(\text{kg})(\text{°C})} \right] \left(\frac{(111 - 150) \text{ °C}}{} - \frac{230 \text{ kJ}}{\text{kg}} + \frac{1.7 \text{ kJ}}{(\text{kg})(\text{°C})} \right) \left(\frac{(90 - 111) \text{ °C}}{} \right) = 0
 \end{aligned}$$

$$105,000 \text{ T}_2 - 2,100,000 - 3,011,758.75 - 3,954,604.5 = 0$$

$$(a) \quad T_2 = \frac{9,066,363.25}{105,000} = \boxed{86.3 \text{ °C}}$$

Enthalpy balance at cooler:

$$\Delta H = 0$$

$$(\Delta H_w^{\text{out}} - H_w^{\text{in}}) - (\Delta H_p^{\text{out}} - H_F) = 0$$

$$\begin{aligned}
 m_w \int_{20}^{60} C_p dT - \left[m_{H_2O} \int_{86.34}^{40} C_p dT - m_{td} \int_{86.34}^{40} C_p dT \right] &= 0 \\
 \frac{m_w}{(\text{kg})(\text{°C})} \left| \frac{4.2 \text{ kJ}}{} \right| \left(60 - 20 \right) \text{ °C} &= \frac{1,251.25 \text{ kg H}_2\text{O}}{(\text{kg})(\text{°C})} \left| \frac{4.2 \text{ kJ}}{} \right| \left(40 - 90 \right) \text{ °C}
 \end{aligned}$$

$$+ \frac{12498.75 \text{ kg tol}}{(\text{kg})(\text{°C})} \left| \frac{1.7 \text{ kJ}}{} \right| \left(40 - 90 \right) \text{ °C}$$

$$m_w 168 \frac{\text{kJ}}{\text{kg}} - 262,762 \text{ kJ} - 1,062,394 \text{ kJ}$$

$$m_w = \frac{1,325,156 \text{ kJ}}{168 \text{ kJ/kg}} = \boxed{7,887 \text{ kg H}_2\text{O}}$$

Solutions Chapter 9

9.3.47

Basis: 1 lb water/steam

Steady-state, open system for each unit

The data:

Tabulation of p, T, \hat{V} , \hat{H} and quality or superheats at the numbered points:

	1	2	3	4	5	6
p (psia)	14.7	250	250	250	40	0.306
T (°F)	65	65	401	550	268	65
\hat{V} (ft ³ /lb)	0.026	0.016	1.844	2.202	10.14	0.016
qual./sup.heat	0%	0%	100%	149°	96.5%	0%
\hat{H} (Btu/lb)	33.09	33.79	1201.1	1291	1137	33.05

Calculate the specific volume at point 5:

$$\hat{V} = 0.965(10.506) + 0.035(0.01715) = 10.14$$

(a) Heat to boiler:

$$Q = \Delta H = H_3 - H_2 = 1201.1 - 33.8 = 1167.3 \text{ Btu/lb}$$

(b) Heat to superheater:

$$Q = \Delta H = H_4 - H_3 = 1291 - 1201.1 = 90 \text{ Btu/lb}$$

(c) Heat removed in condenser = $H_6 - H_5 = 33 - 1137 = -1104 \text{ Btu/lb}$

(d) Work delivered by turbine: $Q + W = \Delta H$

$$Q = 0 \quad W = \Delta H = H_5 - H_4 = 1137 - 1291 = -154 \text{ Btu/lb}$$

(e) Work required by the pump between 1 and 2:

$$Q + W = \Delta H \quad Q = 0 \quad \text{hence } W = \Delta H$$

Because we do not have values of ΔH for compressed water at 65°F, we will use

$$W = \Delta U + \Delta(pV)$$

$$\Delta U = \int_{65^{\circ}\text{F}}^{65^{\circ}\text{F}} C_v dT = 0$$

Solutions Chapter 9

$$\Delta(pV) = p_2 V_2 - p_1 V_1 = (p_2 - p_1)V = \frac{(250 - 14.7)}{0.016} \left| \frac{144}{778} \right| = \boxed{0.70 \text{ Btu/lb}}$$

$$\begin{aligned}\text{Efficiency} &= \frac{\text{Net work delivered}}{\text{Total heat Supplied}} = \frac{154 - 0.70}{1167.3 + 90} \\ &= 0.121\end{aligned}$$

For a water rate of 2000 lb/hr:

$$\text{hp} = \frac{154 \text{ Btu}}{\text{lb}} \left| \frac{2000 \text{ lb steam}}{\text{hr}} \right| \left| \frac{1 \text{ hr}}{3600 \text{ s}} \right| \left| \frac{1.415 \text{ hp}}{1 \text{ Btu/s}} \right| = 121$$

You can improve the efficiency by:

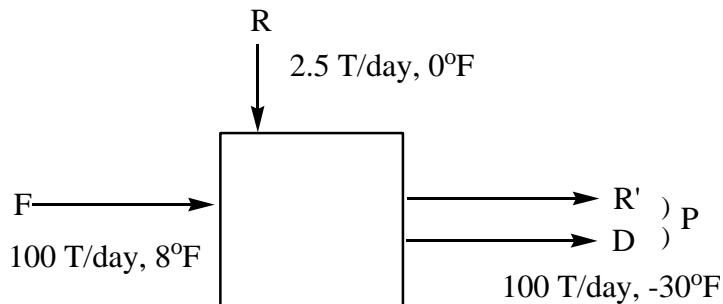
- (a) Exhausting the turbine at a lower pressure.
- (b) Use higher boiler pressure.
- (c) Use higher superheat.

9.3.48

Basis: 100 lb/day liquid C₁₂, feed at 8°F

Assume

- (1) Adiabatic operation of all units
- (2) Flow process, steady-state



First find the enthalpy lost or gained by the C₁₂ in the heat exchanger from which we can get the work done by compressor A on the Freon.

Overall C₁₂ balance through the heat exchanger

$$\begin{aligned}F + R &= P \\ 100 + 2.5 &= 102.5\end{aligned}$$

Solutions Chapter 9

Energy balance for C_{l₂} through the heat exchanger

For a flow process: $Q + W = \Delta H$
 $W = 0$
 $Q = \Delta H$

Choose as the reference state liquid C_{l₂} at -30°F

$$\begin{aligned}\Delta H &= H_{P_{\text{out}}} - H_{F_{\text{in}}} - H_{R_{\text{in}}} \\ &= \frac{8.1 \text{ Btu}}{(\text{lb mol})(^{\circ}\text{F})} \left| \frac{\text{lb mol}}{71 \text{ lb}} \right| \left| \frac{102.5 \text{ lb}}{100 \text{ lb F}} \right| \left[-30 - (-30)^{\circ}\text{F} \right] \\ &\quad - \frac{8.1 \text{ Btu}}{(\text{lb mol})(^{\circ}\text{F})} \left| \frac{\text{lb mol}}{71 \text{ lb}} \right| \left| \frac{100 \text{ lb}}{100 \text{ lb F}} \right| \left[8 - (-30)^{\circ}\text{F} \right] \\ &\quad - \frac{8.1 \text{ Btu}}{(\text{lb mol})(^{\circ}\text{F})} \left| \frac{\text{lb mol}}{71 \text{ lb}} \right| \left| \frac{2.5 \text{ lb}}{100 \text{ lb F}} \right| \left[0 - (-30)^{\circ}\text{F} \right] = 0 - 433.5 - 8.55 = -442.1 \frac{\text{Btu}}{100 \text{ lb F}}\end{aligned}$$

Consequently

$$Q = -442.1 \text{ Btu}/100 \text{ lb F}$$

This means heat is lost by the C_{l₂} and gained by the Freon

Energy balance for the Freon flowing through compressor A:

$$Q + W = \Delta H$$

But since the flow of Freon is cyclical

$$\Delta H = 0$$

$$Q_{\text{Freon}} = -Q_{C_{l_2}} = -(-442.1) = 442.1 \text{ Btu}/100 \text{ lb F}$$

$$W_A = Q_{\text{Freon}} = 442.1 \frac{\text{Btu}}{100 \text{ lb F}}$$

Energy balance for the C_{l₂} flowing through the compressor B:

2.5 lb/day @ -30°F → 2.5 lb/day at 0°F

$$Q + W = \Delta H \quad Q = 0$$

Solutions Chapter 9

$$\Delta H = \text{Enthalpy change across compressor} = H_R - H_{R'}$$

Other units

$$\begin{aligned} W &= 539 \text{ Btu/mole} & H_R &= Cp\Delta T + H_{\text{vap}} \\ &= 1,520,000 \text{ Btu/day} \end{aligned}$$

$$\Delta H = \frac{2.5 \text{ lb}}{100 \text{ lb F}} \left| \frac{8.1}{71} [0 - (-30)] \right.$$

$$+ \frac{4878 \text{ cal}}{\text{g mol}} \left| \frac{1.8 \text{ Btu/lb}}{\text{cal/g mol}} \right| \left| \frac{1 \text{ lb mol}}{71 \text{ lb}} \right| \left| \frac{2.5 \text{ lb}}{100 \text{ lb F}} \right.$$

$$= 8.55 + 309 = 317.5 \frac{\text{Btu}}{100 \text{ lb F}}$$

Total work input needed to make the process operational:

$$hp = \frac{317.5 + 442.1 \text{ Btu}}{100 \text{ lb F}} \left| \frac{2000 \text{ lb}}{\text{ton}} \right| \left| \frac{100 \text{ ton F}}{\text{day}} \right| \left| \frac{778(\text{ft})(\text{lb}_f)}{\text{Btu}} \right|$$

$$\frac{1 \text{ day}}{(24) \times (60) \text{ min}} \left| \frac{(hp)(\text{min})}{33,000(\text{ft})(\text{lb}_f)} \right| \left| \frac{}{0.30} \right|$$

$$= \boxed{82.9 \text{ horsepower}} \quad (\text{actual power input})$$

Solutions Chapter 9

9.3.49

Basis: 1 day; Reference temp = 80°F

- a. Material and Energy Balances:

Overall Material:

In	=	1,000,000 lb
Out : residue	=	500,000 lb
naptha	=	200,000 lb
gasoline	=	<u>300,000 lb</u>
Total out	=	1,000,000 lb

Tower 1:

<i>Material</i>	<u>In</u>		<u>Out</u>
feed	1,000,000	vapor	2,000,000
reflux	<u>1,500,000</u>	residue	<u>500,000</u>
total	2,500,000	total	2,500,000

Energy:

In: feed:	$(1 \times 10^6)(0.53)(480 - 90)$	$10^6(100)$	
	$+ (10^6)(0.45)(500 - 480)$		315,000,000 Btu
reflux:	$(1.5 \times 10^6)(0.59)(180 - 90)$		79,700,000 Btu
steam:	(by difference)		<u>114,500,000 Btu</u>
total:			509,700,000 Btu

Out: residue:	$(5 \times 10^5)(0.51)(480 - 90)$	=	99,200,000
vapor:	$(2 \times 10^6)(111)$	=	222,000,000
liquid:	$(2 \times 10^6)(0.59)(250 - 90)$	=	<u>188,500,000</u>
total (Btu):		=	509,700,000

Furnace:

<i>Material</i>	<u>In</u>		<u>Out</u>
	1,000,000 lb		1,000,000 lb
<i>Energy</i>	<u>In</u>		<u>Out</u>
feed:	$(10^6)(0.53)(200 - 90) = 58,300,000$		
furnace ht:		<u>257,200,000</u>	
total: (Btu)		315,500,000	315,500,000

Condenser I:

Material

In: vapor	=	2.0×10^6 lb
H ₂ O: $304,500,000 / (1)(120 - 70)$	=	6.1×10^6 lb

Solutions Chapter 9

Out: liquid: 2.0×10^6 lb

Energy

H_2O	=	6.1×10^6 lb
In: vapor: $222 \times 10^6 + 188 \times 10^6$	=	410.5×10^6 Btu
Out: liquid: $(2 \times 10^6)(0.59)(180 - 90)$	=	106×10^6 Btu
Removed by water	=	$\underline{304.5 \times 10^6}$ Btu
Total out:	=	410.5×10^6 Btu

Preheater I:

Material

In: liquid = 500×10^6 lb; Out: vapor	=	500×10^6 lb
<i>Energy</i>		
In: liquid: $(5 \times 10^5)(0.59)(180 - 90)$	=	26.5×10^6 Btu
steam:	=	$\underline{78.65 \times 10^6}$ Btu
Total	=	105.15×10^6 Btu
Out: vapor: $(5 \times 10^5)(0.59)(250 - 90)$		
$+(5 \times 10^5)(111)$		
$+(5 \times 10^5)(0.51)(200 - 250)$	=	105.15×10^6 Btu

Tower II

Material

In: feed	=	500,000 lb	Out: vapor	=	900,000
reflux	=	600,000 lb	residue	=	<u>200,000</u>
Total	=	1,100,000 lb	total	=	1,100,000

Energy

In: feed:	=	105,150,000
reflux: $(6 \times 10^5)(0.63)(120 - 90)$	=	11,300,000
steam: (by difference)	=	<u>42,700,000</u>
Total: (Btu):	=	159,150,000

Out: vapor: $(9 \times 10^5)(0.63)(150 - 90) + 9 \times 10^5(118)$	=	140.05×10^6
residue: $(2 \times 10^5)(0.58)(255 - 90)$	=	$\underline{19.1 \times 10^6}$
Total (Btu):	=	159.15×10^6

Condenser II

Material

In: vapor:	=	0.9×10^6 lb
H_2O : $\frac{123.05 \times 10^6}{(1)(110 - 70)}$	=	3.08×10^6 lb
Out: liquid	=	0.9×10^6 lb

Solutions Chapter 9

$$\text{H}_2\text{O} \quad = 3.08 \times 10^6 \text{ lb}$$

Energy

In:	(Btu)	=	140.05×10^6
Out:	liquid: $(9 \times 10^5)(0.63)(120 - 90)$	=	17×10^6
	removed by H_2O :	=	123.05×10^6
	Total (Btu):	=	140.05×10^6

Heat Exchanger II (Assume $T_{\text{out}} = 90^\circ\text{F}$)

<i>Material</i>	<u>In</u>		<u>Out</u>
liquid:	300,000 lb	liquid:	300,000
$\text{H}_2\text{O}: 5,670,000/(1)(80-70) =$	567,000 lb	$\text{H}_2\text{O}: 567,000$	

Energy

In: $(300,000)(0.63)(120-90)$	=	5.67×10^6 Btu
Out: liquid:	=	0.00
removed by H_2O	=	5.67×10^6 Btu

Heat Exchanger III

Material

In = Out:

Bottoms	200,000 lb
Charge	1,000,000 lb

Energy

In: $(200,000)(0.58)(255-90)$	=	19.15×10^6
$(1 \times 10^6)(0.53)(90-90)$	=	<u>0.0</u>
Total (Btu):	=	19.15×10^6
Out: $(2 \times 10^5)(0.58)(26.3-90)$	=	-7.35×10^6
$(1 \times 10^6)(0.53)(140-90)$	=	<u>26.5×10^6</u>
Total (Btu):	=	19.15×10^6

T_{out} of 26.3°F does not seem reasonable

Heat Exchanger IV

Material

In = Out

Bottoms	0.5×10^6 lb
Charge	1.0×10^6 lb

Solutions Chapter 9

Energy

$$\begin{array}{lcl} \text{In: } (5 \times 10^5)(0.51)(480-90) & = & 99.3 \times 10^6 \\ (1 \times 10^6)(0.53)(140-90) & = & 26.5 \times 10^6 \\ \text{Total (Btu):} & = & 125.8 \times 10^6 \end{array}$$

$$\begin{array}{lcl} \text{Out: } (5 \times 10^5)(0.51)(257-90) & = & 67.5 \times 10^6 \\ (1 \times 10^6)(0.53)(200-90) & = & 58.3 \times 10^6 \\ \text{Total (Btu):} & = & 125.8 \times 10^6 \end{array}$$

$$\text{Heat load of furnace} = 315.5 \times 10^6 - 58.3 \times 10^6 = \boxed{257.2 \times 10^6 \text{ Btu}}$$

- b. Additional heat if charge to furnace is at 90°F

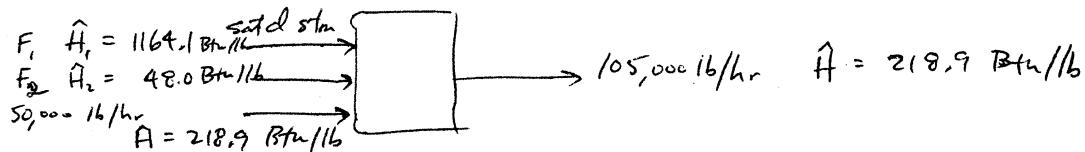
$$\text{Total heat load} = 315.5 \times 10^6 \text{ Btu}$$

$$\text{Additional heat} = 315.5 \times 10^6 - 257.2 \times 10^6 = \boxed{58.3 \times 10^6 \text{ Btu}}$$

9.3.50

Basis: 1 hour Open steady-state process

Deaerator Balance



$$\text{Material Balance: } F_1 + F_2 + 50,000 = 105,000 \quad F_2 = 105,000 - 50,000 - F_1$$

$$\text{Energy Balance: } F_1(1164.1) + F_2(48.0) + 50,000(218.9) = 105,000(218.9)$$

$$F_1(1164.1) + (55,000 - F_1)(48.0) = 55,000(218.9)$$

a. $F_2 = \boxed{8,422 \text{ lb/hr}} \text{ steam}$

b. $F_2 = \boxed{46,578 \text{ lb/hr}} \text{ make-up feedwater}$

Boiler Feedwater Pump

$$\begin{aligned} \dot{m}\hat{V}\Delta p &= \left(105,000 \frac{\text{lb}}{\text{hr}}\right) \left(0.017 \frac{\text{ft}^3}{\text{lb}}\right) \left(800 - 30 \frac{\text{lb}_f}{\text{in}^2}\right) \left(\frac{144 \text{ in.}^2}{\text{ft}^2}\right) \left(\frac{(\text{hp})(\text{s})}{550(\text{ft})(\text{lb}_f)}\right) \left(\frac{\text{hr}}{3600\text{s}}\right) \\ &= 100 \text{ hp} \end{aligned}$$

Solutions Chapter 9

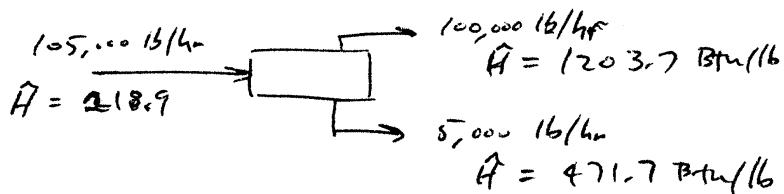
c. For 55% efficiency: 181.7 hp

d. $(181.7 \text{ hp}) \left(0.7457 \frac{\text{kW}}{\text{hp}} \right) = \boxed{135.5 \text{ kW}}$

e. $(135.5 \text{ kW})(8760 \frac{\text{hr}}{\text{yr}})(\$0.05/\text{kWhr}) = \boxed{\$59,360/\text{year}}$

f. Savings = $(105,000)(0.017)(200)(144) \left(\frac{1}{550} \right) \left(\frac{1}{3600} \right) \left(\frac{0.7457}{0.55} \right) (8760)(0.05)$
 $= \boxed{\$15,420/\text{year}}$

Steam Drum

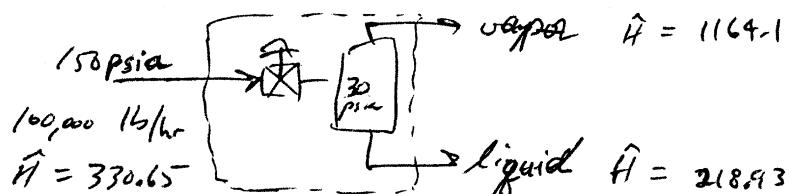


$$(100,000)(1230.7) + (5000)(471.7) - 105,000(218.9) = 102.4 \times 10^6 \text{ Btu/hr}$$

g. Steam Drum Heat Input = $102.4 \times 10^6 \text{ Btu/hr}$

h. Superheater = $(100,000)(1351.8 - 1230.7) = \boxed{12.1 \times 10^6 \text{ Btu/hr}}$

Flash Drum



x = vapor flowrate

$$(100,000 - x)(218.93) + x(1164.1) = 100,000(330.65)$$

x = 11,820 lb/hr = vapor flowrate

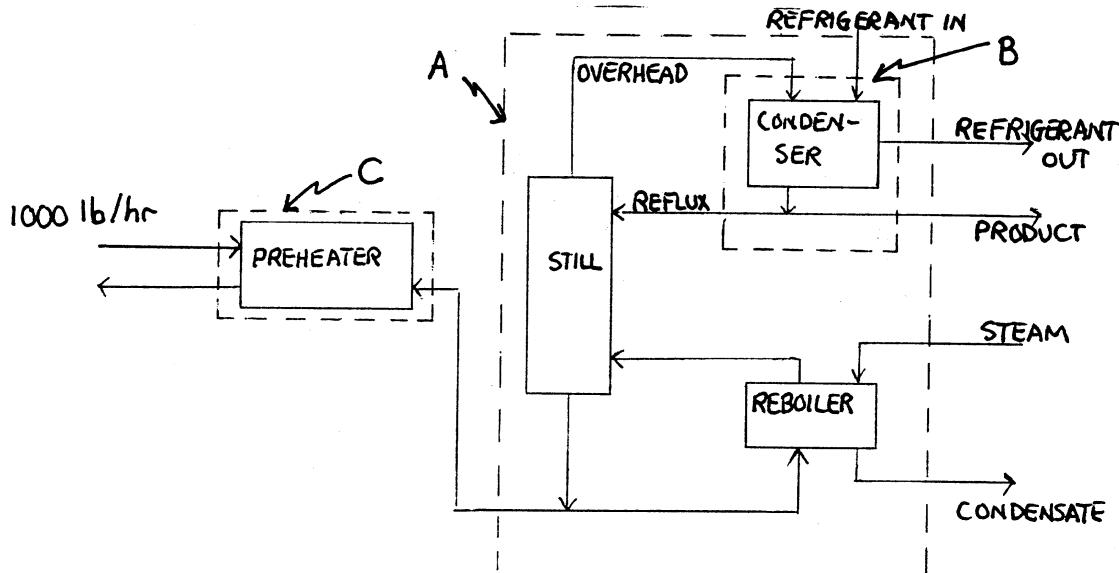
and 88,180 lb/hr = liquid flowrate

i. Steam Lost = $11,820 - 8,422 = \boxed{3,398 \text{ lb/hr}}$

j. Condensate Lost = $88,180 - 50,000 = \boxed{38,180 \text{ lb/hr}}$

Solutions Chapter 9

9.3.51



Basis: one hour operation open, steady-state process.

A material balance initially is necessary to determine amounts and compositions of streams.

A. Feed

<u>Component</u>	<u>Wt.%</u>	<u>lb</u>
C ₂ H ₆	65	650
C ₂ H ₄	35	350

B. Product

Have 97% recovery of ethylene

$$\text{lb C}_2\text{H}_4 = (0.97)(350) = 340$$

Now, since the product is 98% C₂H₄

$$\frac{340 \text{ lb C}_2\text{H}_4}{98 \text{ lb C}_2\text{H}_4} \left| \frac{2 \text{ lb C}_2\text{H}_6}{98 \text{ lb C}_2\text{H}_4} \right. = 6.95 \text{ lb C}_2\text{H}_6$$

<u>Component</u>	<u>Wt.%</u>	<u>lb</u>
C ₂ H ₆	2	6.95

Solutions Chapter 9

C ₂ H ₄	98	340
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C. Bottoms

$$\begin{aligned} \text{lb} & \quad C_2H_4 = 350 - 340 = 10 \\ \text{lb} & \quad C_2H_6 = 650 - 6.95 = 643.05 \end{aligned}$$

<u>Component</u>	<u>Wt.%</u>	<u>lb</u>
C ₂ H ₆	98.47	643.05
C ₂ H ₄	1.53	10

We are now ready to determine, by a series of energy balances, the quantities desired.

Energy Balance on System “A” (see Fig.)

$$\text{Energy in with Feed + energy in with steam} = \begin{cases} \text{Energy out with Product +} \\ \text{Energy out with bottoms +} \\ \text{Energy out with refrigerant} \end{cases}$$

We will assign an arbitrary enthalpy of zero to the liquid feed as it enters the Pre-heater at -100°F. Actually, any reference condition could be chosen since we are only concerned with enthalpy changes in the balances.

The feed undergoes at 20°F rise before it enters the still.

$$T = -80^{\circ}\text{F} \text{ and}$$

$$C_p \text{ feed} = (0.65)(0.65) + (0.35)(0.55) = 0.62 \text{ Btu/(lb)} (\text{°F})$$

$$\begin{aligned} \text{Enthalpy in with feed} &= (\text{lb feed}) (C_p \Delta T) = (1000)(0.62)(-80 - (-100)) \\ &= 12,400 \text{ Btu/hr} \end{aligned}$$

$$\text{Enthalpy in with steam} = (\text{lb steam}) (\Delta H_v) \text{ at } 30 \text{ psig,}$$

$$\Delta H_v = 945 \text{ Btu/lb}$$

$$\text{Enthalpy in with steam} = (S)(945) \text{ btu/hr}$$

From the data given, the temperature of the saturated liquid product is =30°F since it is essentially pure ethylene.

$$C_p = 0.55 \text{ Btu/(lb)} (\text{°F})$$

Solutions Chapter 9

Enthalpy out with product = $(346.95)(0.55)[-30-(-100)] = 13,360 \text{ Btu/hr}$

The bottoms are practically pure ethane so, $T = 10^\circ\text{F}$,

$$C_p = 0.65 \text{ Btu/(lb)} (\text{ }^\circ\text{F})$$

Enthalpy out with bottoms = $(653.05)(0.65)[10-(-100)] = 46,700 \text{ Btu/hr}$

The refrigerant experiences a temperature rise of 25°F as it passes through the condenser. The heat capacity may be assumed to be $1.0 \text{ Btu/(lb)} (\text{ }^\circ\text{F})$

Enthalpy out with refrigerant = $(\text{lb refriger.)})(1.0)(25) m \text{ Btu/hr}$

Now, rewriting the energy balance "A" with a substitution of known terms:

$$12,400 + 945S = 13,360 + 46,700 + 25m \quad (1)$$

It is evident from this first balance that a second balance will be necessary to determine the unknown quantities.

Energy Balance "B"

$$\begin{aligned} \text{Energy in with Overhead} &= \text{Energy out with refrigerant} + \\ &\quad \text{Energy out with Product} + \\ &\quad \text{Energy out with Reflux} \end{aligned}$$

Since we are using a reflux ration of 6.1

$$\text{lb reflux} = (6.1)(346.95) = 2,120 \text{ lb/hr.}$$

Now, the specific enthalpy of the reflux = the specific enthalpy of the product, since they are from the same stream, and the differences in enthalpy between the overhead and the product, or overhead and reflux, is merely the heat of vaporization of ethylene (neglecting the small amount of C_2H_6 present), therefore, we can rewrite Energy Balance "B" as:

$$(\text{lb Overhead}) (\Delta H_v) = 25 m$$

$$(2,120 + 346.95)(135) = 25 m$$

$$\text{or } m = 13,320 \text{ lb/hr.}$$

Now substituting this value into equation (1) we have

$$12,400 + 945 S = 13,360 + 46,700 + (25)(13,320)$$

Solutions Chapter 9

so that $[S = 403 \text{ lb/hr}]$

a. $\frac{403 \text{ lb steam}}{\text{hr}} \left| \frac{\text{hr}}{1000 \text{ lb feed}} \right. = 0.403 \text{ lb steam/lb feed}$

b. $\frac{13,320 \text{ lb refrigerant}}{\text{hr}} \left| \frac{1 \text{ ft}^3 \text{ refrigerant}}{50 \text{ lb refrigerant}} \right| \left| \frac{7.48 \text{ gallons}}{\text{ft}^3} \right. = [1,993 \text{ gallons of refrigerant/hr}]$

The bottoms leave the still and enter the Pre-heater at approximately 10°F, the saturation temperature of pure C₂H₆. The final temperature of the bottoms as it leaves the Pre-heater can be calculated from a simple energy balance around the Pre-heater.

c. Enthalpy Balance “C”

$$(\text{lb bottoms}) [0.65 \text{ Btu/(lb)} (\text{°F})] (10 - T_f) = (\text{lb feed})$$

$$\times [0.62 \text{ Btu/(lb)} (\text{°F})] [-80 - (-100)]$$

$$(653.05) (0.54) (10 - T_f) = (1000) (0.62) (20)$$

$$T_f = 19.2 \text{ °F}$$

Solutions Chapter 10

10.1.1

(b), (d), (f)

10.1.2

(a)

10.1.3

(c)

10.1.4

The ΔH_f° is 0 by definition.

10.1.5

$\hat{\Delta H}_f^\circ$ of Fe_2O_3 is calculated as follows.

$$(1) \quad \Delta H_{Rxn} = \sum_{\text{products}} n_i \hat{\Delta H}_{f_i}^\circ - \sum_{\text{reactants}} n_i \hat{\Delta H}_{f_i}^\circ$$

$$\begin{aligned} -822.200 \text{ kJ} &= \hat{\Delta H}_{f_{Fe_2O_3}}^\circ - \hat{\Delta H}_{f_{Fe}}^\circ (2) - \hat{\Delta H}_{f_{O_2}}^\circ \left(\frac{3}{2}\right) \\ &= \hat{\Delta H}_{f_{Fe_2O_3}}^\circ - 0 - 0 \end{aligned}$$

$$(2) \quad \Delta H_{Rxn} = -284.100 \text{ kJ}$$

$$\begin{aligned} &= \hat{\Delta H}_{f_{Fe_2O_3}}^\circ - \hat{\Delta H}_{f_{FeO}}^\circ (2) - \hat{\Delta H}_{f_{O_2}}^\circ \left(\frac{1}{2}\right) \\ -284.100 &= -822.200 - \hat{\Delta H}_{f_{FeO}}^\circ (2) - 0 \left(\frac{1}{2}\right) \end{aligned}$$

$$\begin{aligned} \hat{\Delta H}_{f_{FeO}}^\circ &= \frac{-538.10}{2} \text{ kJ} = \boxed{-269.05 \text{ kJ}} \\ &\text{vs - 267 in Appendix F} \end{aligned}$$

Solutions Chapter 10

10.1.6

	$\Delta H^\circ(\text{kJ})$
$\text{C}_3\text{H}_8(\text{g}) \rightarrow \text{C}_3\text{H}_6(\text{g}) + \text{H}_2(\text{g})$	+123.8
$3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l}) \rightarrow \text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g})$	+2220.0
$4[\text{H}_2(\text{g}) + 1/2\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})]$	$4 \times (-285.8)$
$3[\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})]$	$3 \times (-393.4)$

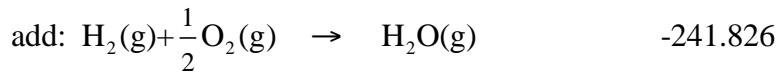


$$\Delta H_f^\circ \text{ of } \text{C}_3\text{H}_6 = \boxed{20.1 \text{ kJ/g mol}}$$

10.1.7

Basis: 1 g mol C_5H_2

ΔH (kJ/g mol)



10.1.8

(a) $\text{NH}_4(\text{l})$: -67.20 kJ/g mol from Appendix F

(b) Formaldehyde gas (H_2CO): -115.89 kJ/g mol from Appendix F

(c) Acetaldehyde liquid (CH_3CHO):

For gas $\Delta H_f^\circ = 166.4 \text{ kJ/g mol}$ from Appendix F

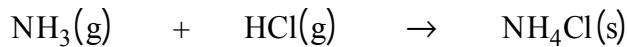
The heat of vaporization at 293.2 K is 25.732 kJ/g mol from the CD. The value is close enough to ΔH_{vap} (298 K) to use.

$$\Delta H_f^\circ = -166.4 + 25.732 = -140.7 \text{ kJ/g mol}$$

Solutions Chapter 10

10.2.1

a. Basis: 1 g mol NH₃(g)



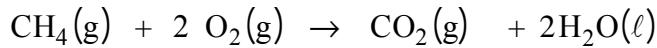
$$\hat{\Delta H}_f^\circ (\text{kJ / g mol}): -46.191 \quad -92.311 \quad -315.4$$

$$\Delta H_{\text{rxn}}^\circ = \sum_{\text{products}} n_i \hat{\Delta H}_i - \sum_{\text{reactants}} n_i \hat{\Delta H}_i$$

$$= (1)(-315.4) - [(1)(-46.191) + (1)(-92.311)]$$

$$= \boxed{-176.9 \text{ kJ / g mol NH}_3(\text{g})}$$

b. Basis: 1 g mol CH₄(g)



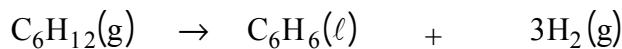
$$\hat{\Delta H}_f^\circ (\text{kJ / g mol}): -74.84 \quad 0 \quad -393.51 \quad -285.840$$

$$\Delta H_{\text{rxn}}^\circ = \sum_{\text{products}} n_i \hat{\Delta H}_i - \sum_{\text{reactants}} n_i \hat{\Delta H}_i$$

$$= [(2)(-285.840) + (1)(-393.51)] - [(1)(-74.84) + 0]$$

$$= -890.4 \text{ kJ / g mol CH}_4(\text{g})$$

c. Basis: 1 g mol C₆H₂(g)



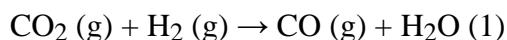
$$\hat{\Delta H}_f^\circ (\text{kJ / g mol}): -123.1 \quad +48.66 \quad 0$$

$$\Delta H_{\text{rxn}}^\circ = [0 + (1)(+48.66)] - [(1)(-123.1)] = \boxed{171.76 \text{ kJ / g mol C}_6\text{H}_{12}(\text{g})}$$

Solutions Chapter 10

10.2.2

a. Basis: 1 g mol CO₂ (g)



$$\Delta H^\circ_{\text{rxn}} = (-110.52 - 285.84) - (-393.51) = \boxed{-2.849 \text{ kJ}}$$

b. Basis: 1 g mol CaO (s)

$$\Delta H^\circ_{\text{rxn}} = (-986.59 - 924.66) = [(-635.55 - 601.83) - 2(285.84)] =$$

$$\boxed{-102.19 \text{ kJ per mol CaO(s)}}$$

Multiply by 2 for the reaction listed $\boxed{-204.38 \text{ kJ}}$

c. Basis: 1 g mol Na₂SO₄ (s)

$$\Delta H^\circ_{\text{rxn}} = (-1090.35 - 110.54) - (-1384.49) = \boxed{183.59 \text{ kJ}}$$

d. Basis: 1 g mol NaCl (s)

$$\Delta H^\circ_{\text{rxn}} = (-92.31 - 1126.33) - (-811.32 - 411.01) = \boxed{3.67 \text{ kJ}}$$

e. Basis: 1 g mol O₂

$$\Delta H^\circ_{\text{rxn}} = [2(-1384.5) + 4(-92.31)] - [(-411.00) + 2(-296.90)]$$

$$+ 2(-285.84)] = \boxed{-1561.76}$$

f. Basis: 1 g mol SO₂ (g)

$$\Delta H^\circ_{\text{rxn}} = (-811.32) - (-285.84 - 296.90) = \boxed{-228.58 \text{ kJ}}$$

g. Basis: 1 g mol N₂

$$\Delta H^\circ_{\text{rxn}} = 2(90.374) = \boxed{180.75 \text{ kJ}}$$

h. Basis: 1 g mol Na₂CO₃ (s)

$$\Delta H^\circ_{\text{rxn}} = [3(-1117.13) + (-393.51)] - [-1130.94 + 2(-373.21)]$$

$$+ 4(-296.90)] = \boxed{-1867.54 \text{ kJ}}$$

Solutions Chapter 10

i. Basis: 1 g mol CS₂ (1)

$$\Delta H^\circ_{\text{rxn}} = (-1394.69 - 60.25) - (+87.86) = \boxed{-287.61 \text{ kJ}}$$

j. Basis: 1 g mol C₂H₂ (g)

$$\Delta H^\circ_{\text{rxn}} = (+105.02) - (52.28 - 92.31) = \boxed{-145.05 \text{ kJ}}$$

k. Basis: 1 g mol CH₃OH (g)

$$\Delta H^\circ_{\text{rxn}} = (-115.90 - 241.82) - (-201.25) = \boxed{-156.48 \text{ kJ}}$$

l. Basis: 1 g mol C₂H₂ (g)

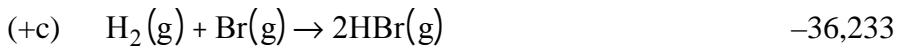
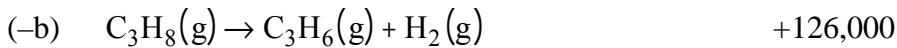
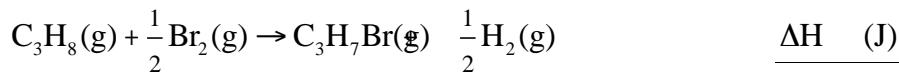
$$\Delta H^\circ_{\text{rxn}} = (-140.7) - (226.75 - 285.84) = \boxed{-81.61 \text{ kJ}}$$

m. Basis: 1 g mol C₄H₁₀ (g)

$$\Delta H^\circ_{\text{rxn}} = (52.28 - 84.67) - (-124.73) = \boxed{92.34 \text{ kJ}}$$

10.2.3

You want to get ΔH for



Total $\boxed{-10,029 \text{ J / g mol C}_3\text{H}_8}$

Solutions Chapter 10

10.2.4

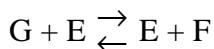
Basis: 1 g mol Fe S₂

$$\Delta H^\circ_{\text{rxn}} = 567.4 \text{ kJ/g mol FeS}_2$$

$$\frac{(-567.4) \text{ kJ}}{\text{g mol FeS}_2} \left| \frac{1 \text{ g mol FeS}_2}{120 \text{ g FeS}_2} \right| \left| \frac{1000 \text{ g}}{1 \text{ kg}} \right| = -4728.3 \frac{\text{kJ}}{\text{kg FeS}_2}$$

Note: The information about conversion does not affect the value of the standard heat of reaction. It will affect the values in the energy balance.

10.2.5



$\hat{\Delta H}_{\text{Rxn}}$ is at 25°C, 1 atm

$$\hat{\Delta H}_{\text{Rxn}} = \sum_{\text{prod.}} \hat{\Delta H}_f^\circ - \sum_{\text{react.}} \hat{\Delta H}_f^\circ = (1.040 \times 10^9 - 0.990 \times 10^9) \text{ J/g mol G}$$

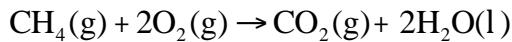
$$= [50 \times 10^6 \text{ J/g mol G converted}]$$

Since 0.48 reacts, $\Delta H_{\text{Rxn}}^\circ = 0.48(50) \times 10^6 \text{ J/g mol G}$

$$= 24 \times 10^6 \text{ J/g mol G fed (not asked for)}$$

10.2.6

No. The value reported is the heat transfer for constant volume, Q_v . The heating value at constant pressure should be reported for the standard heat of reaction (an enthalpy change). Assume the reaction is at 25°C.



Basis: 1 g mol CH₄

$$Q = \Delta U = \Delta H - \Delta(pV)$$

If the gases can be treated as ideal $\Delta(pV) = \Delta(nRT) = \Delta n (RT)$.

$$\Delta n = 1 - 2 - 1 = -2$$

Solutions Chapter 10

The correction is

$$\Delta nRT = -2 (8.314) (298) = -4958 \text{ J/g mol}$$

In SI units of 273.15 K and 101.3 kPa, the volume is 22.415 m³ g mol.

The correction is (ignoring the pressure change from 1000 kPa to p₂)

$$\frac{-4958}{22.415} = 221.2 \text{ J/m}^3 \text{ or } 0.22 \text{ kJ/m}^3$$

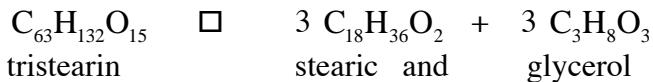
Otherwise you have to calculate p₂V - p₁V where p₂ = 1000 kPa and p₁ = p_{H₂O}^{*} + p_{CO₂}.

The value to be reported should be 39.97 - 0.22 = 39.75 kJ/m³

10.2.7

Yes. Calculate the sensible heats using the tables and using a common reference temperature.

10.2.8



$$\hat{\Delta H}_{rxn}^\circ = -[(3)(-964.3) + (3)(-159.16)] - (-3820)(1) = \boxed{-449.6 \text{ kJ/g mol}}$$

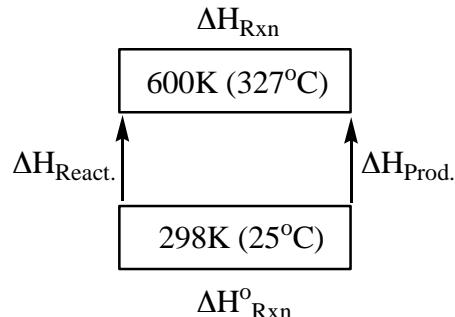
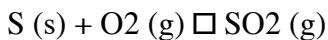
10.2.9

- If the exit temperature is > 25°C, and the dilutent is at the entering temperature of the reactants, then less heat has to be removed from the process.
- Remains the same as the presumption is in calculating ΔH_{rxn}° that stoichiometric quantities react to completion.
- At 25°C, $\hat{\Delta H}_{rxn}^\circ = \hat{\Delta H}_f^\circ$ with H₂O(g) = 241.826 kJ/g mol H₂O.

At 500 K, the sensible heats have to be considered, and ½ O₂ and H₂ together have a larger ΔH than does H₂O so that ΔH_{rxn} at 500 K is less than ΔH_{rxn} at 25°C.

Solutions Chapter 10

10.2.10



Basis: 1 g mol S(s) = 1 g mol SO₂(g)

$$\Delta H_{rxn, 600 K} = \Delta H^o_{rxn} + \sum \Delta H_{prod, 600 K} - \sum \Delta H_{react, 600 K}$$

$$\Delta H^o_{rxn, 298} = \sum_{prod} \Delta H^o_f - \sum_{react} \Delta H^o_f$$

$$\begin{aligned} &= [-296.90) - [0 + 0] = -296.90 \text{ kJ/g mol S} \\ &\quad = -296,900 \text{ J/g mol S} \end{aligned}$$

$$\underline{\sum \Delta H_{prod, 600 K}}$$

$$\Delta H_{SO_2, 600 K} = \int_{25}^{327} (38.91 + 3.904 \times 10^{-2} T - 3.104 \times 10^{-5} T^2 + 8.606 \times 10^{-9} T^3) dT$$

$$= 13,490 \text{ J/g mol} \quad (13,530 \text{ from Enthalpy Tables})$$

$$\underline{\sum \Delta H_{react, 600 K}}$$

This assumes s is really a liquid at 600°C, not a solid as in the equation

$$\begin{array}{ll} \Delta H_{S, 600 K} = \Delta H_{298-386} + \Delta H_{fusion} + \Delta H_{386-600} \\ \text{solid} \qquad \qquad \qquad \text{liquid} \end{array}$$

$$\begin{aligned} &= \int_{298}^{386} (15.2 + 2.68 \times 10^{-2} T) dT + 10,000 + 1/2 \int_{386}^{600} (35.90 + 1.26 \times 10^{-3} T) dT \\ &\quad \frac{1}{2} (S_2 \text{ from Perry}) \\ &= 2144 + 10,000 + 3975 \end{aligned}$$

Solutions Chapter 10

$$= 16,119 \text{ J/g mol}$$

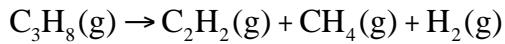
$$\Delta H_{O_2, 600\text{K}} = \int_{25}^{327} (29.10 + 1.158 \times 10^{-2}T - 0.6076 \times 10^{-5}T^2 + 1.311 \times 10^{-9}T^3) dT$$

$$= 9,340 \text{ J/g mol} \quad (8899 \text{ from the enthalpy tables})$$

$$\Delta H_{rxn, 600\text{K}} = -296,900 + (13,490 - 25,429)$$

$$= \boxed{308,840 \text{ J/g mol S}}$$

10.2.11



Basis: 1 g mol C_3H_8

$$\Delta H_{500} = \Delta H_{25} + \sum \Delta H_{prod} - \sum \Delta H_{react}$$

$$\Delta H_{25}^o = 226.75 + (-74.84) + 0 - (-103.85) = 255.76 \text{ kJ/g mol}$$

$$\Delta H = \int C_p dT = aT + b/2 T^2 + c/3 T^3 + d/4 T^4$$

$$\Delta H_{C_3H_8} = 68.032T + 1.130 \times 10^{-1}T^2 - 4.37 \times 10^{-5}T^3 + 7.928 \times 10^{-9}T^4 \Big|_{25}^{500}$$

$$= 55.53 \text{ kJ/g mol}$$

$$\Delta H_{C_2H_2} = 42.43 T + 3.027 \times 10^{-2}T^2 - 1.678 \times 10^{-5}T^3 + 4.55 \times 10^{-9}T^4 \Big|_{25}^{500}$$

$$= 25.89 \text{ kJ/g mol}$$

$$\Delta H_{CH_4} = 34.31 T + 2.735 \times 10^{-2}T^2 + 1.220 \times 10^{-6}T^3 + 2.75 \times 10^{-9}T^4 \Big|_{25}^{500}$$

$$= 23.10 \text{ kJ/g mol}$$

$$\Delta H_{H_2} = 28.84 T + 3.825 \times 10^{-5}T^2 + 1.096 \times 10^{-6}T^3 + 2.175 \times 10^{-10}T^4 \Big|_{25}^{500}$$

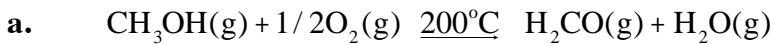
$$= 13.83 \text{ kJ/g mol}$$

$$\Delta H_{500} = (255.76 + 25.89 + 23.10 + 13.83) - 55.53 = \boxed{263.05 \text{ kJ/g mol}}$$

Solutions Chapter 10

10.2.12

All data is from Tables E.1 and F.1 of the Appendix.



Basis: 1 g mol CH_3OH

<u>Comp.</u>	<u>$C_p(\text{J}/(\text{g mol})(\text{K or } {}^\circ\text{C}))$</u>	<u>T</u>	<u>$\hat{\Delta H}_f^\circ(\text{kJ/g mol})$</u>
$\text{CH}_3\text{OH}(g)$	$42.39 + 8.301 \times 10^{-2}T - 1.87 \times 10^{-5}T^2 - 8.03 \times 10^{-9}T^3$	${}^\circ\text{C}$	-201.25
$\text{O}_2(g)$	$29.10 + 1.158 \times 10^{-2}T - 0.6076 \times 10^{-5}T^2 + 1.311 \times 10^{-9}T^3$	${}^\circ\text{C}$	0
$\text{H}_2\text{CO}(g)$	$34.28 + 4.268 \times 10^{-2}T - 8.694 \times 10^{-9}T^3$	${}^\circ\text{C}$	-115.89
$\text{H}_2\text{O}(g)$	$33.46 + 0.6880 \times 10^{-2}T - 0.7604 \times 10^{-5}T^2 - 3.593 \times 10^{-9}T^3$	${}^\circ\text{C}$	-241.826

$$25^\circ\text{C} = 298 \text{ K}$$

$$200^\circ\text{C} = 473 \text{ K}$$

$$\Delta H_{\text{rxn}, 25^\circ\text{C}}^\circ = [-115.89 + (-241.826)] - (-201.25) = 156.47 \text{ kJ/g mol}$$

$$= -156,470 \text{ J/g mol}$$

Products

Add the C_p equations for the two products and integrate (each involves 1 mole).

$$\begin{aligned} \sum \Delta H_{\text{prod}, 200^\circ\text{C}}^\circ &= \int_{25}^{200} (67.74 + 4.95 \times 10^{-2}T + 0.7604 \times 10^{-5}T^2 - 1.228 \times 10^{-8}T^3) dT \\ &= 12,850 \text{ J/g mol} \end{aligned}$$

Reactants

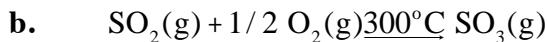
$$\begin{aligned} \Delta H_{\text{CH}_3\text{OH}}^\circ &= \int_{25}^{200} (42.39 + 8.301 \times 10^{-2}T - 1.87 \times 10^{-5}T^2 - 8.03 \times 10^{-9}T^3) dT \\ &= 9000 \text{ J/g mol} \end{aligned}$$

Solutions Chapter 10

$$\Delta H_{O_2} = \frac{1}{2} \int_{25}^{200} (29.10 + 1.158 \times 10^{-2}T - 0.6076 \times 10^{-5}T^2 + 1.311 \times 10^{-9}T^3) dT$$

$$= 2,650$$

$$\Delta H_{rxn, 200^\circ C} = -156,470 + 12,850 - 2,650 \quad \boxed{-146,270 \text{ J/g mol}}$$



Basis: 1 g mol SO_2

DATA:

Comp.	$C_p(\text{J}/(\text{g mol})(\text{K or } {}^\circ\text{C}))$	T	$\hat{\Delta H}_f^\circ(\text{kJ}/\text{g mol})$
$\text{O}_2(g)$	$29.10 + 1.158 \times 10^{-2}T - 0.6076 \times 10^{-5}T^2 + 1.311 \times 10^{-9}T^3$ ${}^\circ\text{C}$		0
$\text{SO}_2(g)$	$38.91 + 3.904 \times 10^{-2}T - 3.104 \times 10^{-5}T^2 + 8.606 \times 10^{-9}T^3$ ${}^\circ\text{C}$		-296.90
SO_3	$48.50 + 9.188 \times 10^{-2}T - 8.540 \times 10^{-5}T^2 + 32.40 \times 10^{-9}T^3$ ${}^\circ\text{C}$		-395.18

$$\Delta H_{rxn, 25^\circ C}^\circ = -395.18 + 296.90 = -98.28 \text{ kJ/g mol} = 98,280 \text{ J/g mol}$$

Products

$$\sum \Delta H_{prod, 300^\circ C} = \int_{25}^{300} (48.50 + 9.188 \times 10^{-2}T - 8.540 \times 10^{-5}T^2 + 32.40 \times 10^{-9}T^3) dT$$

$$= 16,740 \text{ J/g mol}$$

Reactants

$$\Delta H_{\text{SO}_2} = \int_{25}^{300} (38.91 + 3.904 \times 10^{-2}T - 3.104 \times 10^{-5}T^2 + 8.606 \times 10^{-9}T^3) dT$$

$$= 12,180 \text{ J/g mol}$$

$$\Delta H_{\text{O}_2} = 8,470 \text{ J/g mol}$$

$$\Delta H_{rxn, 300^\circ C} = -98,280 + 16,740 - 12,180 - (8,470) \frac{1}{2} = \boxed{97,960 \text{ J/g mol SO}_2}$$

Solutions Chapter 10

10.2.13

Basis: 1 g mol SnO



$$\Delta H_{\text{rxn}, 25^\circ\text{C}} = -577.8 - (-283.3 + 0) = 294.5 \text{ kJ/g mol}$$

$$\Delta H_{90^\circ\text{C}} = \Delta H_{\text{rxn}, 25^\circ\text{C}} + \sum \Delta H_{\text{prod}} - \sum \Delta H_{\text{react}}$$

$$\Delta H = \int_{25^\circ\text{C}}^{90^\circ\text{C}} C_p dT$$

$$\Delta H_{\text{SnO}} = 39.33T + 7.575 \times 10^{-3} T^2 \Big|_{298}^{363} = 2.88 \text{ kJ}$$

$$\Delta H_{\text{SnO}_2} = 73.89 T + 5.02 \times 10^{-3} T^2 + \frac{2.16 \times 10^4}{T} \Big|_{298}^{363} = 2.89 \text{ kJ}$$

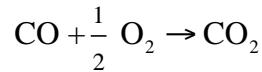
$$\Delta H_{\text{O}_2} = 29.1 T + 5.79 \times 10^{-3} T^2 - 2.025 \times 10^{-6} T^3 + 3.278 \times 10^{-10} T^4 \Big|_{25^\circ\text{C}}^{90^\circ\text{C}} = 1.93 \text{ kJ}$$

$$\Delta H_{90^\circ\text{C}} = -294.5 + 2.89 - (2.88 + 0.5(1.93)) = 295.46 \text{ kJ/g mol}$$

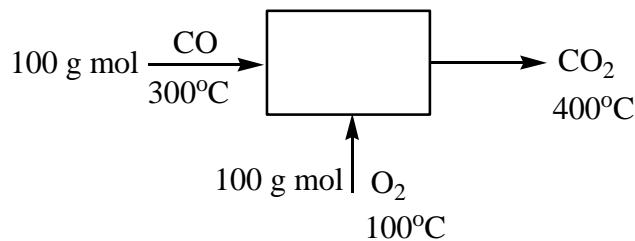
10.2.14

Basis: 100 g mol CO

Assume pressure is 1 atm, and an open, steady state process.



The energy balance reduces to $Q = \Delta H$. The reference temperature is 25°C .



Solutions Chapter 10

Data:

Comp.	mol	T(°C)	$\hat{\Delta}H_f^0$ (kJ/g mol)	Sensible heats from CD: $\hat{\Delta}H$ (kJ/g mol)*	ΔH (kJ)
<u>In</u>					
O ₂	100	100	-	2.235	223.5
CO	100	300	-110.541	8.294	-10,225
<u>Out</u>					
O ₂	50	400	-	11.715	585.8
CO ₂	100	400	-393.505	16.245	-37,726

*You can calculate $\hat{\Delta}H_{\text{sensible}}$ using the tables in the appendix, but the process requires interpolation.

$$Q = \Delta H = (-37,726 + 585.8) - (-10,225 + 223.5) = -27,139 \text{ kJ}$$

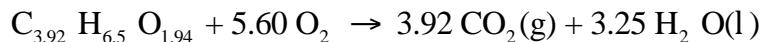
10.2.15

Basis: 1 g mol yeast

The heat of formation is



The heat of combustion is for the reaction



$$-1,518 \text{ kJ} = - \left[\sum_{\text{product}} n_i \hat{\Delta}H_{f,i}^0 - \sum_{\text{reactants}} n_i \hat{\Delta}H_{f,i}^0 \right]$$

$$-1,518 = - \left[(3.92)(-393.51) + (3.25)(-285.840) - 5.60(0) - (1)\hat{\Delta}H_{f,\text{yeast}}^0 \right]$$

$$\hat{\Delta}H_{f,\text{yeast}}^0 = 963.54 \text{ kJ/g mol}$$

The molecular weight of $\text{C}_{3.92}\text{H}_{6.5}\text{O}_{1.94}$ is 84.63. Per 100 g yeast

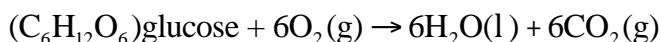
$$\hat{\Delta}H_{f,\text{yeast}}^0 = 1139 \text{ kJ/100 g yeast}$$

Solutions Chapter 10

10.2.16

The problem requires more information to solve. To make the solution easier but approximate, assume the reaction takes place at 25°C and 1 atm. Assume that the energy balance reduces to $Q = \Delta H$, and that Q represents the desired kJ. Data:

$\hat{\Delta H}_{f, H_2O}^\circ = -285.840$ $\hat{\Delta H}_{f, CO_2}^\circ = -393.51$, both in kJ/g mol. Ref. temp. = 25°C. Basis: 1 g mol glucose. MW of glucose = 180.



$$\Delta H^\circ = \Delta H_{\text{products}}^\circ - \Delta H_{\text{reactants}}^\circ$$

$$= [6(-285.840) + 6(-393.51)] - [1(-1260) + 6(0)] = -2816 \text{ kJ}$$

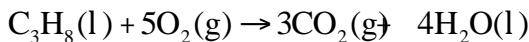
$$\frac{0.90(-2816)}{180} = \boxed{14.0 \text{ kJ/g glucose}}$$

At 37°C (body temperature), assume only the O_2 is used in a reaction

$$\frac{6 \text{ g mol } O_2}{1 \text{ g mol suc.}} \left| \frac{22.4 \text{ L at SC}}{g \text{ mol } O_2} \right| \left| \frac{310 \text{ K}}{273 \text{ K}} \right| \left| \frac{1 \text{ g mol suc.}}{180 \text{ g suc.}} \right| = \boxed{0.85 \text{ L/g at } 37^\circ\text{C and 1 atm}}$$

10.2.17

The reaction is



Need to calculate the heat of formation of C_3H_8 (l) and H_2O (l) first



$$\hat{\Delta H}_{f, C_3H_8(l)}^\circ = \hat{\Delta H}_{f, C_3H_8(g)}^\circ - \hat{\Delta H}_{\text{vap}}^\circ(25^\circ\text{C})$$

$$= -24.820 - 3.820 = 28.643 \text{ k cal/g mol}$$



$$\hat{\Delta H}_{f, H_2O(l)}^\circ = \hat{\Delta H}_{f, H_2O(g)}^\circ - \hat{\Delta H}_{\text{vap}}^\circ(25^\circ\text{C})$$

Solutions Chapter 10

$$= -57.798 - 10.519 = \boxed{68.317 \text{ k cal/g mol}}$$

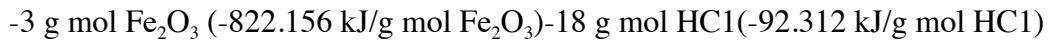
Basis: 1 g mol C₃H₈ (l)

$$\Delta H_{\text{Rxn}, \text{C}_3\text{H}_8(\text{l})} = 4(-68.317) + 3(-94.052) - (-28.643) = \boxed{-526.781 \text{ k cal/g mol}}$$

10.2.18

a.

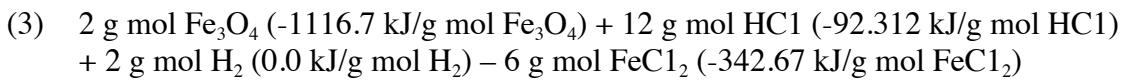
Presumably H₂, O₂, Cl₂, HCl, and H₂O are gases.



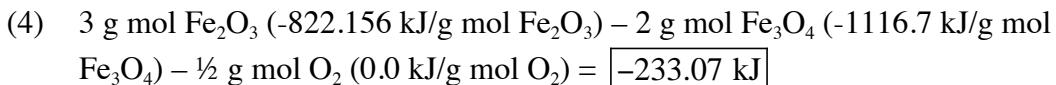
$$= \boxed{-468.39 \text{ kJ}}$$



$$-6 \text{ g mol FeCl}_3 \text{ (-403.34 kJ/g mol FeCl}_3\text{)} = \boxed{364.02 \text{ kJ}}$$

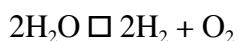


$$-8 \text{ g mol H}_2\text{O} \text{ (-241.826 kJ/g mol H}_2\text{O)} = \boxed{649.48 \text{ kJ}}$$



$$-3 \text{ g mol H}_2\text{O} \text{ (-241.826 kJ/g mol H}_2\text{O)} - 3 \text{ g mol Cl}_2 \text{ (0.0 kJ/g mol Cl}_2\text{)} = \boxed{171.61 \text{ kJ}}$$

b.



$$\sum \Delta H^\circ_{\text{n,i}} = \boxed{483.65 \text{ kJ}}$$

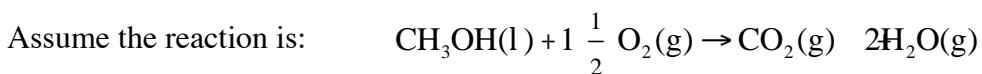
Solutions Chapter 10

10.2.19

Basis: 1 g gasoline

$$\Delta H = \frac{40 \text{ kJ}}{\text{g}} \left| \frac{0.84}{\text{cm}^3} \right. = 33.6 \text{ kJ/cm}^3$$

Methanol:



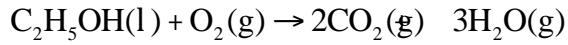
$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}) \quad -238.64 \quad 0 \quad -393.51 \quad -241.826$$

$$\Delta H_{\text{Rxn}} = 638.52 \text{ kJ/g mol}$$

$$\frac{638.52 \text{ kJ}}{\text{g mol}} \left| \frac{1 \text{ g mol}}{32.04 \text{ g}} \right| \left| \frac{0.792 \text{ g}}{\text{cm}^3} \right. = 15.79 \text{ kJ/cm}^3$$

$$\frac{33.6 \text{ kJ}}{\text{cm}^3 \text{ gas}} \left| \frac{\text{cm}^3 \text{ methanol}}{15.79 \text{ kJ}} \right. = 2.13 \frac{\text{cm}^3 \text{ methanol}}{\text{cm}^3 \text{ gas}} \quad \text{a. } (2.13-1) 100 = \boxed{113\% \text{ larger tank}}$$

Ethanol:



$$\Delta \hat{H}_f^\circ (\text{kJ/g mol}) \quad -277.63 \quad 0 \quad -393.51 \quad -241.826$$

$$\Delta H_{\text{Rxn}} = 1235 \text{ kJ/g mol}$$

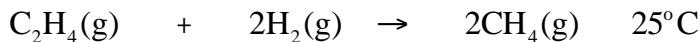
$$\frac{1235}{\text{g mol EtOH}} \left| \frac{1 \text{ g mol}}{46.07 \text{ g}} \right| \left| \frac{0.789 \text{ g}}{\text{cm}^3} \right. = 21.15 \text{ kJ/cm}^3$$

$$\frac{33.6 \text{ kJ}}{\text{cm}^3 \text{ gas}} \left| \frac{\text{cm}^3 \text{ EtOH}}{21.15 \text{ kJ}} \right. = 1.59 \quad \text{b. } (1.59) 100 - 100 = \boxed{59\% \text{ larger}}$$

Solutions Chapter 10

10.2.20

Basis: 1 g mol C₂H₄(g)



$\Delta\hat{H}_f^\circ \left(\frac{\text{kJ}}{\text{g mol}} \right)$	52.283	0	-74.84
$\Delta H^\circ_{\text{rxn}} = 2(-74.84) - 52.283 = 202.0 \text{ kJ/g mol}$			

The reaction gives Q = ΔU = ΔH - Δ(pV). Assume ideal gases so that Δ(pV) = Δ(nRT) = Δn(RT)

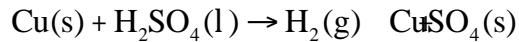
$$Q = -202.0 - (-1)(8.31 \times 10^{-3})(298)$$

$$\boxed{Q = -199.5 \text{ kJ/g mol}}$$

10.2.21

Basis: 1 g mol Cu and 1 g mol H₂SO₄

Data from Perry



$$\Delta H^\circ_{\text{rxn}} = (0 - 772.78) - (0 - 810.40) = 37.61 \text{ kJ}$$

For a constant volume process:

$$Q = \Delta U = \Delta H - \Delta(pV) = \Delta H - \Delta n(RT) \quad \Delta n = 1$$

$$Q = 37.61 - (1)(8.314 \times 10^{-3})(298) = 35.13 \text{ kJ/g mol}$$

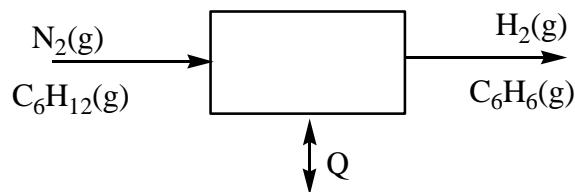
Basis: 1 lb mol of each reactant

$$\frac{(37.13)(1000)\text{J}}{\text{g mol}} \left| \frac{454 \text{ g}}{1 \text{ lb}} \right| \left| \frac{1 \text{ Btu}}{1055 \text{ J}} \right| = \boxed{15,978 \text{ Btu/lb mol}}$$

Solutions Chapter 10

10.2.22

Assume steady state flow process with reaction.



Ref. temp. = 25°C



The standard heat of reactions is

$$\hat{\Delta H}_{\text{Rxn}}^{\circ} = [1(82,927) + 3(0)] - [1(-123,100)] = 2.06 \times 10^5 \text{ J/g mol C}_6\text{H}_{12}$$

Material balance:

Step 5: Basis: 1 g mol C₆H₁₂ (g) in

Steps 6 to 9:

Make balances for each species so that the unknowns H₂ and C₆H₆ can be calculated.

Results:	n _{H₂}	out	=	0.70(1)(3)	=	2.10	n _{C₆H₁₂}	in	=	1.0
	n _{C₆H₆}	out	=	0.70(1)(1)	=	0.70	n _{N₂}	in	=	0.50
	n _{C₆H₁₂}	out	=	0.30(1)	=	0.30				
	n _{N₂}	out	=	0.50						

Energy balance

Component	$\hat{\Delta H}_{\text{f}}^{\circ}$ (J/gmol)	$\int_{25}^T C_p dT$ (or use tables)*; T = 300°C	n _i	ΔH_{25}^{300} (kJ)
Out:	H ₂ (g)	0	8031	2.10
	C ₆ H ₆ (g)	+ 82.927 × 10 ³	18,824 or	0.70
	C ₆ H ₁₂ (g)	- 123.1 × 10 ³	35,408	0.30
	N ₂ (g)	0	8,031	0.50
In:	C ₆ H ₁₂ (g)	-123.1 × 10 ³	0 or	1.00
	N ₂ (g)	0	0	0.50
				<u>44.556</u>
				<u>16.865</u>
				<u>71.226</u>
				<u>-47.552</u>
				<u>4.016</u>
				<u>0</u>
				<u>-123.1</u>

(a) Q = 1.44 × 10⁵ J/gmol

(b) Q = + 1.68 × 10⁵ J/gmol

*at 25°C exit temp. and entrance temp. these terms are 0.

Solutions Chapter 10

10.2.23

Basis: 1 gal of each fuel

		<u>MW</u>	<u>density (g/cm³)</u>
(1) Ethanol :	$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$	46	0.789
(2) Benzene :	$C_6H_6(l) + 7.5O_2(g) \rightarrow 6CO_2(g) + 3H_2O(l)$	78	0.879
(3) Isooctane :	$C_8H_{18}(l) + 12.5O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$	114	0.692

Example calculation

$$\text{Benzene: } \frac{1 \text{ gal Bz}}{\text{cm}^3 \text{Bz}} \left| \frac{0.879 \text{ g Bz}}{\text{cm}^3 \text{Bz}} \right| \frac{3.785 \text{ L}}{1 \text{ gal}} \left| \frac{1000 \text{ cm}^3}{1 \text{ L}} \right| \frac{1 \text{ g mol Bz}}{78 \text{ g Bz}} \left| \frac{6 \text{ g mol CO}_2}{1 \text{ g mol Bz}} \right|$$

$$\times \frac{44 \text{ g CO}_2}{1 \text{ g mol CO}_2} \left| \frac{1 \text{ lb}}{454 \text{ g}} \right| = \boxed{24.8 \text{ lb CO}_2 / \text{gal Bz}}$$

Other results:

Ethanol: 12.5 lb CO₂ / gal EtOH

Isooctane: 17.8 lb CO₂ / gal iso

Carry out the standard combustion material balance for stoichiometric air. The ratios are at SC or the same temperature and pressure.

Example of the calculation for benzene (Reaction 2)

Use data from the CD, heat capacity equations, or tables to get the sensible heats. The data below are from the CD. Reference T = 25°C.

IN:	T(°C)	mol	$\Delta\hat{H}^\circ_f$ (kJ / g mol)	$\Delta\hat{H}_{\text{sensible}}$ (kJ / g mol)	ΔH (kJ)
ΔH (kJ)					
C ₆ H ₆ (l)	25	1	+ 44.66	-	46.66
O ₂ (g)	100	7.5	-	2.235	16.763
N ₂ (g)	100	28.21	-	2.183	61.553

OUT:

CO ₂ (g)	25	6	-393.505	-	2361.030
H ₂ O(l)	25	3	-285.840	-	857.520
N ₂ (g)	25	28.21	-	-	-

Solutions Chapter 10

$$\Delta H_{\text{Rxn}} = (-2361.030 - 857.520) - (46.66 + 16.763 + 61.553) = 3093.6 \text{ kJ/g mol Bz}$$

$$\frac{-3093.6 \text{ kJ}}{\text{g mol Bz}} \left| \frac{1 \text{ gal Bz}}{0.879 \text{ g Bz}} \right| \left| \frac{3.785 \text{ L}}{\text{cm}^3 \text{ Bz}} \right| \left| \frac{1000 \text{ cm}^3}{1 \text{ L}} \right| \left| \frac{1 \text{ g mol Bz}}{78 \text{ g Bz}} \right| \left| \frac{1 \text{ Btu}}{1.055 \text{ kJ}} \right|$$

$$= [-1.251 \times 10^5 \text{ Btu per gal Bz}] \quad (\text{exothermic})$$

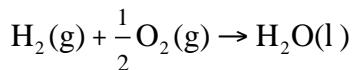
Ethanol: -7.55 × 10⁴ Btu per gal EtOH

Isooctane: -1.21 × 10⁵ Btu per gal isooctane

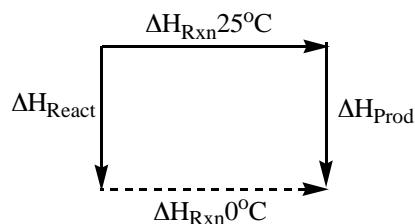
	<u>lb CO₂/10⁶ Btu</u>
Ethanol	166
Benzene	198
Isooctane	147

10.2.24

At 25°C and 1 atm H₂O is a liquid.



$$\Delta H^\circ_c(\text{kJ/g mol}): -285.84 \quad 0 \quad 0$$



Basis: 1 g mol H₂ (g)

$$\Delta H^\circ_{\text{rxn}} = -[\sum \Delta H^\circ_{\text{c,Prod}} - \sum \Delta H^\circ_{\text{c,React}}]$$

$$= -[(1)(0) - (1)(-285.84) - \left(\frac{1}{2}\right)(0)] \quad 285.84 \text{ kJ/g mol H}_2$$

H₂O at 25°C is a liquid

Solutions Chapter 10

$$\Delta H_{\text{Prod}} = \int_{25^{\circ}\text{C}}^{0^{\circ}\text{C}} C_p dT = \frac{4.184 \text{ J}}{(\text{g})(^{\circ}\text{C})} \left| \frac{18 \text{ g}}{1 \text{ g mol}} \right| \left| \frac{(-25^{\circ}\text{C})}{(0^{\circ}\text{C})} \right| = -1.883 \text{ kJ}$$

$$\Delta H_{\text{React}} = (1) \int_{25^{\circ}\text{C}}^{0^{\circ}\text{C}} C_{pH_2(g)} dT + \left(\frac{1}{2} \right) \int_{25}^{0^{\circ}\text{C}} C_{pO_2(g)} dT = -(718)(1) - (727)\left(\frac{1}{2} \right) = -1.084 \text{ kJ}$$

$$\Delta H_{\text{rxn}}(0^{\circ}\text{C}) = (-1.883) - (-1.081) + (-285.84) = \boxed{-286.64 \text{ kJ/g mol H}_2}$$

10.2.25

Basis: 1 g mol dry cells

The heat of reaction is

$$\begin{aligned} \Delta H_{\text{rxn}}^{\circ} &= - \left[\sum_{\text{products}} n_i \hat{H}_{i,c}^0 - \sum_{\text{reactants}} n_i \hat{H}_{i,c}^0 \right] \\ &= -[(1)(-1,517) + 2.75(-393.51) + 3.42(-285.840) \\ &\quad - 6.67(-2,817) - 2.10(0)] = -15,213 \text{ kJ/g mol cells} \end{aligned}$$

For 100 g dry cells

$$\frac{-15,213 \text{ kJ}}{\text{g mol dry cells}} \left| \frac{1 \text{ g mol}}{84.58 \text{ g dry cells}} \right| \left| \frac{100 \text{ g dry cells}}{} \right| = \boxed{-1.800 \times 10^4 \text{ kJ}}$$

10.3.1

Steady State, open process. Ref T = 25°C

Basis: 100 g mol feed

The moles out come from the material balance, and the other data from the CD.

$$Q = \Delta H$$

ΔH data from the CD.

Comp.	% = g mol	T(°C)	<u>$\Delta \hat{H}_f^{\circ}$(kJ / g mol)</u>	<u>$\Delta \hat{H}_{\text{sensible}}$ (kJ)</u>	<u>ΔH(kJ)</u>
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IN with gas

Solutions Chapter 10

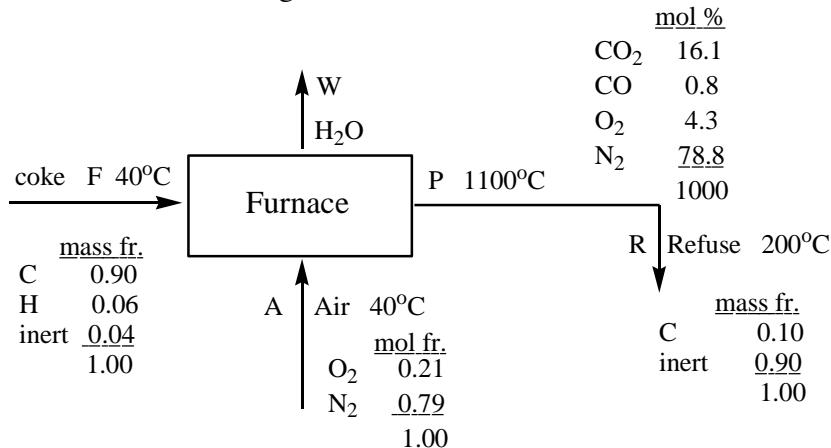
CO ₂	6.4	500	-393.505	20.996	-2384.06
O ₂	0.2	500	-	15.034	3.04
CO	40.0	500	-110.541	14.690	-3834.04
H ₂	50.8	500	-	13.834	702.77
N ₂	<u>2.6</u>	500	-	14.242	<u>37.03</u>
		100.0			-5,475.29
<u>In with air</u>					
O ₂	63.28	25	-	0	0
N ₂	<u>240.65</u>	25	-	0	0
		303.93			
<u>Out with fg</u>					
CO ₂	46.4	720	-393.505	32.006	-16,773.55
H ₂ O(g)	50.8	720	-241.835	26.133	-10,957.66
N ₂	240.65	720	-	21.242	5,111.89
O ₂	<u>18.1</u>	720	-	22.555	<u>408.25</u>
		356.0			-22,211.08
Q = ΔH = (-22,211.08) - (-5,475.29) = -16,736 kJ					
(Heat leaving)					

Solutions Chapter 10

10.3.2

Steady state, open process. Ref T = 25°C

Basis: 100 g mol P



Data come from the material balances and the CD.

$$\frac{C_p \text{ (J/g mol)}(\text{°C})}{H \text{ 20.8}} \\ C \text{ 14.3}$$

Comp.	Percent (g)	g mol	T(°C)	$\Delta\hat{H}_f^\circ \text{ (kJ/g mol)}$	$\Delta\hat{H}_{\text{sensible}} \text{ (kJ/gmol)}$	$\Delta H \text{ (kJ)}$
<u>In F (214.8 g) solid</u>						
C	90.0	16.11	40	-	0.214	3.456
H	6.0	12.79	40	-	0.312	3.991
Inert	4.0	-	40	-	ignore	-
	100.0	28.90				7.447

In air (99.7 g mol)

O ₂	20.94	40	-	0.442	9.255
N ₂	78.76	40	-	0.436	34.339
	99.70				43.595

Solutions Chapter 10

<u>Out in P (g)</u>					
CO ₂	16.1	1100	-393.505	24.744	-5937.05
CO	0.8	1100	-110.541	25.032	-68.41
O ₂	4.3	1100	-	26.209	112.70
N ₂	<u>78.8</u>	1100	-	38.891	<u>3064.59</u>
Water out (g)	100.0 6.80	1100	-241.826	30.174	-2828.17 205.18
Refuse	10 g	200	-	1.488 per g	14.88
$Q = \Delta H = (-2828.17 + 205.18 + 14.88) - (7.447 + 43.595) = \boxed{-2659.2 \text{ kJ}}$					
(heat exiting)					

10.3.3

Basis: 1 g mol CaCl₂ · 6H₂O(s)

Unsteady state, open process. Reference T = 25°C.

68°F → 20°C and 86°F → 30°C

$$\Delta U = Q - \Delta H_{\text{H}_2\text{O exiting}} \quad \text{Assume } \Delta U; \Delta H \text{ inside the system}$$

<u>Data</u>	<u>$\hat{\Delta}H_f^\circ$(kJ/g mol)</u>	<u>C_p(J/(g)(°C))</u>	<u>MW</u>
CaCl ₂ · 6H ₂ O(s)	-2607.89	1.34	219
CaCl ₂ · 2H ₂ O(s)	-1402.90	0.97	147

Calculate $\hat{\Delta}U$

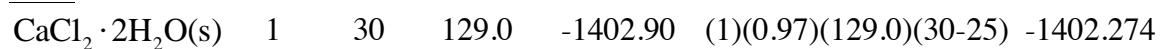
<u>Comp.</u>	<u>g mol</u>	<u>T(°C)</u>	<u>MW</u>	<u>$\hat{\Delta}H_f^\circ$(kJ/g mol)</u>	<u>$\Delta H_{\text{sensible}}$(J)</u>	<u>ΔH(kJ)</u>
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Initial

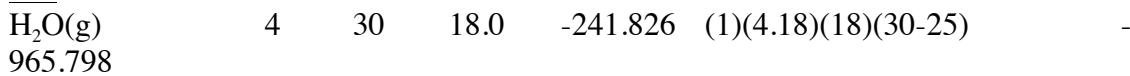
$$\text{CaCl}_2 \cdot 6\text{H}_2\text{O}(s) \quad 1 \quad 20 \quad 219.1 \quad -2607.89 \quad (1)(1.34)(219.1)(25-20) \quad -2606.422$$

Solutions Chapter 10

Final



Out



Per g mol $\text{CaCl}_2 \cdot 6\text{H}_2\text{O(s)}$:

$$Q = \Delta U + \Delta H_{\text{existing}} = [(-1402.274) - (-2606.422)] + (-965.798)$$

$$= 238 \text{ kJ} \quad \text{or } 226 \text{ Btu/g mol } \text{CaCl}_2 \cdot 6\text{H}_2\text{O(s)}$$

$$\frac{200,000 \text{ Btu}}{\text{226 Btu}} \left| \frac{1 \text{ g mol CaCl}_2 \cdot 6\text{H}_2\text{O(s)}}{226 \text{ Btu}} \right| \left| \frac{219 \text{ g}}{1 \text{ g mol}} \right| \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right| = \boxed{194 \text{ kg}}$$

(427 lb)

10.4.1

$$\begin{aligned} (\text{a}) \quad \text{HHV} &= 14,544 (.80) + 62,028 \left(0.0003 - \frac{0.005}{8} \right) + 4050(0.006) \\ &= 11,640 \text{ Btu/lb} \end{aligned}$$

$$\text{LHV} = 11,800 - 91.23(0.3) = 11,770 \text{ Btu/lb}$$

$$\begin{aligned} (\text{b}) \quad \text{HHV} &= 17,887 + 57.5(30) - 102.2 (0.5) = 19,560 \text{ Btu/lb} \\ \text{LHV} &= 19,560 - 91.23 (12.05) = 18,460 \text{ Btu/lb} \end{aligned}$$

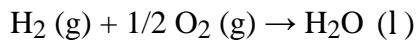
10.4.2

If the fuel cannot produce H_2O as a product, $\text{HHV} = \text{LHV}$, but the concept really refers to cases in which water is produced so that $\text{HHV} \neq \text{LHV}$.

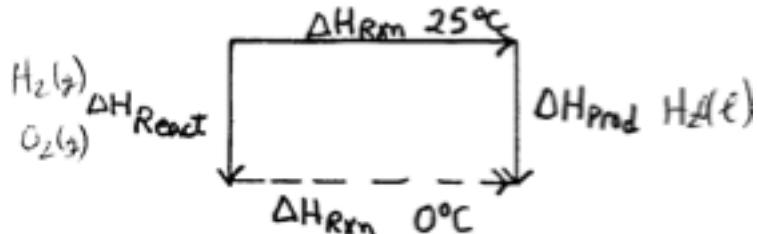
Solutions Chapter 10

10.4.3

Both H₂ and O₂ enter at 0°C, and the products leave at 0°C. The reference temperature is 25°C. Stoichiometric quantities react according to the reaction equation.



$$\Delta H_f^\circ \text{ (kJ/g mol):} \quad 0 \quad 0 \quad -285.83$$



Basis: 1 g mol H₂ (g)

$$\Delta H_{\text{Rxn}}(0^\circ\text{C}) = \Sigma \Delta H_{\text{Products}} - \Sigma \Delta H_{\text{Reactants}}$$

$$\Sigma \text{Products} = (-285.83) + \int_{25^\circ\text{C}}^{0^\circ\text{C}} \frac{4.184 \text{ J}}{(g)(^\circ\text{C})} \left| \frac{18 \text{ g H}_2\text{O}}{\text{g mol}} \right| dT = -287.71 \text{ kJ}$$

Alternately you can use the steam tables or the CD to get the value. The reactants are gases, hence ΔH can be obtained from tables.

$$\Sigma \text{Reactants} = (0 + 0) + (1) \int_{25^\circ\text{C}}^{0^\circ\text{C}} (28.84 + 0.00765 \times 10^{-2} T) dT$$

$$+ \left(\frac{1}{2}\right) \int_{25^\circ}^{0^\circ\text{C}} (29.10 + 1.158 \times 10^{-2} T) dT = -1.45 \text{ kJ}$$

$$\Delta H_{\text{Rxn}}(0^\circ\text{C}) = -287.71 - (-1.45) = \boxed{-286.26 \text{ kJ}}$$

Solutions Chapter 10

10.4.4

Basis: 100 lb mol gas

The reaction for each compound is the stoichiometric amount of O₂ going to CO₂ gas and H₂O (l)

<u>Comp.</u>	<u>lb mol</u>	<u>$\Delta\hat{H}$(Btu/lb mol)</u>	<u>ΔH (Btu)</u>
CO ₂	9.2	0	0
C ₂ H ₄	0.4	598,000	239,000
CO	20.9	122,000	2,544,000
H ₂	15.6	123,000	1,918,000
CH ₄	1.9	383,000	728,000
N ₂	<u>52.0</u>	0	<u>0</u>
	100.0		5,429,000

Note: NGI standard state is 60°F

$$\frac{\text{Btu}}{\text{ft}^3} = \frac{5,429,000 \text{ Btu}}{100 \text{ lb mol}} \left| \frac{1 \text{ lb mol}}{359 \text{ ft}^3} \right| \frac{520^\circ\text{R}}{492^\circ\text{R}}$$

$$= 143 \text{ Btu / ft}^3 \text{ at std. conditions of NGI}$$

10.4.5

Basis: 1 m³ gas at 25°C and 1 atm with 40% relative saturation

Calculate the moles of C₉H₁₂ gas. Its pressure at 25°C is calculated as follows:

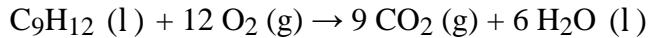
$$(p_{\text{H}_2\text{O}}^* = 3.2 \text{ kPa})$$

(3.2) (0.40) = 1.28 kPa, and thus the pressure of the C₉H₁₂ (g) is (101.3 - 1.28) = 100 kPa.

$$n = \frac{pV}{RT} = \frac{100 \text{ kPa}}{1 \text{ atm}} \left| \frac{1 \text{ m}^3}{298 \text{ K}} \right| \left| \frac{1(\text{kg mol})(\text{K})}{8.314(\text{kPa})(\text{m}^3)} \right| = 0.0404 \text{ kg mol}$$

Basis: 1 g mol n-propyl benzene (C₆H₅ • CH₂ • C₂H₅)

The higher heating value is with H₂O as a liquid. Also, at 25°C, C₉H₁₆ is a liquid; its normal boiling point is 432 K.



Solutions Chapter 10

$$\Delta \hat{H}^\circ_f \left(\frac{\text{kJ}}{\text{g mol}} \right): -38.40 \quad 0 \quad -393.51 \quad -285.840$$

$$\Delta \hat{H}^\circ_{\text{rxn}} = [6 (-285.840) + 9 (-393.51)] - [(1) (-38.40)]$$

$$= -5218.2 \text{ kJ/g mol C}_9\text{H}_{12}$$

$$\text{HHV} = - \frac{-5218.2 \text{ kJ}}{\text{g mol C}_9\text{H}_{12}} \left| \frac{40.4 \text{ g mol C}_9\text{H}_{12}}{1 \text{ m}^3 \text{ gas}} \right| = \boxed{2.11 \times 10^5 \text{ kJ/m}^3}$$

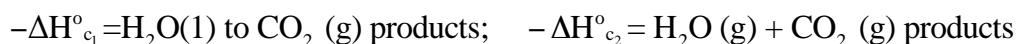
10.4.6

Basis: 100 mol of gas

(a₁)

<u>Comp.</u>	<u>mol.wt.</u>	Mol% =	<u>lb</u>	$-\Delta H^\circ_{c1}$	$-\Delta H^\circ_{c2}$
		<u>Vol.%</u>		<u>kJ/g mol</u>	<u>kJ/g mol</u>
CH ₄	16	88	1408	890.35	802.32
C ₂ H ₆	30	6	180	1559.88	1427.84
C ₃ H ₈	44	4	176	2220.05	2044.00
C ₄ H ₁₀	58	2	116	2878.52	2658.45
Total		100	1880		

$$\text{mol. wt. mixture} = 18.80 \text{ lb/lb mol}$$



$$\Delta H^\circ_{1 \text{ rxn}} = -[\Delta H_c \text{ prod} - \Delta H^\circ_c \text{ react}] = 1022.90 \text{ kJ/g mol}$$

$$(a_1) \quad \Delta H^\circ_{\text{rxn}} = \frac{-1022.90}{\text{g mol}} \left| \frac{454 \text{ g mol}}{\text{lb mol}} \right| \left| \frac{\text{Btu}}{1.055 \text{ kJ}} \right| \left| \frac{\text{lb mol}}{18.80 \text{ lb}} \right| = -23,600 \frac{\text{Btu}}{\text{lb}}$$

$$\boxed{\text{HHV} = 23,600 \text{ Btu/lb}}$$

$$(a_2) \quad \Delta H^\circ_{\text{rxn}} = (-23,600) (18.80) = -439,000 \text{ Btu / lb mol}$$

$$\boxed{\text{HHV} = 439,000 \text{ Btu/lb mol}}$$

$$(a_3) \quad \Delta H^\circ_{\text{rxn}} = \frac{-439,000 \text{ Btu}}{\text{lb mol}} \left| \frac{1 \text{ lb mol}}{379.2 \text{ ft}^3 \text{ at } 60^\circ\text{F, 760 mm Hg}} \right| = -1160$$

Solutions Chapter 10

$$\text{HHV} = \boxed{1160 \text{ Btu / ft}^3 \text{ at } 60^\circ\text{F, 760 mm Hg}}$$

(b₁) $\Delta H^\circ_{2 \text{ rxn}} = -925.71 \text{ kJ/g mol}$

$$\Delta H^\circ_{2 \text{ rxn}} = \frac{-925.71}{1.055} \left| \frac{454}{18.80} \right| = -21,200 \text{ Btu/lb}$$

$$\boxed{\text{LHV} = 21,200 \text{ Btu/lb}}$$

(b₂) $\Delta H^\circ_{2 \text{ rxn}} = (-21,200) (18.80) = \boxed{-398,000 \text{ Btu/lb mol}}$

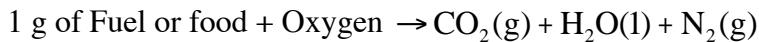
$$\boxed{\text{LHV} = 398,000 \text{ Btu / lb mol}}$$

(b₃) $\Delta H^\circ_{2 \text{ rxn}} = (-398,000)/(379.2) = -1051$

$$\boxed{\text{LHV} = 1051 \text{ Btu/ft}^3 \text{ at } 60^\circ\text{F and 760 mm Hg}}$$

10.4.7

Write the equation for the combustion for 1 gram as:



Both the reactants and the products are at 25°C and 1 atm. The chemical energy released by the complete combustion of 1 g of a food or fuel according to the above equation at standard conditions is the heat of combustion. Assume the ΔH_c are additive. Then

$$\Delta H_C = (17.1)(28) + (39.5)(10) + (14)(4) = 930 \text{ kJ}$$

The High Energy bar has (capital C for calorie)

$$\frac{220 \text{ Calories}}{1 \text{ Calorie}} \left| \frac{1000 \text{ calories}}{1 \text{ Calorie}} \right| \left| \frac{4.184 \text{ J}}{1 \text{ calorie}} \right| \left| \frac{1 \text{ kJ}}{1000 \text{ J}} \right| = 921 \text{ kJ}$$

The values are close enough.

Solutions Chapter 10

10.4.8

When the combustion results in a single component.

10.4.9

Basis: 1 lb mixture

Get the data for the ΔH_c in Btu/lb, not Btu/mol.

Component	Mass fr., ω_i	ΔH_c (Btu / lb)	ΔH (Btu)	Basis 1200 lb
Hexachloroethane, C_2Cl_6	0.0487	828	40	58.44
Tetrachloroethene, C_2Cl_4	0.0503	2141	108	60.36
Chlorobenzene, C_6H_5Cl	0.2952	11,876	3,506	354.24
Toluene, C_7H_8	<u>0.6058</u>	18,246	<u>11,053</u>	<u>726.96</u>
Total	1.000		14,707	1200.00

The Btu/lb are **14,707** from the heat of combustion data, a deviation of 3.2% from 15,200. For DuLong's equation, the component elements are needed.

Basis: 1200 lb

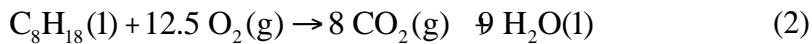
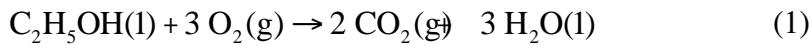
	C	H	C1	O	MW	Total (lb)
C_2Cl_6	24	0	213	0	237.00	
ω_i	0.10	0.00	0.90	0.00		
lb	5.84	0.00	52.60	0.00		58.44
C_2Cl_4	24	0	142	0	166.00	
ω_i	0.14	0.00	0.86	0.00		
lb	8.45	0.00	51.91	0.00		60.36
C_6H_5Cl	72	5	35.5	0	112.50	

Solutions Chapter 10

ω_i	0.64	0.04	0.32	0.00	
lb	226.71	14.17	113.36	0.00	354.24
C_7H_8	84	8	0	0	9200
ω_i	0.91	0.09	0.00	0.00	
lb	661.53	65.43	0.00	0.00	726.91
Total	902.53	79.60	217.87	0	1200
ω_i	0.75	0.07	0.18	0	1.00
$HHV = 14,455 C + 62,028 H - 7753.5O_2 + 4050 S$ $= (14,455)(0.75) + (62,028)(0.07)$ $= \boxed{15,183} \text{ Btu/lb (the higher heating value) a deviation of 0.11\%}$					

10.4.10

The reactions are:



$$\Delta H_{rxn} = - \left[\sum_{\text{products}} n_i \Delta \hat{H}_{c,i}^o - \sum_{\text{reactants}} n_i \Delta \hat{H}_{c,i}^o \right]$$

$$\text{For (1): } -[(2)(0) + (3)(0) - (3)(0) - (1)(-1366.91)] = 1366.91 \text{ kJ/g mol } C_2H_5OH$$

$$\text{For (2): } -[(8)(0) + (9)(0) - (12.5)(0) - (-1307.53)(4.184)] = 5470.71 \text{ kJ/g mol } C_8H_{18}$$

Note: the $\Delta \hat{H}_c = 1307.53 \text{ k cal/g mol}$ for n-octane liquid is from Perry.

Solutions Chapter 10

Basis: 1 kg gasahol

<u>Component</u>	<u>mass.fr. = kg</u>	<u>MW</u>	<u>g mol</u>	<u>$\Delta\hat{H}$(kJ)</u>
C ₂ H ₅ OH	0.10	46.05	2.17	-2,966
C ₈ H ₁₈	<u>0.90</u>	114.14	7.89	-43,137
Total	1.00			-46,103

If the fuel were all octane

$$\frac{1 \text{ kg octane}}{114.14 \text{ kg octane}} \left| \frac{1 \text{ kg mol octane}}{1 \text{ kg}} \right| \left| \frac{1000 \text{ g}}{\text{g mol octane}} \right| \left| \frac{-5470.71 \text{ kJ}}{1 \text{ kg}} \right| = -47,930 \text{ kJ}$$

$$\frac{-47,930 - (-46,103)}{-47,930} (100) = \boxed{3.8\%}$$

Solutions Chapter 11

11.1.1

Basis: gas as given in problem statement

$$(a) 0.030 = \frac{p_{H_2O}}{p_{Tot} - p_{H_2O}} = \frac{p_{H_2O}}{101.6 - p_{H_2O}} \text{ so, } p_{H_2O} = 2.96 \text{ kPa}$$

$$p^*_{H_2O} \text{ at } 60^\circ\text{C} = 19.9 \text{ kPa}$$

$$\% \text{ humidity} = 100 \left(\frac{2.96}{19.9} \right) \left[\frac{101.6 - 19.9}{101.6 - 2.96} \right] = \boxed{12.2\%}$$

(b) Relative humidity

$$(100) \frac{2.96}{19.9} = \boxed{14.9\%}$$

(c) Dewpoint occurs where $p^*_{H_2O} = 2.96 \text{ kPa}$, or $T = \boxed{24^\circ\text{C}}$ from the steam tables.

11.1.2

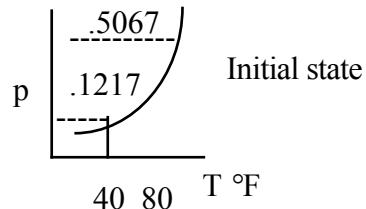
At 27°C , $p^*_{H_2O} = 3.52 \text{ kPa}$. The actual pressure of the water vapor is obtained from

$$p = \frac{nRT}{V} = \left(\frac{0.636}{18.01} \right) \left(\frac{8.314}{300 \text{ K}} \right) \left(\frac{300 \text{ K}}{28.0} \right) = 3.15 \text{ kPa}$$

$$100 \left(\frac{3.15}{3.52} \right) = \boxed{89\% \text{ RH}}$$

Solutions Chapter 11

11.1.3



At 80 °F, $p_{H_2O}^* = 0.5067$ psia from the steam tables

At 40 °F, $p_{H_2O}^* = 0.1217$ psia

At 58 °F, $p_{H_2O}^* = 0.2384$ psia

$$(a) 100 \frac{0.1217 \text{ psia}}{0.5067 \text{ psia}} = \boxed{24\%}$$

(b) The mol fraction of H₂O vapor is constant on compression unless saturation is reached. At the initial conditions

$$y_{H_2O} = \frac{0.1217}{14.696} = 8.28 \times 10^{-3}$$

$$\text{At 2 atm, } p_{H_2O} = p_{\text{Tot}} y_{H_2O} = (14.692)(2) \left(\frac{0.1217}{14.696} \right) = 0.2437 \text{ psia}$$

$$\frac{0.2437}{0.2384} > 1 \text{ hence water condenses and the relative humidity is } 100\%$$

Solutions Chapter 11

11.1.4

$$T = 140^\circ F$$

$$P^*_{H_2O} = 5.878 \text{ in Hg}$$

$$p = 30 \text{ in Hg}$$

$H = 0.03 \text{ mol H}_2\text{O/mol BDA} \Rightarrow \text{Basis: 1 mol BDA}$

$$\frac{\text{mol H}_2\text{O}}{\text{mol H}_2\text{O} + \text{BDA}} = \frac{0.03}{1 + .03} = 0.0291 = y_{H_2O}$$

$$p_{H_2O} = 30 (.0291) = 0.874 \text{ in Hg}$$

$$p_{air} = 30 (1 - 0.0291) = 29.13 \text{ in Hg}$$

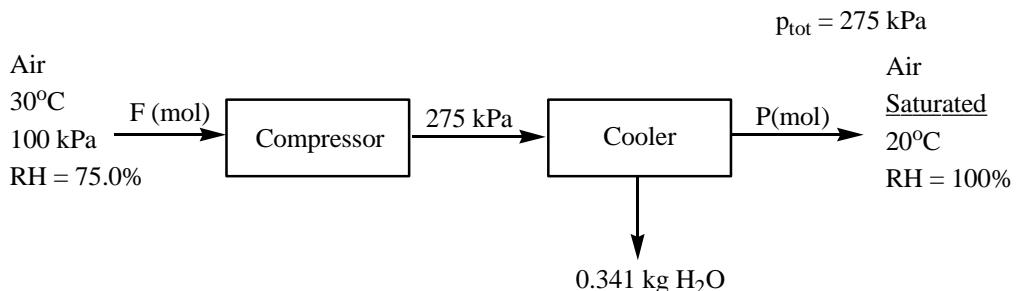
(a) % rel. humidity = $100 \frac{p_{H_2O}}{p^*_{H_2O}} = 100 \left(\frac{0.874}{5.878} \right) = \boxed{14.9\%}$

(b) Dew point is the temperature at which vapor first condenses on cooling at constant humidity, hence $p^* = 0.874 \text{ in Hg } \boxed{\sim 75^\circ F.}$

Solutions Chapter 11

11.1.5

Steps 1, 2, 3, and 4:



$$\begin{aligned} p_{\text{H}_2\text{O}}^* &= 0.6153 \text{ psia} \\ &= 4.241 \text{ kPa} \end{aligned}$$

$$\begin{aligned} p_{\text{H}_2\text{O}}^* &= 0.3388 \text{ psia} \\ &= 2.34 \text{ kPa} \end{aligned}$$

$$p_{\text{H}_2\text{O}} = 4.241 (.75) = 3.18 \text{ kPa}$$

System: overall

Step 5: Basis: $0.341 \text{ kg H}_2\text{O}$ $(0.341/18) \text{ kg mol}$

Step 6 and 7: Unknowns: F, P Balances: air, H_2O

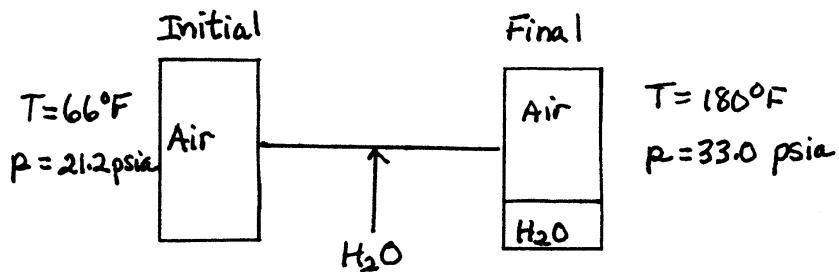
Steps 8 and 9: Balances are in kg mol

$$\begin{aligned} \text{Total: } F &= P + \frac{0.341}{18} \\ \text{Air: } F \left(\frac{100 - 3.18}{100} \right) &= P \left(\frac{275 - 2.34}{275} \right) \\ \text{H}_2\text{O: } F \left(\frac{3.18}{100} \right) &= \frac{0.341}{18} + P \left(\frac{2.34}{275} \right) \end{aligned} \quad \left. \begin{array}{l} \text{Solve any two to get} \\ F = 0.804 \text{ kg mol} \end{array} \right\}$$

$$V = \frac{0.804 \text{ kg mol}}{8.314} \left| \frac{303}{100} \right| = [20.3 \text{ m}^3 \text{ at } 30^{\circ}\text{C and } 100 \text{ kPa}]$$

Solutions Chapter 11

11.1.6



Basis: Air at $T = 66^{\circ}\text{F}$ and 21.2 psia; assume V is constant.

(a) Initial

$$p_{\text{air},i} V = n_{\text{air}} RT_{66^{\circ}\text{F}}$$

Final

Assume all of the water evaporates, and check later on to see if the assumption is true.

$$p_{\text{air},f} + p_{\text{H}_2\text{O}} = p_t \text{ so } p_{\text{air},f} = p_t - p_{\text{H}_2\text{O}}$$

$$p_{\text{air},f} V = n_{\text{air}} RT_{180^{\circ}\text{F}}$$

The material balance is simple: all the initial air = final air.

$$\frac{p_{\text{air},i}}{p_t - p_{\text{H}_2\text{O}}} = \frac{66 + 460}{180 + 460} = \frac{526}{640} = \frac{21.2}{33.0 - p_{\text{H}_2\text{O}}}$$

$$p_{\text{H}_2\text{O}} = 7.20 \text{ psia}$$

Since $p^* = 7.51 \text{ psia}$, all of the water can evaporate and the air will not be saturated.

(b) Basis: 1 lb H₂O (0.0555 lb mol H₂O)

At the final condition

$$\frac{p_{\text{H}_2\text{O}}}{p_t} = \frac{7.20}{33.0} = \frac{n_{\text{H}_2\text{O}}}{n_t} = \frac{0.0555}{n_t} \text{ so } n = 0.254 \text{ lb mol}$$

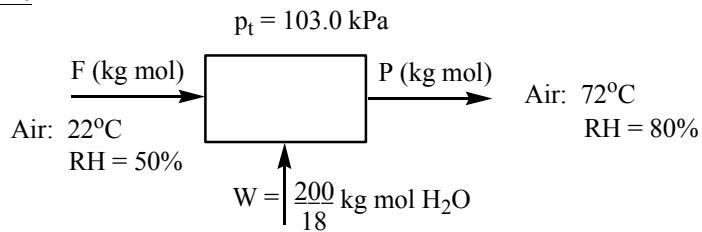
$$V = \frac{nRT}{p} = \left(\frac{0.254}{33.0} \right) \left(\frac{10.73}{33.0} \right) \left(\frac{640}{1} \right) = [53.0 \text{ ft}^3]$$

$$(c) n_{\text{air}} = 0.254 - 0.0555 = 0.1985 \text{ lb mol} \quad \frac{1 \text{ lb H}_2\text{O}}{0.1985(29)} = \boxed{\frac{0.17 \text{ lb H}_2\text{O}}{\text{lb air}}}$$

Solutions Chapter 11

11.1.7

Steps 1, 2, 3, and 4:



	<u>T (°C)</u>	<u>p^* (kPa)</u>
Data for p^* from the steam tables:	22°C (295K)	2.622
	72°C (345K)	33.77

These calculations provide the composition of F and P.

<u>In</u>	<u>kPa</u>	<u>Out</u>	<u>kPa</u>
$p_{\text{H}_2\text{O}} = 0.50 (2.60)$	= 1.31	$p_{\text{H}_2\text{O}} = 0.80 (33.77) = 27.02$	
$p_{\text{air}} = 103.0 - 1.31$	= <u>101.69</u> p_{air}	= $102.0 - 27.0 = 75.0$	= <u>76.0</u>
p_t	= 103.0		$p_t = 103.0$

Step 5: Basis: $W = 200 \text{ kg H}_2\text{O}$ (1 hour)

Steps 6 and 7: Unknowns are: F, P Balances are: H_2O , air

Steps 8 and 9: This is a steady state process without a reaction

<u>Balances</u>	<u>In</u>	<u>Out</u>
H_2O	$F(1.3) + 20\%_8(1.00) = P(27)$	
air:	$F(101)$	$= P(7)$

$$F = 32.86 \text{ kg mol} \quad P = 43.95 \text{ kg mol}$$

$$\text{Bone dry air: } F(1.0) = 32.45 \text{ kg mol} \quad P(7) = 32.43 \text{ kg mol}$$

Step 10: Check using total balance

$$\text{Weight in kg of dry air used} = 32.45 (29 = \boxed{941 \text{ kg}})$$

Solutions Chapter 11

11.1.8

(a)

Entering

$$80^{\circ}\text{F} = 26.8^{\circ}\text{C}$$

Leaving

$$70^{\circ}\text{F} = 21.0^{\circ}\text{C}$$

$$p^* \text{ at } 26.8^{\circ}\text{C} = 26 \text{ mm Hg}$$

$$p^* \text{ at } 21.0^{\circ}\text{C} = 19 \text{ mm Hg}$$

$$\text{Rel. Humidity} = \frac{p}{p^*} = \frac{5 \text{ mm Hg}}{26 \text{ mm Hg}} (100)$$

$$\text{Rel. Humidity} = \frac{p}{p^*} = \frac{18 \text{ mm Hg}}{19 \text{ mm Hg}} (100)$$

$$= 19.2\%$$

$$= 94.8\%$$

(b)

Entering

$$\text{Vol fr.} = \frac{V}{V_{\text{tot}}} = \frac{p}{p_{\text{tot}}}$$

$$\text{H}_2\text{O}: \frac{5 \text{ mm Hg}}{740 \text{ mm Hg}} (100) = 0.676\%$$

$$\text{Vol fr.} = \frac{p}{p_{\text{tot}}}$$

$$\text{H}_2\text{O}: \frac{18 \text{ mm Hg}}{740 \text{ mm Hg}} (100) = 2.43\%$$

$$\text{Air: } 100 - 0.0676 = 99.324\%$$

$$\text{Air: } 100 - 2.43 = 97.57\%$$

(c)

Entering

$$\begin{aligned} \text{Basis: } 1 \text{ lb mol at } 80^{\circ}\text{F}, 740 \text{ mm Hg} \\ \text{Vol \%} = \text{mol \%} \end{aligned}$$

$$\text{Basis: } 1 \text{ lb mol at } 70^{\circ}\text{F}, 740 \text{ mm Hg}$$

	<u>lb</u>	<u>wt %</u>		<u>lb</u>	<u>wt %</u>
$\text{H}_2\text{O}: (0.00676)(18)$	0.12	0.4	$\text{H}_2\text{O}: (0.0243)(18)$	0.44	1.53
Air: $(99.324)(29)$	<u>28.80</u> 28.92	<u>99.6</u> 100.0	Air: $(0.9757)(29)$	<u>28.30</u> 28.74	<u>98.47</u> 100.00

(d)

Entering

$$\text{Basis: } 1 \text{ lb mol at } 80^{\circ}\text{F}, 740 \text{ mm Hg}$$

$$\text{Basis: } 1 \text{ lb mol at } 70^{\circ}\text{F}, 740 \text{ mm Hg}$$

$$\text{Actual: } p_{\text{vap}} = 5 \text{ mm Hg}$$

$$\text{Actual: } p_{\text{vap}} = 18 \text{ mm Hg}$$

$$p_{\text{vapor-free gas}} = 740 - 5 = 735 \text{ mm Hg}$$

$$p_{\text{vapor-free air}} = 740 - 18 = 722 \text{ mm Hg}$$

Solutions Chapter 11

$$\text{Humidity} = \frac{\text{g mol H}_2\text{O}}{\text{g mol dry air}} \left| \frac{18 \text{ g}}{1 \text{ g mol H}_2\text{O}} \right| \frac{1 \text{ g mol dry air}}{29 \text{ g}}$$

$$\frac{n_{H_2O}}{n_{\text{dry air}}} = \frac{p_{H_2O}}{p_{\text{dry air}}}$$

Entering

Leaving

$$\text{Humidity} = \frac{5}{735} \left| \frac{18}{29} \right| = 4.22 \times 10^{-3} \frac{\text{g H}_2\text{O}}{\text{g dry air}} \quad \frac{18}{722} \left| \frac{18}{29} \right| = 0.0155 \frac{\text{g H}_2\text{O}}{\text{g dry air}}$$

(e) Basis: 1000 ft³ of mixture at 740 mm Hg and T

Entering

Leaving

$$\text{Vol \% H}_2\text{O} = 0.676 \%$$

$$\text{Vol \% H}_2\text{O} = 2.43 \%$$

$$\text{Vol H}_2\text{O} = (0.00676)(1000 \text{ ft}^3) = 6.76 \text{ ft}^3 \quad \text{Vol H}_2\text{O} = (0.0243)(1000 \text{ ft}^3) = 24.3 \text{ ft}^3$$

@ 26.8 °C and 740 mm Hg

@ 21.0°C and 740 mm HG

$$\frac{6.76 \text{ ft}^3}{359 \text{ ft}^3} \left| \frac{1 \text{ lb mol}}{492^\circ\text{R}} \right| \left| \frac{740 \text{ mm Hg}}{540^\circ\text{R}} \right| \left| \frac{18 \text{ lb}}{760 \text{ mm Hg}} \right| \left| \frac{1 \text{ lb mol}}{18 \text{ lb}} \right|$$

$$= 0.30 \text{ lb H}_2\text{O / 1000 ft}^3 \\ \text{at } 80^\circ\text{F and 740 mm Hg}$$

$$\frac{24.3 \text{ ft}^3}{359 \text{ ft}^3} \left| \frac{1 \text{ lb mol}}{492^\circ\text{R}} \right| \left| \frac{740 \text{ mm Hg}}{530^\circ\text{R}} \right| \left| \frac{18 \text{ lb}}{760 \text{ mm Hg}} \right| \left| \frac{1 \text{ lb mol}}{18 \text{ lb}} \right|$$

$$= 1.10 \text{ lb H}_2\text{O / 1000 ft}^3 \\ \text{at } 70^\circ\text{F and 740 mm Hg}$$

(f)

Entering

Leaving

$$\frac{0.30}{0.99324}$$

$$\frac{1.10}{0.9757}$$

$$= 0.302 \text{ lb H}_2\text{O / 1000 ft}^3 \text{ vapor free air}$$

$$= 1.127 \text{ lb H}_2\text{O / 1000 ft}^3 \text{ vapor free air}$$

(g) Basis: 800,000 ft³/day at 80°F, 740 mm Hg

Entering

Leaving

$$\text{Vol \% air} = 99.324 \%$$

$$\text{Vol dry air} = 794,600 \left(\frac{530}{540} \right)$$

$$\text{Vol dry air} = (800,000)(0.99324)$$

$$= 779,900 \text{ ft}^3 \text{ at } 70^\circ\text{F}$$

Solutions Chapter 11

= 794,600 ft ³	Vol % = 97.57 %
Vol H ₂ O vapor = (800,000)(0.00676)	Total vol = $\frac{779,900}{0.9757} = 799,300 \text{ ft}^3$
= 5400 ft ³ at 80°F, 740 mm Hg	Vol H ₂ O vap = 799,300 – 779,900
$5400 \text{ ft}^3 \left(\frac{740}{760} \right) \left(\frac{492}{540} \right)$	= 19,400 ft ³ at 70°F, 740 mm Hg
= 4790 ft ³ at SC	$19,400 \left(\frac{492}{530} \right) \left(\frac{740}{760} \right) = 17,535 \text{ at SC}$

Water evaporated = 17,535 – 4,790 = 12,745 ft³ at SC

$$\frac{12,745 \text{ ft}^3}{359 \text{ ft}^3} \left| \frac{1 \text{ lb mol}}{\text{lb mol}} \right| \left| \frac{18 \text{ lb}}{\text{lb mol}} \right| = 639 \text{ lb H}_2\text{O/day}$$

Part g could also be worked using part f and the volume of dry air:

<u>Entering</u>	<u>Leaving</u>
794,600 ft ³ dry air	779,900 ft ³ dry air
0.302 lb H ₂ O/1000 ft ³ dry air (see f)	1.127 lb H ₂ O/1000 ft ³ dry air (see f)
$\frac{794,600}{1000} \left \frac{0.302}{1000} \right = 240 \text{ lb H}_2\text{O}$	$\frac{779,900}{1000} \left \frac{1.127}{1000} \right = 879 \text{ lb H}_2\text{O}$

Water evaporated = 879 – 240 = 639 lb H₂O / day

11.2.1

- a. Dew point = 10°C
- b.
$$\%RH = \frac{p_{H_2O}}{p_{sat}} 100 = \frac{p_{10^\circ C}}{p_{27^\circ C}} 100 = \frac{1.27 \text{ kPa}}{3.356 \text{ kPa}} 100 = \boxed{38\%}$$
- c.
$$H = \frac{p_{H_2O}}{p_{air}} = \frac{1.27}{101.3 - 1.27} \left| \frac{18}{29} \right| = \boxed{0.79 \text{ kg H}_2\text{O/kg air}}$$

Solutions Chapter 11

11.2.2

When the air is saturated.

11.2.3

Draw a horizontal line until it intersects with the saturation curve. The temperature at the intersection is the dew-point temperature.

11.2.4

When the air is saturated (100% relative humidity).

11.2.5

The two temperatures are approximately equal at atmospheric temperatures and pressure.

11.2.6

$$\text{If by "air" is meant wet air, } H = \frac{0.02}{0.98} = 0.204 \frac{\text{lb H}_2\text{O}}{\text{lb dry air}}$$

From the SI humidity chart

- a. Dew point = 25.2°C
- b. %RH ≈ 59%

11.2.7

From the SI chart at the intersection of $T_{DB} = 30^\circ\text{C}$ and RH = 65%

$$H = \boxed{0.0174 \text{ kg H}_2\text{O/kg dry air}}$$

Solutions Chapter 11

11.2.8

Let A = alcohol and C = CO₂. MW of A = 46; MW of C = 44.

At 40°C, p_A* = 134.26 mm Hg or 17.90 kPa

a. p_A = 0.10 (100) = 10 kPa

$$H = \frac{(46)(10)}{(44)(100-10)} = \boxed{0.116 \text{ g A/g C}}$$

b. %RS = $\frac{p}{p^*}(100) = \frac{10}{17.90}(100) = \boxed{55.9\%}$

c. C_s = 1.00 + 1.88(H) = 1.00 + 1.88 (0.116) = 1.22 J/(K) (g C)

d. $\hat{V}' = 2.83 \times 10^{-3} T_K + 4.56 \times 10^{-3} (H)$

$$= (2.80)(10^{-3})(313.15) + (4.56)(10^{-3})(0.116) = \boxed{0.877 \text{ m}^3 / \text{kg C}}$$

At saturation at 40°C

$$\mathcal{H} = \frac{(46)(17.90)}{(44)(100-17.90)} = \boxed{0.228 \text{ g A/g C}}$$

$$\hat{V}' = (2.80)(10^{-3}) (313.15) + 4.56 \times 10^{-3} (0.228) = \boxed{0.878 \text{ m}^3 / \text{kg C}}$$

11.2.9

They are almost parallel to each other.

Solutions Chapter 11

11.2.10

Condenses water from the air in humid climates.

11.2.11

- a. From Humidity Chart, where $t_{DB} = 90^\circ\text{C}$ (194°F) and $t_{WB} = 46^\circ\text{C}$ (115°F) $H = 0.049 \frac{\text{kg H}_2\text{O}}{\text{kg air}}$. Upon cooling to 43°C (109°F), no condensation occurs, therefore H is constant.

$$\frac{0.049 \frac{\text{kg H}_2\text{O}}{\text{kg air}}}{1 \frac{\text{kg air}}{\text{kg mol air}}} \left| \frac{29 \frac{\text{kg air}}{\text{kg mol air}}}{1 \frac{\text{kg mol air}}{\text{kg mol H}_2\text{O}}} \right| \frac{1 \frac{\text{kg mol H}_2\text{O}}{18 \frac{\text{kg H}_2\text{O}}{\text{kg mol H}_2\text{O}}}}{0.079 \frac{\text{kg mol H}_2\text{O}}{\text{kg mol air}}} = \boxed{0.079 \frac{\text{kg mol H}_2\text{O}}{\text{kg mol air}}}$$

b. Final pressure = $100 \left(\frac{273 + 43}{273 + 90} \right) = \boxed{87.1 \text{ kPa}}$

c. At saturation: $0.079 = \frac{p_{H_2O}^*}{87.1 - p_{H_2O}^*}$; solving $p_{H_2O}^* = 6.38 \text{ kPa}$

At the dew point, the vapor pressure of pure water is equal to 6.38 kPa. Dew point = $\boxed{37^\circ\text{C} (99^\circ\text{F})}$

The same answer can be obtained by proceeding to the dew point at constant H on a humidity chart for the correct pressure.

Solutions Chapter 11

11.2.12

Basis: 1 lb dry air

Data from the humidity chart.

Initial state:

$$T_{DB} = 180^{\circ}\text{F} \text{ and } T_{WB} = 120^{\circ}\text{F}$$

$$H = 0.0637 \text{ lb H}_2\text{O/lb dry air}$$

$$H_{\text{saturated}} \cong 120 \text{ Btu/lb dry air}$$

$$\underline{\delta H_{\text{deviation}} \cong -1.5 \text{ Btu/lb dry air}}$$

$$H = 118.5 \text{ Btu/lb dry air}$$

Final state

$$T_{DB} = 115^{\circ}\text{F}, \quad T_{WB} = ?, \quad H = 0.0657 \text{ lb H}_2\text{O/lb dry air}$$

$$H_{\text{saturated}} \cong 101 \text{ Btu/lb dry air}$$

$$\Delta H = 101 - 118.5 = \boxed{-17.5 \text{ Btu/lb dry air}}$$

11.2.13

From the SI psychometric chart at 29°C and 40% relative humidity read

$$T_{WB} = 19.3^{\circ}\text{C}$$

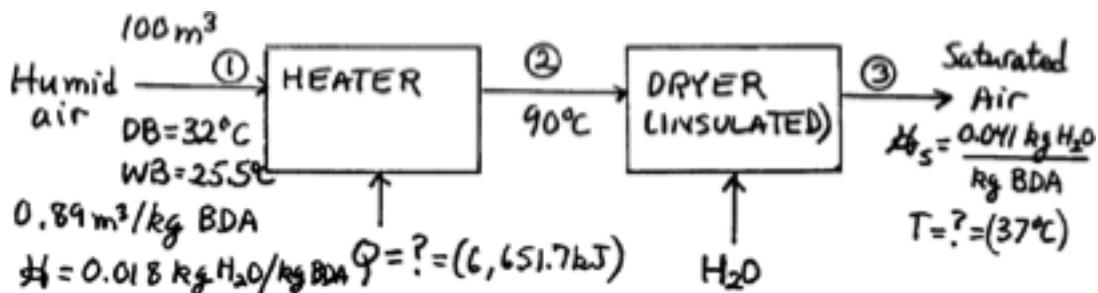
Assuming the liquid water is supplied at a temperature not much different than the exit temperature of the air stream, the evaporative cooling process follows a line of constant wet-bulb temperature, which is the lowest temperature that can be obtained on an evaporative cooler. That is,

$$T_{\min} = T_{WB} = 19.3^{\circ}\text{C}$$

Solutions Chapter 11

11.2.14

Basis: 1 lb bone dry air (BDA)



Basis: 100 m³

Data from psychometric chart (BDA = bone dry air).

a. @ 1, Dew point = 23°C

b. @ 1, humidity = $0.018 \text{ kg H}_2\text{O / kg dry air}$

c. @ 1, Relative humidity = $\frac{H}{H_2} = \frac{0.018}{0.033} (100 =) [54.5\%]$

d. $\Delta H = Q + W$ $W = 0$

$$Q = \Delta H_2 - \Delta H_1 = (141.5 - 3.6) \frac{\text{kJ}}{\text{kg BDA}} - (79.0 - 0.3) \frac{\text{kJ}}{\text{kg BDA}} = 59.2 \frac{\text{kJ}}{\text{kg BDA}}$$

$$m = \frac{V}{\hat{V}} = \frac{100 \text{ m}^3 \text{ entering air}}{0.89 \text{ m}^3} \Big| \frac{\text{kg BDA}}{\text{kg BDA}} = 112.36 \text{ kg BDA}$$

$$Q = \frac{59.2 \text{ kJ}}{\text{kg BDA}} \Big| \frac{112.36 \text{ kg BDA}}{112.36 \text{ kg BDA}} = [6,651.7 \text{ kJ}]$$

e. Adiabatic cooling by evaporation yields a saturated humidity of 0.041 kg H₂O/kg BDA:

$$\frac{(0.041 - 0.018) \text{ kg H}_2\text{O}}{\text{kg BDA}} \Big| \frac{112.36 \text{ kg BDA}}{110 \text{ m}^3 \text{ air}} = \frac{2.58 \text{ kg H}_2\text{O}}{100 \text{ m}^3}$$

f. $T_{exit} = 37^\circ\text{C}$

Solutions Chapter 11

11.3.1

- a. The humidity of the entering air at 225°F DB and 110°F WB is obtained from the humidity chart.

$$\text{Humidity} = 0.031 \frac{\text{lb H}_2\text{O}}{\text{lb dry air}}$$

Assume the exit air to be saturated at 125°F.

$$\text{Humidity} = \boxed{0.0955 \frac{\text{lb H}_2\text{O}}{\text{lb dry air}}}$$

- b. Basis: 1 hr

$$\frac{10 \text{ tons}}{\text{day}} \left| \begin{array}{c} 1 \text{ day} \\ 24 \text{ hr} \end{array} \right| \frac{2000 \text{ lb}}{\text{ton}} = 835 \text{ lb/hr}$$

$$\text{Water in} = (0.1) (835) = 83.5 \text{ lb/hr}$$

$$\text{Water out} = \frac{(0.9) (835) \text{ lb dry grain}}{99 \text{ lb dry grain}} \left| \begin{array}{c} 1 \text{ lb H}_2\text{O} \\ \hline 99 \text{ lb dry grain} \end{array} \right. = 7.59 \text{ lb/hr}$$

$$\text{lb H}_2\text{O removed/hr} = \text{water in} - \text{water out} = 83.5 - 7.59 = \boxed{75.9 \text{ lb H}_2\text{O / hr}}$$

$$\text{c. Product output} = \left[(0.9) (835) \frac{\text{lb dry grain}}{\text{hr}} + 7.59 \frac{\text{lb H}_2\text{O}}{\text{hr}} \right] \left(\frac{24 \text{ hr}}{1 \text{ day}} \right) = \boxed{18,200 \text{ lb / day}}$$

$$\text{d. } \frac{\text{lb BDA}}{\text{hr}} = \frac{7.59 \text{ lb H}_2\text{O/hr}}{(0.0955 - 0.0310) \text{ lb H}_2\text{O/lb BDA}} = 1175 \text{ lb BDA/hr}$$

$$Q = \Delta H = \text{Enthalpy out} - \text{Enthalpy in}$$

$$= \Delta H_{\text{air}} + \Delta H_{\text{dry grain}} + \Delta H_{\text{water}}$$

$$= 1175 \frac{\text{lb BDA}}{\text{hr}} \left[136.5 \frac{\text{Btu}}{\text{lb BDA}} - (92.25 - 2.25) \frac{\text{Btu}}{\text{lb BDA}} \right]$$

$$+ \frac{(0.9) (835) \text{ lb dry grain}}{\text{hr}} \left| \begin{array}{c} 0.18 \text{ Btu} \\ \hline (\text{lb}) (\text{°F}) \end{array} \right| \left| \begin{array}{c} (110 - 70) \text{ °F} \\ \hline \end{array} \right|$$

Solutions Chapter 11

$$\begin{aligned}
 & + \frac{7.59 \text{ lb H}_2\text{O}}{\text{hr}} \left| \frac{1.0 \text{ Btu}}{(\text{lb}) (\text{°F})} \right| \frac{(110 - 32) \text{ °F}}{} \\
 & - \frac{83.5 \text{ lb H}_2\text{O}}{\text{hr}} \left| \frac{1.0 \text{ Btu}_2}{(\text{lb}) (\text{°F})} \right| \frac{(70 - 32) \text{ °F}}{} \\
 & = 5.46 \times 10^4 + 0.54 \times 10^4 + 0.059 \times 10^4 - 0.32 \times 10^4 = \boxed{5.74 \times 10^4 \text{ Btu / hr}}
 \end{aligned}$$

11.3.2

Assume in this problem

1. Steady operating conditions
2. Dry air and water vapor are ideal gases
3. $\Delta KE = \Delta PE = W = 0$
4. The mixing is adiabatic ($Q = 0$)

Data from the humidity chart:

Stream 1:

$$\begin{aligned}
 H_1 &= 110.3 \text{ kJ/kg dry air} \\
 H &= 0.0272 \text{ kg H}_2\text{O/kg dry air}
 \end{aligned}$$

Stream 2:

$$\begin{aligned}
 H_2 &= 50.9 \text{ kJ/kg dry air} \\
 H &= 0.0130 \text{ kg H}_2\text{O/kg dry air}
 \end{aligned}$$

The specific humidity and the enthalpy of the mixture can be determined from mass and energy balances for the adiabatic mixing of the two streams:

Basis: 1 kg dry air

Total Mass balance: $8 + 6 = 14 \text{ kg total}$

Water mass balance:

$$8(0.0272) + 6(0.0130) = 14 (H_{\text{mixture}})$$

b. $\boxed{H = 0.0211 \text{ kg H}_2\text{O/kg dry air}}$

Solutions Chapter 11

Energy balance ($\Delta H = 0$)

$$8(110.3) + 6(50.9) = 14 (H_{\text{mixture}})$$

$$H = 84.8 \text{ kJ/kg dry air}$$

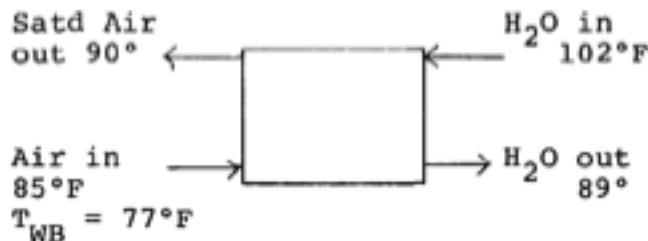
These two properties fix the state of the mixture. Other properties of the mixture are determined from the psychometric chart.

a. $T = 30.7^\circ\text{C}$

c. $\text{RH} = 75.1\%$

11.3.3

Data from Humidity Chart



a. $H_{\text{air in}} = [0.01813 \text{ lb H}_2\text{O / lb air}]$

b. $H_{\text{air out}} = [0.031 \text{ lb H}_2\text{O / lb air}]$

$$\text{H}_2\text{O picked up} = 0.031 - 0.01813$$

$$= 0.0129 \text{ lb H}_2\text{O/lb air}$$

Energy Balance:

$$\Delta H_{\text{air out}} - \Delta H_{\text{air in}} = \Delta H_{\text{water in}} - \Delta H_{\text{water out}}$$

Basis: 1 lb dry air Ref. temp = 85°F

$$\frac{\Delta H_{\text{air out}}}{\frac{0.24 \text{ Btu}}{(\text{lb})(^\circ\text{F})} \overbrace{\left| \frac{1 \text{ lb}}{} \right| \overbrace{\left(90 - 85 \right)}^{} } + \frac{0.45 \text{ Btu}}{(\text{lb})(^\circ\text{F})} \overbrace{\left| 0.031 \text{ lb} \right| \overbrace{\left(90 - 85 \right)}^{} }}$$

$$\Delta H_{\text{H}_2\text{O out}}$$

Solutions Chapter 11

$$\begin{array}{c}
 \Delta H_{H_2O \text{ out}} \quad \Delta H_{\text{air} + H_2O \text{ in}} \quad \Delta H_{H_2O \text{ in}} - \Delta H_{H_2O \text{ out}} \\
 \overbrace{\frac{+1040 \text{ Btu}}{\text{lb}}}^{} \left| \overbrace{0.0129 \text{ lb}}^{} \right. \quad \overbrace{-0}^{} \quad \overbrace{\frac{1 \text{ Btu}}{\left(\text{lb} \right) \left({}^\circ \text{F} \right)}}^{} \left| \overbrace{\frac{\text{m lb}}{\left({}^\circ \text{F} \right)}}^{} \right| \left| \overbrace{\left(102 - 89 \right)}^{} \right|
 \end{array}$$

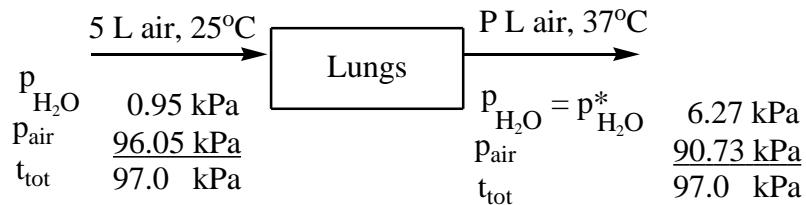
$$m = 1.136 \text{ lb H}_2\text{O/lb air or } \boxed{0.915 \text{ lb air / lb H}_2\text{O}}$$

c. % H₂O vaporized = $\left(\frac{0.0129}{1.136} \right) 100 = \boxed{1.14\%}$

11.3.4

Steps 1, 2, 3, and 4

The process will be assumed to be a steady state, open, continuous one with 5L flowing in (in the material balance the air is invariant). All of the data for the stream flows and compositions have been placed on the figure. The lungs will be the system.



$$p_{H_2O}^* = 3.17 \text{ kPa}$$

$$p_{H_2O} = 3.17(0.3) = 0.95 \text{ kPa}$$

Step 5: Basis: 5 L air \rightarrow 1 min

Steps 6, 7, 8, and 9:

Material balances

$$\text{In: } n_{\text{air}} = \frac{96.05 \text{ kPa}}{101.3 \text{ kPa}} \left| \frac{1 \text{ atm}}{298 \text{ K}} \right| \left| \frac{5 \text{ L}}{0.08206(\text{L})(\text{atm})} \right| = 0.194 \text{ g mol}$$

Solutions Chapter 11

$$n_{H_2O} \left(\frac{0.95}{95.05} \right) (0.194) = 1.92 \times 10^{-3} \text{ g mol}$$

Out:

$$n_{air} = 0.194 \text{ g mol}$$

$$n_{H_2O} = 0.194 \left(\frac{6.27}{90.73} \right) = 0.0134 \text{ g mol}$$

Energy balance

The energy balance reduces to $Q = \Delta H$. The reference temperature will be 25°C. Assume the increase in water vapor comes from water vaporized at 37°C ($\hat{\Delta H}_{vap} = 2414.3 \text{ kJ/kg}$).

ΔH_{in} : Both the air and water enter at 25°C so $\Delta H = 0$ for both the input streams.

ΔH_{out} :

$$\Delta H_{air} = 0.194 \int_{298}^{310} (27.2 + 0.0041 T_K) dT = 66.2 \text{ J}$$

$$\begin{aligned} \Delta H_{H_2O} &= 1.92 \times 10^{-3} \int_{298}^{310} (34.4 - 0.0063 T_K) dT \\ &\quad + (0.0134 - 1.92 \times 10^{-3}) (2414.3)(18) = 499 \text{ J} \end{aligned}$$

$$Q = \Delta H = 499 + 66.2 = 565 \text{ J/min or } [33.9 \text{ kJ/hr}]$$

Solutions Chapter 11

11.3.5

Basis: 180 kg/hr of product

Material Balance

$$\text{Dry product} = \frac{92 \text{ kg dry P}}{100 \text{ kg P}} \left| \frac{180 \text{ kg P}}{1 \text{ hr}} \right. = 166 \text{ kg dry P/hr}$$

- a. Water removed from solid:

$$\begin{aligned} \text{In} &= \frac{1.25 \text{ kg H}_2\text{O}}{1.00 \text{ kg dry P}} \left| \frac{166 \text{ kg/hr dry P}}{(0.08)(180) \text{ kg/hr}} \right. \\ &= 207.5 - 14.4 = \boxed{193 \text{ kg H}_2\text{O / hr}} \end{aligned}$$

Basis: 1 BDA

Water picked up in dryer

$$\begin{aligned} \text{out} & \qquad \qquad \qquad \text{in} \\ \left(\frac{0.0571 \text{ kg H}_2\text{O}}{\text{kg BDA}} \right)_{\text{out}, 53^\circ} - \left(\frac{0.0083 \text{ kg H}_2\text{O}}{\text{kg BDA}} \right)_{\text{in}, 21^\circ} &= 0.0488 \frac{\text{kg H}_2\text{O}}{\text{kg BDA}} \\ \frac{\text{kg BDA}}{\text{hr}} &= \frac{193 \text{ kg H}_2\text{O}}{0.0488 \text{ kg H}_2\text{O/kg BDA}} = \boxed{3955 \text{ kg BDA / hr}} \end{aligned}$$

- b. Energy balance

<u>Air:</u>	$\Delta \hat{H}$ (kJ/kg BDA)
-------------	------------------------------

air in (21°C, 52% RH):	58.2
------------------------	------

air out (53°C, 60% RH):	219.7
-------------------------	-------

$$\Delta \hat{H} = \qquad \qquad \qquad 161.5 \text{ kJ/kg BDA}$$

Basis: 1 hr

$$\Delta H = (161.6)(3955) = 6.387 \times 10^5 \text{ kJ}$$

Solid (ref. 21°C)

Solutions Chapter 11

$$\text{solid out: } \Delta \hat{H} = \int_{21}^{43} C_p dT = \frac{0.18 \text{ cal}}{(g) (\text{°C})} \left| \frac{4.184 \text{ J}}{\text{cal}} \right| \left| \frac{10^3}{10^3} \right| \left| \frac{(43 - 21) \text{ °C}}{} \right| = 16.57 \text{ kJ/kg P}$$

solid in: $\Delta \hat{H} = 0$ (because of reference temperature)

Basis: 1 hr

$$\Delta H = (16.57) (180) = 2983 \text{ kJ}$$

If the dryer and re heater are insulated, then for the system

$$Q - W = \Delta H \quad \text{and} \quad W = 0$$

$$Q_{\text{reheater}} = 2983 + 6.387 \times 10^5 = \boxed{6.42 \times 10^5 \text{ kJ/hr}}$$

11.3.6

Initial air: $T_{DB} = 38^\circ\text{C}$, $T_{WB} = 27^\circ\text{C}$,

$$H_1 = 0.0175 \text{ kg/kg dry air}$$

Air from scrubber: $T = 24^\circ\text{C}$, $RH = 100\%$, $RH_2 = 0.0188 \text{ kg/kg dry air}$

Heated to 93°C : $H_3 = 0.0188$

From drier: $T_{DB} = 49^\circ\text{C}$, $H_4 = 0.0377$

$(1000 \text{ kg/hr}) (0.05) = 50.0 \text{ kg H}_2\text{O}$ to be evaporated

$$50.0 / (0.0377 - 0.0188) = 2650 \text{ kg dry air/hr}$$

$$2650 (0.0377) = 100 \text{ kg H}_2\text{O/hr}$$

$$V_4 \left(\frac{2650}{29} + \frac{100}{18} \right) \left| \frac{22.4}{273} \right| \left| \frac{273 + 49}{273} \right| = 2560 \text{ m}^3 \text{ at } 49^\circ\text{C} \text{ and } 1 \text{ atm}$$

Heat supplied:

$$Q = [(2650) (1.00) + 100 (0.200)] (93 - 24) = 1.84 \times 10^5 \text{ kJ/hr}$$

Water at 93°C has $p^* = 79.4 \text{ kPa}$

Solutions Chapter 11

$$H_3 = \frac{(18)}{(29)} \left| \frac{(79.4)}{(101.3 - 79.4)} \right| = 2.25 \text{ kg H}_2\text{O/kg dry air}$$

$$[(0.0188/2.25)] (100) = 0.83\% \quad \text{RH air from heater}$$

Answers:

- | | | | |
|----|-----------------|-----------|-------------------------------------|
| a. | 1. $H = 0.0175$ | b. 1. 42% | c. 2650 kg dry air/hr |
| | 2. $H = 0.0188$ | 2. 100% | d. $2560 \text{ m}^3/\text{hr}$ |
| | 3. $H = 0.0188$ | 3. 0.83% | e. $1.84 \times 10^5 \text{ kJ/hr}$ |
| | 4. $H = 0.0377$ | 4. 47% | |

11.3.7

Step 5: Basis: 1 hr

Assume:

1. $\Delta PE = \Delta KE = W = 0$,
2. No reaction occurs,
3. open, steady state process,
4. ideal gas behavior

Data:

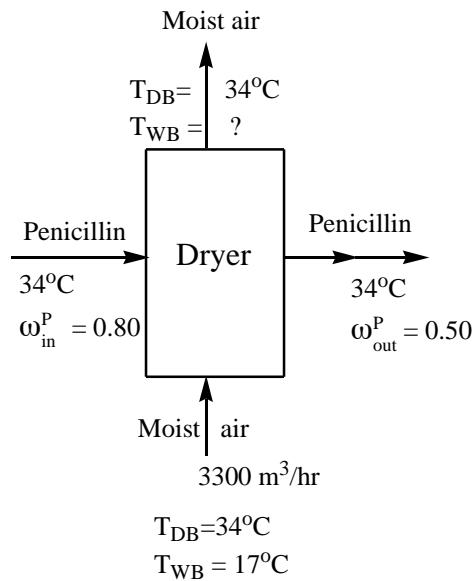
Entrance air (in)

\hat{H} (kJ/kg dry air)	50.5
H (kg H ₂ O/kg dry air)	0.00587
\hat{V} (m ³ /kg dry air)	0.88

Assume the properties of the wet penicillin are the same as those of water. ΔH_{vap} at 34°C = 2420.25 kJ/kg water. Let P = kg dry penicillin per hour, and F = kg dry air/hr.

Steps 3 and 4

Solutions Chapter 11



$$\text{air in} = \frac{4500 \text{ m}^3}{0.88 \text{ m}^3} \left| \frac{1 \text{ kg dry air}}{0.88 \text{ m}^3} \right. = 5114 \text{ kg dry air}$$

Steps 6 and 7:

The exit conditions for the air are not known, but the H and \hat{H} are related on the humidity chart hence only one is unknown. P (dry penicillin is unknown).

The balances are water, dry air, and dry penicillin.

Steps 8 and 9

	$T_{WB} (\text{ }^\circ \text{C})$	$\mathcal{H} \left(\frac{\text{kg H}_2\text{O}}{\text{kg dry air}} \right)$	$\hat{H} (\text{kJ/kg dry air})$
Assume:	20	0.009	57.0
	21	0.010	60.6
	22	0.0115	64.0

Water balance: $5114 (0.009 - 0.00587) = \text{water evaporated} = 16.0 \text{ kg}$
 $5114 (0.010 - 0.00587) = 21.1 \text{ kg}$
 $5114 (0.0115 - 0.00587) = 28.8 \text{ kg}$

Energy balance: $5114 (57.0 - 50.5) / (2420.25) = 13.73 \text{ kg}$
 $5114 (60.5 - 50.5) / (2420.25) = 21.1 \text{ kg}$
 $5114 (64.0 - 50.5) / (2420.25) = 28.5 \text{ kg}$

The solution is very sensitive to the values read from the psychometric chart. Assume the final T_{WB} ; 21 or 22°C .

a. Water evaporated = 28.5 kg

Solutions Chapter 11

b. $\Delta H(21^\circ\text{C}) = 51,140 \text{ kJ/kg dry air} \Rightarrow [51,140 \text{ kJ/hr}]$
 c.

Steps 6 and 7

Unknowns P, exit T_{WB}

Equations air, water

Steps 8 and 9

Water balance on air gives water evaporated $(5114)(0.010 - 0.00587) = 21.1 \text{ kg H}_2\text{O}$

Energy balance: $(60.5 - 50.5)(5114) + 21.1(2420.25) = 0$

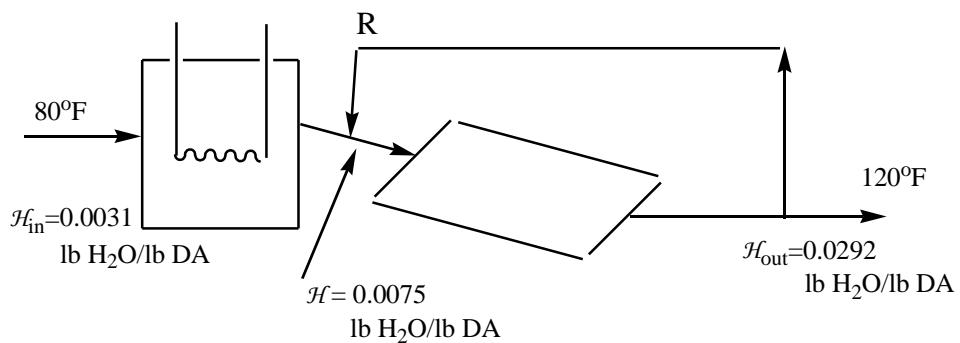
$$0.80 \rightarrow 0.60$$

Use 21°C

$$21.1 \text{ kg H}_2\text{O evap} = P \left(\frac{0.80}{0.20} - \frac{0.50}{0.50} \right) \quad \exists P$$

$$P = \frac{21.1}{3} = [7 \text{ kg/hr}]$$

11.3.8



Basis = $2000 \text{ lb dry waste (DW)}$

Comp.	in %	out	waste in =
H_2O	63.4	22.7	$\frac{2000}{0.773} \frac{100}{36.6} = 4,220 \text{ lb}$
DW	<u>36.6</u>	<u>77.3</u>	DW out = <u>2,000 lb</u>

Solutions Chapter 11

$$100.0 \quad 100.0 \quad H_2O \text{ evap.} \quad = 2,220 \text{ lb}$$

Basis: 1 lb dry air

Air in, 80°F, 29.92 in. Hg, and a wet bulb temperature = 54°F:

$$H_{in} = 0.0031 \text{ lb H}_2\text{O/lb dry air} \quad \hat{H}'_{in} = 22.62 - 0.18 = 22.54 \text{ Btu/lb dry air}$$

Air out, 120°F, 29.92 Hg, and a wet bulb temperature = 94°F:

$$H_{out} = 0.0292 \text{ lb H}_2\text{O/lb dry air} \quad \hat{H}' = 61.77 - 0.4 = 61.37 \text{ Btu/lb dry air}$$

Overall

$$H_{out} = 0.0292 \text{ lb H}_2\text{O/lb dry air}$$

$$H_{in} = 0.0031$$

$$H_2\text{O evaporated} = 0.0261 \text{ lb H}_2\text{O/lb dry air}$$

$$\text{b. air used per ton dust} = \frac{(1 + 0.0031)}{0.0261} \left| \frac{2220}{0.0261} \right| = [85,400 \text{ lb}] \text{ moist inlet air}$$

per ton DW

$$\text{Air out} = \frac{1.00}{0.0261} \left| \frac{2220}{0.0261} \right| = 2,930 \text{ lb mol dry air out}$$

$$\frac{0.0292}{0.0261} \left| \frac{2220}{0.0261} \right| = 138 \text{ mol H}_2\text{O out}$$

3068 total mol out

$$\text{c. } \frac{3068}{0.0261} \left| \frac{359}{0.0261} \right| = [1,300,000] \text{ ft}^3 \text{ wet air exiting/ton DW}$$

Air Recirculated

R = lb air added at mixing point before kiln

Water balance: $(0.0031)(1) + (0.0292)(W) = (0.0075)(1+W)$

$$0.0292 W = 0.0075$$

$$-0.0075 W = -0.0031$$

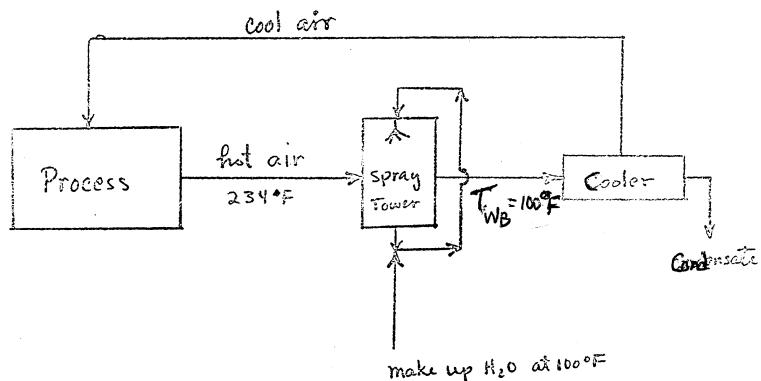
$$0.0217 W = 0.0044$$

$$R = \frac{0.0044}{0.0217} = 0.203 \text{ lb}$$

$$\text{a. Recirculation} = \frac{0.203}{1.203} \left| \frac{100}{1.203} \right| = [16.8\%] \text{ of gas out is recirculated}$$

Solutions Chapter 11

11.3.9



Adiabatic operation removes 425,000 Btu/hr from the process.

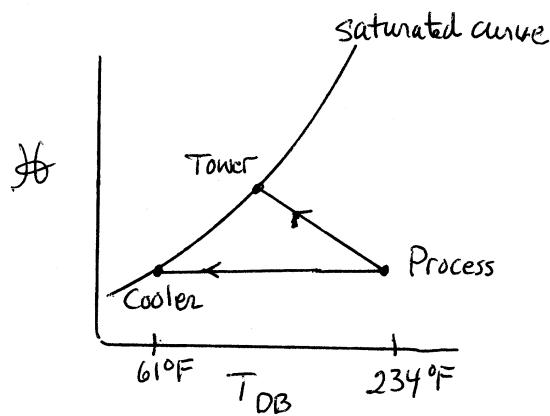
Basis: 1 hr

The energy balance is $\Delta H = 0$ overall.

- a. For the process:

$$\left. \begin{array}{l} T_{WB} = 100^{\circ}\text{F} \\ T_{DB} = 234^{\circ}\text{F} \end{array} \right\} R_H = 1.3\%$$

- b. Temperature leaving the cooler is 61°F (dew point constant H)
- c.



d. $\Delta H = (72 - 27)\text{Btu/lb BDA} \quad 45$

$$\frac{425,000 \text{ Btu}}{\text{hr}} \left| \frac{1 \text{ lb BDA}}{45 \text{ Btu}} \right. = \boxed{9450 \text{ BDA/hr}}$$