Instructor's Manual and
Solutions Manual
to accompany

Thermodynamics and Heat Power

Sixth Edition

Kurt C. Rolle

PEARSON
Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

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This manual is intended to be an aid in using and studying from the textbook, *Thermodynamics and Heat Power, Sixth Edition,* by Kurt C. Rolle. There are included solutions to the practice problems at the end of each chapter and some brief suggested answers to the discussion questions. In addition, there are eleven suggested lesson plans for various courses and I am including an example syllabus of a course which I have offered in engineering from time to time.

The approaches to solving thermodynamic problems are often subject to various interpretations and assumptions, so more than one correct method may be used for the same problem. The methodology and solutions set down in this manual often include some discussion about the assumptions or observations that can help to clarify the methods. Calculations are shown in as complete a manner as possible and answers are indicated with an underline. Many of the problem solutions are quite lengthy and then some details are omitted. In those cases it is usual that other previous problem solutions demonstrate the same sort of detailed calculations. Also, some of the problems were solved using the computer with the software package of programs mentioned in the textbook and listed in the appendix A. In those instances, the solution set down in this manual often includes only the program inputs and the resulting outputs. Numerical answers are given to at least three significant figures or, in the case of irrational numerical answers, a series of dots (...) indicate that the answer has been left in an incomplete form. For example the value of pi, π, may be expressed as 3.14159... and the value for 1/3 as 0.333.... Since many problems are long, with extended calculations, round-off discrepancies will occur and this can give slightly different answers to the same problem. The emphasis has been placed on giving methods and solutions that the students and readers can closely match and be satisfied with their methodology for solving the practice problems.

When giving the solutions to a large number of problems, particularly when there is such a wide variety of problems and a dual system of units (SI and English) to consider, there will be errors and discrepancies. The author and publisher appreciate all of the comments and suggestions made by those readers of the past editions and we solicit your input regarding any corrections or suggested revisions to this edition as well.

Finally, I want to thank all of the users of the earlier editions of this textbook and manual. In many ways you contributed to developing a more accurate and clear publication. I appreciate the work done by Dan Mueller in preparing the programs in a windows format and Hans Jensen for doing some editorial work on those programs. James Wiese and Andrew Cravens helped in facilitating the preparation of the CD as well. I also want to thank Debbie Yarnell and Jon Tenthoff at Prentice-Hall who provided the environment for creating this sixth edition. Again, I hope that you find this manual useful and complimentary to the textbook.

Kurt C. Rolle
Summer, 2004

TABLE OF CONTENTS

Thermodynamics and Heat Power has been written to provide the engineering and engineering technology students with a textbook that attempts to cover the most important aspects of thermodynamics and its technological applications. The text is intended to provide enough depth in the coverage as well as a variety of topics so that it may be used in a number of special emphasis or distinct courses. It can be supplemented with a set of BASIC programs, available from the publisher on a diskette for use with a personal computer, that allows for computer aided instruction of some of the material.

The following lesson plans have been set down as suggested approaches for some specific course work. The lesson plans are written for two or three hour semester courses and include those topics and sections from the text that would be considered. There is usually enough material in the book sections to spend more time than indicated in the lesson plans. Individual experiences will give each instructor added insights into improved variations from these plans.

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LESSON PLAN 1

3 Semester credits of **HEAT POWER**

Week	Topics	Book Sections
1	Introduction, System	Chapters 1 and 2
2	Work, Power, and Heat	Sections 3.1-3.3
3	Energy and Conservation of Mass	Sections 3.4-4.2
4	Steady Flow Energy Equation	Sections 4.3-4.6
5	Conservation of Energy	Sections 4.7-4.9
6	Equations of State	Chapter 5
7	Processes	Sections 6.1-6.4
8	Carnot Cycle and Entropy	Sections 7.1-7.8
9	Otto Cycle	Sections 9.1-9.4
10	Diesel and Dual Cycles	Sections 9.5-9.10
11	Gas Turbines	Sections 10.1-10.5,10.9
12	Steam Turbine Power Cycles	Sections 11.1-11.6
13	Analysis of Rankine Cycles	Sections 11.7-11.11
14	Refrigeration Cycles	Sections 12.1-12.3
15	Mixtures and Psychometrics	Sections 13.1-13.4
16	Combustion Analysis	Sections 14.1-14.5

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LESSON PLAN 2

2 Semester Credits of HEAT POWER

Week	Topics	Book Sections
1	Introduction	Chapter 1
2	System	Chapter 2
3	Work and power	Sections 3.1-3.2
4	Heat, energy, and conservation of mass	Sections 3.3-3.7 and 4.1-4.2
5	Conservation of energy	Sections 4.3-4.5.4.8
6	Equations of state, Perfect gas	Sections 5.1-5.3
7	Properties of pure substance	Sections 5.4-5.6
8	Processes of perfect gases	Sections 6.1-6.2
9	Processes of pure substances	Sections 6.6-6.7
10	Carnot cycle	Sections 7.1-7.5
11	Otto cycle	Sections 9.1-9.3
12	Diesel cycle	Sections 9.5-9.7
13	Rankine cycle	Sections 11.1-11.7
14	Refrigeration	Sections 12.1-12.3
15	Mixtures, combustion	Sections 13.1-13.2 14.1
16	Combustion	Sections 14.2-14.5

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LESSON PLAN 3

2 Semester credits of POWER PLANTS

Week	Topics	Book Sections
1	Introduction, systems	Chapters 1 and 2
2	Work, power, and heat	Chapter 3
3	Conservation and mass and energy	Chapter 4
4	Properties of pure substances	Chapter 5
5	Processes of steam, heat engines	Sections 6.6,7.1, 7.2
6	Thermal efficiency	Sections 7.3-7.6
7	Isentropic processes	Sections 7.7,7.8
8	Rankine cycle components	Sections 11.1-11.5
9	Analysis of rankine cycles	Sections 11.6,11.7
10	Reheat cycle	Section 11.8
11	Regenerative cycle	Section 11.9
12	Reheat-regenerative cycles	Sections 11.10,11.11
13	Gas turbine analysis	Sections 10.1,10.2, 10.5
14	Regenerative gas turbines electric generators	Sections 10.6,10.7, 17.1
15	Combustion processes	Sections 14.1-14.3
16	Combustion analysis	Sections 14.4-14.8

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LESSON PLAN 4

3 Semester credits of **INTRODUCTORY THERMODYNAMICS** followed by a second
3 semester credits of **APPLIED THERMODYNAMICS**.

Week	Topics	Book Sections
1	Introduction	Chapter 1
2	System and properties	Chapter 2
3	Work, power, and heat	Sections 3.1-3.3
4	Energy forms and types	Sections 3.4-3.8
5	Conservation of mass and energy	Sections 4.1-4.6
6	Steady flow energy equation	Sections 4.7-4.9
7	Equations of state	Sections 5.1-5.3
8	Calorimetry	Sections 5.4-5.6
9	Processes of perfect gases	Sections 6.1-6.2
10	Processes of liquids and solids	Sections 6.3-6.5
11	Processes of pure substances	Section 6.6
12	Heat engines and heat pumps	Sections 7.1-7.5
13	Entropy and the third law	Sections 7.6-7.9
14	Carnot cycle analysis	Sections 7.10-7.11
15	Useful work and availability	Sections 8.1-8.3
16	Free energies	Section 8.4

3 Semester credits of **APPLIED THERMODYNAMICS**

Week	Topics	Book Sections
1	Otto cycle analysis	Sections 9.1-9.4
2	Diesel and dual cycles	Sections 9.5-9.8
3	Brayton cycle components	Sections 10.1-10.4
4	Gas turbine, jet propulsion	Sections 10.5-10.7 10.9
5	Rankine cycle components	Sections 11.1-11.6
6	Analysis of rankine cycles	Sections 11.7-11.11
7	Vapor compression cycles	Sections 12.1-12.3
8	Air cycle, cryogenics, heat pumps	Sections 12.4, 12.6, 12.7,12.8
9	Mixture analysis	Sections 13.1-13.3
10	Processes of water-air mixtures	Sections 13.4-13.7
11	Combustion processes	Sections 14.1-14.3
12	Combustion analysis	Sections 14.4-14.8
13	Conduction, convection heat transfer	Sections 15.1-15.3
14	Radiation, heat exchangers	Sections 15.6-15.8
15	Electrical processes	Sections 17.1-17.3
16	MHD, bio-systems, Stirling cycle	Sections 17.4-17.7

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LESSON PLAN 5

2 semester credits of **THERMODYNAMICS** followed by a second 2 semester credits of **APPLIED THERMODYNAMICS**

Week	Topics	Book Sections
1	Introduction	Chapter 1
2	System, pressure, density	Sections 2.1-2.9
3	Temperature, energy	Sections 2.10-2.14
4	Work, power, and heat	Sections 3.1-3.3
5	Reversibility, energy forms	Sections 3.4-3.8
6	Conservation of mass and energy	Sections 4.1,4.2,4.4
7	Steady flow energy equation	Sections 4.5-4.9
8	Equations of state	Sections 5.1-5.3
9	Properties of pure substances	Sections 5.5-5.6
10	Processes of perfect gases	Sections 6.1,6.2
11	Processes of pure substances	Sections 6.3-6.7
12	Heat engines	Sections 7.1,7.2
13	Thermal efficiency	Sections 7.3,7.4
14	Entropy	Sections 7.5,7.6
15	Isentropic processes	Sections 7.7-7.9
16	Carnot cycle analysis	Section 7.10

2 Semester credits of **APPLIED THERMODYNAMICS**

Week	Topics	Book Sections
1	Otto cycles	Sections 9.1-9.3
2	Diesel cycles	Sections 9.4,9.5
3	Diesel and dual cycles	Sections 9.6-9.8
4	Brayton cycle	Sections 10.1-10.4
5	Gas turbine analysis	Section 10.5
6	Rankine cycle	Sections 11.1-11.3
7	Analysis of rankine cycles	Sections 11.4-11.7
8	Reheat and regeneration	Sections 11.8-11.9
9	Reheat-regeneration cycles	Section 11.10
10	Vapor compression refrigeration	Sections 12.1-12.3
11	Heat pumps, mixture analysis	Sections 12.7,13.1
12	Psychometrics	Sections 13.2-13.4
13	Combustion processes	Sections 14.1-14.3
14	Combustion analysis	Sections 14.4,14.5
15	Heat transfer	Sections 15.1-15.3
16	Other applications	Chapter 17

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LESSON PLAN 6

2 Semester credits of **HEAT TRANSFER**

Week	Topics	Book Sections
1	Review of terms	Chapters 1 and 2
2	Work, power, and heat	Sections 3.1-3.3
3	Conduction heat transfer	Section 15.1
4	Conservation of mass	Sections 4.1-4.4
5	First law of thermodynamics	Sections 4.5,4.6
6	Steady flow energy equation	Sections 4.7,4.8
7	Properties of pure substances	Sections 5.3,5.5
8	Processes of fluids and solids	Sections 6.4-6.6
9	Convection heat transfer	Section 15.2
10	Fins	Section 15.3
11	Lumped heat capacity	Section 15.3
12	Forced convection	Section 15.4
13	Natural convection	Section 15.5
14	Radiation heat transfer	Section 15.6
15	Radiation analysis	Section 15.6
16	Heat Exchangers	Section 15.7

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LESSON PLAN 7

3 Semester credits of **HEAT TRANSFER**

Week	Topics	Book Sections
1	Introduction, review of terms	Chapters 1 and 2
2	Work, heat and mass flow	Sections 3.1-3.3, 4.1,4.2
3	Conservation of energy and equations of state	Sections 4.4,4.5 5.1,5.3
4	Processes of fluids and solids	Sections 6.4-6.6
5	Conduction heat transfer	Section 15.1
6	Convection heat transfer	Section 15.2
7	Fins, lumped heat capacity	Section 15.3
8	Flow of fluids, pure substances	Sections 4.7,4.8, 5.5
9	Forced convection	Section 15.4
10	Natural convection	Section 15.5
11	Radiation heat transfer	Section 15.6
12	Radiation analysis	Section 15.6
13	Heat exchangers	Section 15.7
14	Psychometrics	Sections 13.1-13.4
15	Analysis of heating	Sections 16.1,16.2
16	analysis of air conditioning	Section 16.3

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LESSON PLAN 8

2 Semester credits of **INTERNAL COMBUSTION ENGINES**

Week	Topics	Book Sections
1	Introduction, system	Chapters 1 and 2
2	Work, power, and heat	Sections 3.1-3.4
3	Conservation of mass	Sections 4.1-4.4
4	Conservation of energy	Sections 4.5,4.7, 4.8
5	Equations of state	Sections 5.1-5.3
6	Processes of perfect gases	Sections 6.1,6.2
7	Carnot heat engine	Sections 7.1-7.3, 7.5
8	Isentropic processes	Sections 7.6-7.8
9	Carnot cycle analysis	Sections 7.10,9.1
10	Otto cycle analysis	Sections 9.2-9.4
11	Diesel and dual cycles	Sections 9.5-9.7
12	Computer aided analysis	Sections 9.8-9.10
13	Brayton cycle	Sections 10.1-10.4
14	Gas turbine analysis	Section 10.5
15	Regenerative cycles	Sections 10.6,10.7
16	Computer aided analysis of gas turbines	Section 10.9

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LESSON PLAN 9

3 Semester credits of **INTERNAL COMBUSTION ENGINES**

Week	Topics	Book Sections
1	Introduction, system	Chapters 1 and 2
2	Work, power, and heat	Chapter 3
3	Conservation of mass and energy	Sections 4.1,4.2, 4.4,4.5,4.8
4	Equations of state	Sections 5.1-5.3
5	Processes of gases, heat engines	Sections 6.1,6.2,7.1
6	Carnot heat engine	Sections 7.2-7.5
7	Isentropic processes	Sections 7.6-7.8
8	Carnot cycle analysis	Sections 7.9,7.10
9	Otto cycle analysis	Sections 9.1-9.4
10	Diesel engines	Sections 9.5,9.6
11	Dual cycle analysis	Sections 9.7-9.10
12	Brayton cycle	Sections 10.1-10.3
13	Gas turbine analysis	Sections 10.4,10.5
14	Regenerative cycles	Section 10.6
15	Jet propulsion	Sections 10.7,10.9
16	Rockets, Stirling engine	Sections 10.8,17.6

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LESSON PLAN 10

3 Semester credits of **HEATING AND AIR CONDITIONING**

Week	Topics	Book Sections
1	Introduction, system	Chapters 1 and 2
2	Work and heat	Chapter 3
3	Conservation of mass and energy	Sections 4.1,4.2,4.4
4	Steady flow energy equation	Sections 4.5-4.9
5	Property equations	Sections 5.1,5.3,5.5
6	Processes of perfect gases and pure substances	Sections 6.1,6.4,6.6
7	Heat pump analysis	Sections 7.1,7.4,7.10
8	Vapor compression refrigeration	Sections 12.1-12.3
9	Air cycle analysis	Sections 12.4,12.5
10	Cryogenics	Sections 12.6,12.7
11	Mixtures and psychometrics	Sections 13.1-13.4
12	Conduction and convection	Sections 15.1-15.3
13	Heat exchangers	Sections 15.5,15.7
14	Parameters in heating and air conditioning	Section 16.1
15	Analysis of heating	Section 16.2
16	Analysis of air conditioning,	Sections 16.3,17.6

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LESSON PLAN 11

2 Semester credits of HEATING AND AIR CONDITIONING

Week	Topics	Book Sections
1	Introduction	Chapter 1
2	System and properties	Chapter 2
3	Work, power, and heat	Chapter 3
4	Conservation of mass	Sections 4.1,4.2
5	Conservation of energy	Sections 4.4,4.5,4.8
6	Equations of state	Sections 5.1-5.3
7	Pure substances	Sections 5.5,6.1
8	Perfect gases and incompressible substances	Sections 6.2,6.4
9	Processes of pure substances	Sections 6.6,7.1
10	Carnot heat pump	Sections 7.2-7.4
11	Vapor compression refrigeration	Sections 12.1-12.3
12	Conduction and convection	Sections 15.1,15.2
13	Applications of heat transfer	Section 15.3
14	Parameters in heating and a/c	Section 16.1
15	Analysis of space heating	Section 16.2
16	Analysis of air conditioning	Section 16.3

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Basic Thermodynamics for Engineers

Course Information

Description:

Thermodynamic systems, Properties, zeroth law of thermodynamics, conservation of mass and energy, first and second laws of thermodynamics, Ideal gases, steam, Refrigerants, Power and refrigeration cycles, Heat Transfer.

Text:

Thermodynamics and Heat Power, Fifth Edition, K.C.Rolle

Prerequisites:

Physics Mechanics, Heat light and Sound
Differential and Integral Calculus

Requirements:

The student is expected to attend class, be prepared by reading the assignments for the day, and do the practice problems.

Grading:

The students semester grades will be based on examinations, homework, and bonus quizzes. There will be 4 examinations, each examination pertaining to the material covered since the last examination and each based on 100 points. The homework is due on the days indicated on the semester schedule. Each homework problem is worth 5 points maximum; that is,

5 points - done correctly
4 points - done with calculation error
3 points - done with conceptual error
2 points - done with more than one error
1 point - attempted

There will be 16 homework problems due. There will also be 5 quizzes, unannounced and closed-book each worth 5 points. These are Bonus Points and if you miss the quiz by being late or absent from class it cannot be made up. The semester grade will be determined by the semester percentage score (SPS).

$$SPS = \frac{\text{Students test scores, homework, and quizzes}}{480}$$

Letter grades will be assigned by the scientific scale:

A 90 to 100%
B 80 to 89%
C 70 to 79%
D 60 to 69%
F Below 60%

Thermodynamics for Engineers

Semester Schedule

Class	Topics	Readings	Practice Problems	Home Work
1	Introduction, Units	1.1 thru 1.8	1.5, 1.6	
2	System and properties	2.1 thru 2.7	1.14,1.22,	
3	Pressure, Temperature,	2.8 through 2.13	1.26,1.28 1.30, 2.16	
4	Work and Power	3.1,3.2	2.18,2.25 2.24, 2.35 2.40, 2.43	
5	Heat and Energy Forms	3.3-3.7	3.10. 3.14 3.24, 3.25	**2.27**
6	Conservation of Mass and Steady Flow	4.1,4.2	4.2,4.8 4.10,4.18	**3.9**
7	Uniform Flow and Unsteady Flow	4.3,4.4	4.20,4.22	**4.25**
8	First Law of Thermo	4.5-4.8	4.38,4.40	**4.57**
9	Problem Session		4.44,4.48 4.41	
10	Review			
11	**Examination One**			
12	Equations of state	5.1,5.2	5.2,5.4 5.10	
13	Calorimetry	5.3,5.4	5.16,5.20 5.28,5.30, 5.38	**5.23**
14	Properties of Pure Substances	5.5	5.54,5.58 5.66, 5.45	**5.43**

Class	Topics	Readings	Practice Problems	Home Work
15	Processes	6.1	6.2,6.8	
16	Adiabatic Processes of Perfect Gas	6.2	6.12, 6.20	
17	Processes of Comp.Gases	6.3	6.26, 6.30	**6.35**
18	Processes of Liquids and Solids	6.4-6.5	6.43, 6.44 6.50, 6.52	
19	Processes of Pure Substances		6.58, 6.62 6.68, 6.77 6.85	
20	Review			
21	**Examination Two**			
22	Heat Engines	7.1-7.4	7.2,7.4	
23	Carnot Cycle Heat Pumps		7.6, 7.8 7.12	
24	Second Law of Thermo	7.5-7.6	7.16, 7.18	**7.13**
25	Entropy Isentropic Processes	7.7-7.9	7.20, 7.24 7.26	
26	Mixtures	13.1-13.2	13.2, 13.3	**7.29**
27	Psychrometrics	13.3	13.4, 13.6	
28	Psychrometric Processes	13.4	13.12,13.14	
29	Rankine Cycle	11.1-11.7	13.16, 13.18 13.26	
30	Rankine Cycle Analysis	11.8-11.9	11.5,11.12 11.20, 11.28	
31	Refrigeration Cycles	12.1-12.4	12.2, 12.6, 12.10, 12. 11,	**13.25**

Class	Topics	Readings	Practice Problems	Home Work
32	Problem Session		12.17, 12.18	
33	Review			
34	**Examination Three**			
35	Conduction Heat Transfer	15.1	15.2, 15.6, 15.10	**15.2**
36	Convection Heat Transfer	15.2	15.12,15.14	
37	Conduction/Convection	15.3	15.20,15.24 15.28	
38	Forced and Free Convection	15.4 15.5	15.30, 15.36 15.40, 15.39	**15.21**
39	Radiation Heat Transfer	15.6	15.44, 15.50	
40	Heat Exchangers	15.7	15.54, 15.55	
41	Useful Work	8.1, 8.2	8.2, 8.8	**15.31**
42	Availability and Free Energy	8.3, 8.4	8.10, 8.12	**15.49**
43	Review		8.13, 8.16	**8.9**
44	**Examination Four**			

CHAPTER 1

THE PROBLEMS IN SECTION 1.4 ARE INTENDED TO PROVIDE A REVIEW OF ARITHMETIC, ALGEBRAIC, AND TRIGONOMETRIC OPERATIONS.

1.1. $\dfrac{(3.70)(40.1)}{(136)(270)(3)} = \underline{0.0013468....}$

1.2. $(1870)(26.0)(9.80) = \underline{476,476}$

1.3. $260^2 = \underline{67,600}$

1.4. $260^{1/4} = \underline{4.0155....}$

1.5. $(62.1)\left(\dfrac{35.1}{26.1}\right)^{1.6} = \underline{99.76....}$

1.6. $(333)\left(\dfrac{1}{1-1.2}\right) = \underline{-1665}$

1.7 a.) $1.3 \sin 25° = \underline{0.5494...}$

b.) $3.7 \sin\left(\frac{2\pi}{9}\right) = 3.7 \sin(40°) = \underline{2.378....}$

1.8 a.) $(5.6\ kJ) \cos 160° = \underline{-5.262..\ kJ}$

b.) $\left(9.1\ \frac{BTU}{lbm}\right) \cos \frac{\pi}{16} = 9.1 \cos 11.25° = \underline{8.925..\ \frac{BTU}{lbm}}$

CHAPTER 1

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Class	Topics	Readings	Practice Problems	Home Work
32	Problem Session		12.17, 12.18	
33	Review			
34	**Examination Three**			
35	Conduction Heat Transfer	15.1	15.2, 15.6, 15.10	**15.2**
36	Convection Heat Transfer	15.2	15.12,15.14	
37	Conduction/Convection	15.3	15.20,15.24 15.28	
38	Forced and Free Convection	15.4 15.5	15.30, 15.36 15.40, 15.39	**15.21**
39	Radiation Heat Transfer	15.6	15.44, 15.50	
40	Heat Exchangers	15.7	15.54, 15.55	
41	Useful Work	8.1, 8.2	8.2, 8.8	**15.31**
42	Availability and Free Energy	8.3, 8.4	8.10, 8.12	**15.49**
43	Review		8.13, 8.16	**8.9**
44	**Examination Four**			

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1.9. a.) $6.48 \log(37.6) = \underline{10.2072\ldots}$

b.) $(0.2\ kN\text{-}m)\ln(37000) = \underline{2.1037..\ kN\text{-}m}$

1.10 $e^{1.7} = \underline{5.4739\ldots}$

$e^{-20.0} = \underline{(2.061..)\times 10^{-9}}$

$e^{\pi/2} = \underline{4.810\ldots}$

1.11 SOLVE FOR P:

$$3P + 17 = 22\cos 28^\circ$$

$$3P = 22\cos 28^\circ - 17$$

$$P = (22\cos 28^\circ - 17)/3$$

$$\underline{P = 0.808\ldots\ psi}$$

1.12 SOLVE FOR x; $x^3 = 324$

$$x = 324^{1/3} = \underline{6.868\ldots\ ft}$$

1.13 SOLVE FOR V:

$$V^2 + 2V = 265\ m^6$$

THIS IS A QUADRATIC EQUATION AND

$$V = \frac{-2 \pm \sqrt{(2)^2 - 4(1)(-265)}}{2(1)} = \underline{15.3\ m^3}$$

THE SOLUTION $V = -17.3..$ IS NOT A REAL SOLUTION.

1.14. SOLVE FOR T:

$$27.315\,°C = 27.600°C - 0.003T$$

$$0.003T = 27.600 - 27.315 = 0.285$$

$$T = 0.285/0.003$$

$$\underline{T = 95°C}$$

1.15 SOLVE $pV = mRT$ FOR T. WE HAVE

$$\underline{T = \frac{pV}{mR}}$$

1.16 FOR $xy^{1.6} = 2.3$

$$\underline{x = \frac{2.3}{y^{1.6}}} \qquad \underline{y = \left(\frac{2.3}{x}\right)^{1/1.6}}$$

PROBLEMS IN SECTION 1.5 PROVIDE SOME PRACTICE IN APPROXIMATING AREAS UNDER CURVES AND USING TRAPEZOID RULE.

1.17. AREA UNDER CURVE = AREA OF RECTANGLE

$$= \text{BASE} \times \text{HEIGHT}$$

$$= (1.5\,m^3 - .06\,m^3)\left(500\,\frac{kN}{m^2}\right)$$

$$= 720\,\frac{kN\text{-}m^3}{m^2}$$

$$\underline{= 720\,kN\text{-}m}$$

1.18. AREA UNDER CURVE = AREA OF TRAPEZOID

$$A = \frac{1}{2}(\text{BASE})(\text{SUM OF TWO SIDES})$$

$$A = \frac{1}{2}(100°C - 10°C)(c_v @ 100°C + c_v @ 10°C)$$

$$c_v @ 100°C = 3.5 + .01 \times 100 = 4.5 \text{ kJ/kg C}$$

$$c_v @ 10°C = 3.5 + .01 \times 10 = 3.6 \text{ kJ/kg C}$$

SO $A = \frac{1}{2}(90°C)\left(4.5 + 3.6 \frac{kJ}{kg\,C}\right)$

$$= 364.5 \text{ kJ/kg}$$

1.19. AREA UNDER CURVE = A = AREA UNDER CURVE WHERE y VARIES INVERSELY WITH x AS IN APPENDIX A.4d.

$$A = C \ln V_2/V_1$$

WHERE $C = 50{,}000 \frac{lbf}{ft^2} \times 1.0 ft^3 = 50{,}000 \text{ ft-lbf}$

SO

$$A = (50{,}000 \text{ ft-lbf}) \ln 4.0/1.0$$

$$= 69{,}314.7 \text{ ft-lbf}.$$

AN ALTERNATE APPROXIMATE SOLUTION CAN BE OBTAINED BY USING SMALL TRAPEZOID AREAS SUMMED AS IN APPENDIX FIG Ax.1

AS ONE EXAMPLE OF THIS, USING 3 TRAPEZOIDAL AREAS :

$V_1 = 1.0\ ft^3$ $P_1 = 50{,}000\ lbf/ft^2$

$V_2 = 2.0\ ft^3$ $P_2 = 25{,}000$

$V_3 = 3.0\ ft^3$ $P_3 = 16{,}667$

$V_4 = 4.0\ ft^3$ $P_4 = 12{,}500$

THEN THE AREA CAN BE APPROXIMATED

$$A \approx \frac{1}{2}(V_2 - V_1)(P_2 + P_1) + \frac{1}{2}(V_3 - V_2)(P_3 + P_2)$$

$$+ \frac{1}{2}(V_4 - V_3)(P_4 + P_3)$$

$$\approx \frac{1}{2}(1\ ft^3)\left(75{,}000\ \frac{lbf}{ft^2}\right) + \frac{1}{2}(1)(41{,}667)$$

$$+ \frac{1}{2}(1)(29{,}167) = \underline{72{,}917\ ft\text{-}lbf}$$

THIS PROBLEM CAN ALSO BE SOLVED BY USING COMPUTER PROGRAM AREA AND MICRO COMPUTER.

1.20 AREA UNDER CURVE = A = AREA UNDER A CURVE $y = B/x^n$ WHERE $y = P$, $x = V$ $n = 1.5$ $B = C$ IN APPENDIX A4.e.

THEN

$$A = \frac{1}{1-n}\left(p_2 V_2 - p_1 V_1\right)$$

WHERE $V_1 = 15.0 \text{ in}^3$

$P_2 = 20.0 \text{ lbf/in}^3$

$V_2 = 100.0 \text{ in}^3$

$$P_1 = P_2\left(\frac{V_2}{V_1}\right)^{1.5} = 20.0\left(\frac{100}{15.0}\right)^{1.5} = 344.265$$

AND

$$A = \frac{1}{1-1.5}\left(20.0\times 100.0 - 344.265\times 15.0\right)$$

$$= 6327.95 \frac{\text{lbf-in}^3}{\text{in}^2} = \underline{6327.95 \text{ in-lbf}}$$

1.21 APPROXIMATE AREA UNDER CURVE = A

AND

A = SUM OF SMALL TRAPEZOIDAL AREAS.

$$= \frac{1}{2}(.0108 - .01 \text{ ft}^3)(1000 + 900 \text{ lbf/in}^2)$$

$$+ \frac{1}{2}(.0117 - .0108)(900 + 800) + \frac{1}{2}(.0130 - .0117)$$

$$(800 + 700) + \frac{1}{2}(.0145 - .0130)(700 + 600)$$

$$+ \frac{1}{2}(.0160 - .0145)(600 + 500) + \frac{1}{2}(.020 -$$

$$.0160)(500 + 400) = 6.1 \frac{\text{lbf-ft}^3}{\text{in}^2}$$

$$= \underline{878.4 \text{ ft-lbf}}$$

1.22. AREA UNDER CURVE ON T-S DIAGRAM = A

$A \cong$ SUM OF TRAPEZOIDAL AREAS.

THIS CAN BE DONE USING SAME SORT OF CALCULATION AS IN PROBLEM 1.21 OR BY USING PROGRAM AREA AND A MICRO COMPUTER. INPUT TO THE PROGRAM AREA WILL BE N=7, AND

$Y(1) = 3400$, $X(1) = 6.78$
$Y(2) = 3500$, $X(2) = 6.81$
$Y(3) = 3600$, $X(3) = 6.831$
$Y(4) = 3700$, $X(4) = 6.873$
$Y(5) = 3800$, $X(5) = 6.904$
$Y(6) = 3900$, $X(6) = 6.942$
$Y(7) = 4000$, $X(7) = 6.960$

THE RESULT IS $A = 665$ kJ/kg

1-23 AREA UNDER CURVE ON T-S DIAGRAM = A

$A \approx$ SUM OF TRAPEZOIDAL AREAS.

THIS CAN BE DONE USING SAME SORT OF CALCULATIONS AS IN PROBLEM 1-21 OR BY USING PROGRAM AREA AND

A MICRO COMPUTER. INPUT TO THE PROGRAM AREA WILL BE; N = 5 AND

Y(1) = 500, X(1) = 3.456

Y(2) = 600, X(2) = 3.789

Y(3) = 700, X(3) = 3.954

Y(4) = 800, X(4) = 4.002

Y(5) = 900, X(5) = 4.011

THE RESULT IS A = 334.05 BTU

1.24 FOR p = 20.5 V WE FIND p AT V OF FROM 1 TO 10:

P	V
20.5	1
41.0	2
61.5	3
82.0	4
102.5	5
123.0	6
143.5	7
164.0	8
184.5	9
205.0	10

THE AREA UNDER THE CURVE $p = 20.5V$ IS APPROXIMATED BY THE SUM OF TRAPEZOID AREAS, USING THE METHOD OF PROBLEM 1.21 OR USING PROGRAM <u>AREA</u> AND A PERSONAL COMPUTER. INPUT TO THE PROGAM COULD BE $N = 10$ AND VALUES OF P FOR THE Y-VALUES AND V FOR THE X-VALUES. THE RESULT IS

$$\underline{A = 1014.75}$$

USING CALCULUS:

$$A = \int_1^{10} p\,dv = \int_1^{10} f(v)\,dv = \int_1^{10} 20.5\,v\,dv$$

$$= \frac{1}{2}(20.5)v^2\Big|_1^{10} = \frac{1}{2}(20.5)(100-1)$$

$$\underline{A = 1014.75}$$

1.25 FOR THE CHANGE IN INTERNAL ENERGY OF A PERFECT GAS, Δu, WE HAVE

$$\Delta u \approx \sum_{n=1}^{N} c_v \delta T = \text{AREA UNDER A CURVE IN } c_v - T \text{ DIAGRAM.}$$

1.25 (CONT.) USING δT OF 50 DEGREES, WE CALCULATE C_V AT T = 100 TO T = 500: $C_V = 3.56 + .0346T$

$C_V = 7.02$, T = 100

$C_V = 8.75$, T = 150

$C_V = 10.48$, T = 200

$C_V = 12.21$, T = 250

$C_V = 13.94$, T = 300

$C_V = 15.67$, T = 350

$C_V = 17.40$, T = 400

$C_V = 19.13$, T = 450

$C_V = 20.86$, T = 500

USING <u>AREA</u> AND A PERSONAL COMPUTER WITH INPUTS OF N = 10, C_V-VALUES FOR Y-VALUES, AND T FOR X-VALUES, THE RESULT IS

$$\underline{\Delta u = 5576} \text{ kJ/kg}$$

USING CALCULUS:

$$\Delta u = \int_{100}^{500} C_V \, dT = \int_{100}^{500} (3.56 + .0346T) \, dT$$

$$= 3.56T + \tfrac{1}{2}(.0346T^2)\Big|_{100}^{500}$$

$$\underline{\Delta u = 5576 \text{ kJ/kg}}$$

1.26 AREA UNDER CURVE OF $pV^{1/2} = 2700$ IS GIVEN IN APPENDIX A.4e:

$$A = \frac{2700}{1-1/2}\left(300^{1/2} - 10^{1/2}\right) = \underline{76454.44}$$

THE SAME AREA CAN BE APPROXIMATED BY THE SUM OF TRAPEZOIDAL AREAS. USING <u>AREA</u> AND A PERSONAL COMPUTER WITH N = 30 AND VALUES OF P FOR Y-VALUES AND V (FROM 10 TO 300 IN INCREMENTS OF 10) FOR X. VALUES OF P ARE DETERMINED FROM $p = 2700/\sqrt{V}$ SO THAT, AT V = 10, p = 853.8; AT V = 20, p = 603.7 AND SO ON. PROGRAM <u>AREA</u> NEEDS TO BE REVISED TO RUN THIS PROBLEM WITH 30 POINTS. CHANGE LINE 100 TO READ:

```
100    DIM X(31)
```

AND LINE 110 TO READ:

```
110    DIM Y(31)
```

1.26 (CONT.) THEN THE COMPUTER RUN WILL GIVE

<u>A = 76788.2</u> (DEPENDING ON ROUND-OFF OF p-VALUES)

THE PROBLEMS IN SECTION 1.7 ARE INTENDED TO PROVIDE PRACTICE IN USING ENGINEERING EQUATION SOLVER (EES)

1.27 OPENING EES EQUATION WINDOW AND ENTERING:

```
{Problem 1-27}

x+2*y=3.4
x**2+y**2=4.5
```

THEN CLICKING <u>CALCULATE</u> AND THON <u>SOLVE</u> GIVES:

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]
x = 2.003 y = 0.6985

No unit consistency or conversion problems were detected.

1.28 OPENING EES EQUATION WINDOW AND ENTERING:

{Problem 1-28}

s=3.458
T*s**1.4=4456

THEN CLICK CALCULATE ON THE TOOLBAR AND SOLVE GIVES:

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]
s = 3.458

T = 784.5

No unit consistency or conversion problems were detected.

1.29 OPEN EES EQUATION WINDOW AND ENTER:

{Problem 1-29}

p*V**1.4=280

THEN CLICK TABLES ON TOOLBAR AND NEW PARAMETRIC TABLE SET NO. OF RUNS TO 20, PUT P AND V IN VARIABLES IN TABLE BY CLICKING ON P, THEN ADD, THEN ON V, AND ADD. CLICK

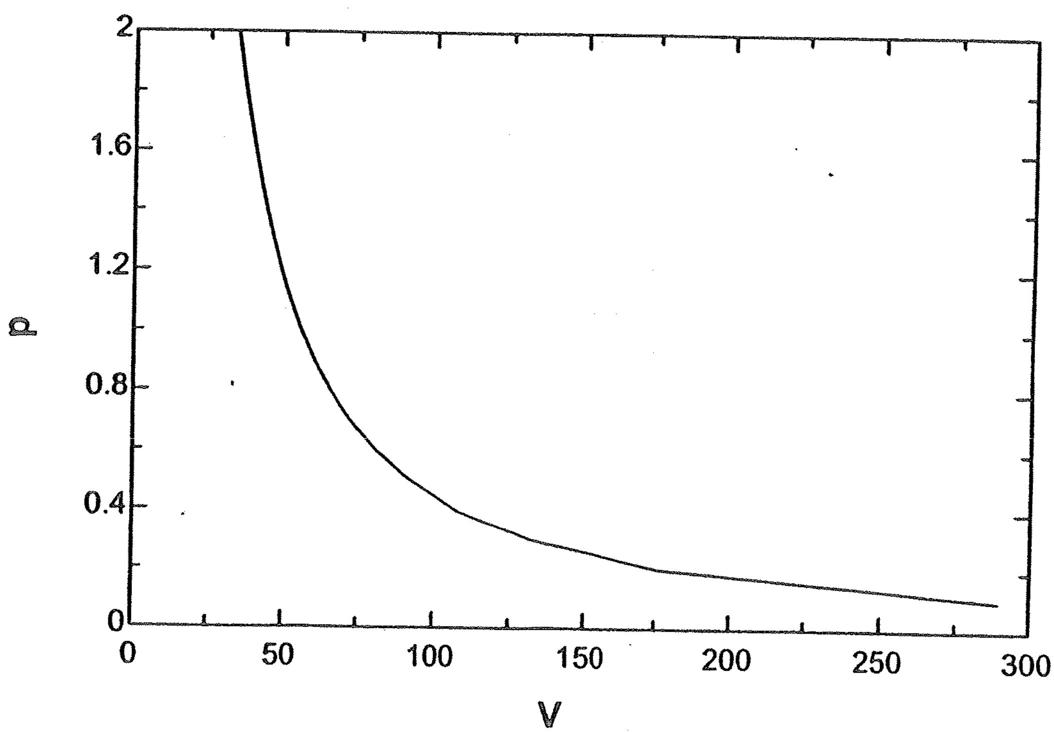
1.29 (CONT.)

OK AND ENTER ALL VALUES FOR ρ FROM 0.1 TO 2. THEN CLICK CALCULATE AND SOLVE TABLE. CLICK OK AND RESULT IS:

Parametric Table: Table 1

	p	V
Run 1	0.1	289.9
Run 2	0.2	176.7
Run 3	0.3	132.3
Run 4	0.4	107.7
Run 5	0.5	91.83
Run 6	0.6	80.62
Run 7	0.7	72.21
Run 8	0.8	65.64
Run 9	0.9	60.35
Run 10	1	55.97
Run 11	1.1	52.29
Run 12	1.2	49.14
Run 13	1.3	46.41
Run 14	1.4	44.01
Run 15	1.5	41.9
Run 16	1.6	40.01
Run 17	1.7	38.31
Run 18	1.8	36.78
Run 19	1.9	35.39
Run 20	2	34.12

1.30 TO PLOT RESULTS OF PROBLEM 1.29, CLICK PLOTS ON TOOLBAR, THEN NEW PLOTS WINDOW. CLICK V FOR x-AXIS AND P FOR y-AXIS. THEN CLICK OK AND PLOT RESULTS:



1.31 OPEN EES EQUATION WINDOW AND ENTER:

```
{Problem 1-31}

Wk=p*v**1.4
p*v=4.56*T
Wk=Q-0.234*T
Q=456/T
T=23*p
```

THEN CLICK <u>CALCULATE</u> AND <u>SOLVE</u> TO OBTAIN:

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

p = 0.1708 Q = 116.1 T = 3.928 v = 104.9

Wk = 115.2

No unit consistency or conversion problems were detected.

Chapter 2 Discussion Questions

Section 2.1

2.1 A *system* is a region in space having at least a volume.

2.2 A system needs a boundary to define the volume of that system.

Section 2.2

2.3 A *mole* or *mol* is a given number of molecules or atoms. Avogadro's Number is the number of molecules or atoms in one mole based on a gram. That is, one gram-mole of a substance has 6.022×10^{23} atoms or molecules, which is Avogadro's number.

2.4 Yes, a gram-mole is only 1/454 of a lbm-mol.

Section 2.3

2.5 A property helps describe a system.

2.6 Intensive properties of a system are properties based on one unit of mass of the system. Extensive properties describe the total system.

2.7 Specific energy is the energy per unit mass of a system.

Section 2.4

2.8 A state of a system is the complete description of a system, or the list of properties describing the system.

Section 2.5

2.9 A process is a change in a system's state.

Section 2.6

2.10 A cycle is a set of processes of a system which returns the system to its

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{Problem 1-31}

```
Wk=p*v**1.4
p*v=4.56*T
Wk=Q-0.234*T
Q=456/T
T=23*p
```

THEN CLICK CALCULATE AND SOLVE TO OBTAIN:

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

p = 0.1708 Q = 116.1 T = 3.928 v = 104.9

Wk = 115.2

No unit consistency or conversion problems were detected.

original state.

Section 2.7

2.11 Weight is the gravitational attraction between two bodies. The mass is a quantity of matter and weight is mass multiplied by the gravitational acceleration.

2.12 The term g_c is a constant of proportionality between momentum change (or mass times acceleration) and force (or weight)

Section 2.8

2.13 Specific volume is the volume per unit mass of a system.

2.14 Specific weight is the weight per unit volume of a system.

2.15 Specific Gravity is the ratio of the density of a substance to that of water at 4^0 C, standard atmospheric pressure of 1 bar.

2.16 Density is the mass per unit volume, or inverse specific volume.

2.17 Gage pressure is the pressure measured by a gage, usually when the gage is placed in a standard atmosphere of 1 bar pressure. It is a difference in pressure between absolute pressure of a system and the atmospheric pressure. Gage pressure is the pressure "felt" by a system at its boundary.

Section 2.9

2.18 The zeroth law of thermodynamics makes a temperature measurement independent of a system. Thus, a temperature of, say 30 degrees, is the same anywhere and anytime.

Section 2.10

2.19 Temperature is a measure of the "hotness" of a system.

2.20 A thermopile a group of thermocouples, all connected in series to each other.

Section 2.11

2.21 Energy is the capacity of a system to affect changes to its surroundings.

2.22 Internal energy is the form of energy manifested by the hotness or temperature, or the thermal energy. It is the kinetic energy of the individual atmos or molecules making up the system.

Section 2.12

2.23 Some outputs from a system would be, for instance, power produced by an engine, amount of water boiled in a boiler, or an amount of air pressurized in an air compressor.

2.24 Some inputs to a system would be, for instance, rate of fuel used by an engine, amount of energy used by a boiler, or power to drive a compressor.

Section 2.13

2.25 A derived unit is a unit or combination of fundamental units for describing a particular property or quantity.

CHAPTER 2

THE PROBLEMS IN SECTIONS 2.7 AND 2.8 ARE INTENDED TO HELP UNDERSTAND THE CONCEPTS OF WEIGHT, MASS, VOLUME, DENSITY, SPECIFIC VOLUME, AND PRESSURE.

2.1 WEIGHT $W = mg$. THUS, AT $g = 9.8\, m/s^2$

$$W = (2\ kg)(9.8\ m/s^2) = 19.6 \text{ NEWTONS (N)}$$

AT $g = 9.78\, m/s^2$

$$W = (2\ kg)(9.78\ m/s^2) = 19.56\ N$$

SO THAT <u>THE GOLD CUBE HAS GREATER WEIGHT AT LOCATION WHERE $g = 9.8\, m/s^2$.</u> THE MASS IS THE SAME AT BOTH LOCATIONS.

2.2 $W = mg = (3\ kg)(9.79\ m/s^2) = \underline{29.37\ N}$

2.3 $W = mg/g_c$ FOR ENGLISH ENGR. UNITS.

SO THAT $m = Wg_c/g$.

AT SEA LEVEL $g = 32.174\ ft/s^2$ SO THAT

$$m = (8.333\ lb_f)\left(32.174\ \frac{ft \cdot lb_m}{lb_f \cdot s^2}\right) \Big/ \left(32.174\ ft/s^2\right)$$

$m = 8.333\ lbm$

ALSO, $32.174\ lbm = 1\ slug$ SO THAT

$m = 8.333/32.174 = 0.2589\ldots$ SLUGS

2.4 THE MASS OF THE BATTERY IS THE SAME ON THE EARTH AND ON THE MOON.

$$m = Wg_c/g = \frac{(32\ lbf)(32.174\ ft\cdot lbm/lbm\cdot s^2)}{(32.174\ ft/s^2)}$$

$$= 32\ lbm.$$

ON THE MOON, WHERE $g = 5.47\ ft/s^2$

$$W = mg/g_c = (32\ lbm)(5.47)/(32.174)$$

$$W = 5.44..\ lbf$$

2.5 (a.) $1\ lbm = 453.59$ grams ≈ 454 grams

(b.) $2\ lbm = 2 \times 0.45359\ kg = 0.90718\ kg$

(c.) POUNDS-FORCE IS A FORCE OR WEIGHT UNIT. IF $g = 32.174\ ft/s^2$ AND SINCE 20 SLUGS IS A MASS, WE HAVE

$$W = mg = (20\ slugs)(32.174\ ft/s^2)$$

$$= 643.48\ lbf$$

(d.) DYNE IS A FORCE OR WEIGHT UNIT.

IF $g = 9.8\ m/s^2$ AND $m = 100$ grams = 0.1 kg, THEN

$$W = mg = (0.1\ kg)(9.8\ m/s^2) = 0.98\ N$$

BUT $1\ N = 10^5$ DYNES, SO

$$\underline{W = 98{,}000 \text{ DYNES}}$$

(e.) THIS IS A CONVERSION FROM MASS TO FORCE AND FROM SI TO ENGLISH UNITS. SINCE $m = 200\ kg$ AND $g = 9.8\ m/s^2$, WE HAVE

$$W(F) = mg = (200\ kg)(9.8\ m/s^2)$$
$$= 1960\ N$$

SINCE $1\ N = 0.2248\ lb_f$ WE HAVE

$$\underline{W(F) = 440.6..\ lb_f}$$

2.6 (a.) $\text{VOLUME} = V = \pi \times \frac{(\text{DIAMETER})^2}{4} \times \text{LENGTH}$

$$V = \pi\left(\frac{1m^2}{4}\right)(1.5\ m) = \underline{1.178..\ m^3}$$

(b.) $\text{SPECIFIC WEIGHT} = \frac{W}{V} = \frac{6000\ N}{1.178\ m^3} = \gamma$

$$\underline{\gamma = 5093\ N/m^3}$$

(c.) $\text{DENSITY} = \rho = m/V = W/gV = \gamma/g$

$$\rho = \frac{5093\ N/m^3}{9.82\ m/s^2} = \underline{518.6\ kg/m^3}$$

(d.) SPECIFIC GRAVITY $S.G. = \rho/1000$

$\underline{S.G. = 0.5186..}$

2.7 $W = mg$ AND $V = mv$. THEN $m = V/v$ AND $W = Vg/v$. SUBSTITUTING VALUES:

$$W = \frac{(4800\ cm^3)(9.78\ m/s^2)(10^{-6}\ m^3/cm^3)}{0.9\ m^3/kg}$$

$\underline{W = 0.052 \ldots\ N}$

2.8 (a.) $p = p_g +$ atmospheric pressure

$p = 1.0\ kPa + 101\ kPa = \underline{102\ kPa}$

(b.) IF atmospheric pressure = 768 mm Hg

1 mm Hg ≈ 0.1333 kPa

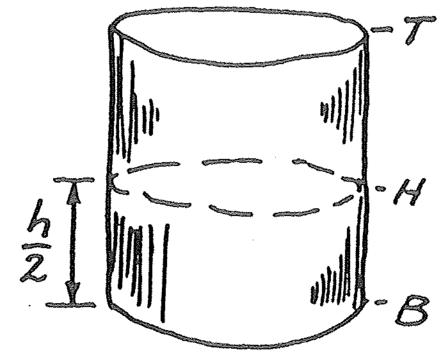
AND THEN

$p = 1.0\ kPa + 768 \times 0.1333\ kPa$

$\underline{p = 103.39.\ kPa \approx 103.4\ kPa}$

2.9 A TANK IS 5m HIGH AND HALF-FULL OF WATER.

(a.) ASSUME AIR PRESSURE IS CONSTANT AT 13 kPa IN TOP HALF OF TANK. THEN THE GAGE PRESSURE IS THE SAME AT THE TOP OF THE WATER.



$$P_H = 13 \text{ kPa}$$

(b.) PRESSURE AT BOTTOM $= P_B = P_H + \gamma_{H_2O} \times \frac{h}{2}$

$$P_B = 13 \text{ kPa} + \left(998 \frac{kg}{m^3} \times 9.8 \frac{m}{s^2}\right)(2.5 m)$$

$$= 13 \text{ kPa} + 24.451 \text{ kPa} = 37.451 \text{ kPa}$$

(c.) $P_H = 13 \text{ kPa} + 101 \text{ kPa} = 114 \text{ kPa}$

$P_B = 37.451 + 101 = 138.451 \text{ kPa}$

2.10 (a.) DENSITY $\rho = \frac{1}{v} = \frac{1}{10.07 \text{ ft}^3/\text{lbm}} = .0993 \text{ lbm/ft}^3$

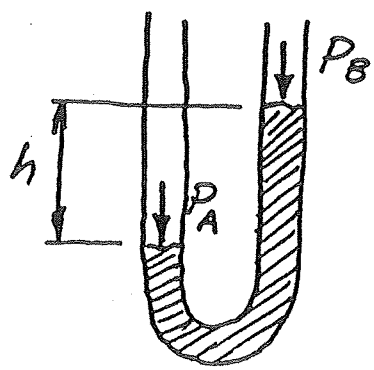
(b.) SPECIFIC WEIGHT $\gamma = \frac{g}{g_c} \rho$

$$\gamma = \left(\frac{32.1 \text{ ft/s}^2}{32.174 \text{ ft}\cdot\text{lbm/lbf}\cdot\text{s}^2}\right)\left(.0993 \frac{\text{lbm}}{\text{ft}^3}\right)$$

$$\gamma = .0991 \text{ lbf/ft}^3$$

(C.) SPECIFIC GRAVITY = $\rho/62.43$ = .00159

2.11 AIR IS ASSUMED TO HAVE A CONSTANT PRESSURE THROUGHOUT ANY ONE CLOSED VOLUME SO THAT P_A ACTS ON MERCURY IN MANOMETER AS SHOWN. THE PRESSURE IN THE MERCURY IS THE SAME AT ANY ONE ELEVATION. THUS



$$P_A = P_B + \gamma_{Hg} \times h$$

SOLVING FOR h:

$$h = \frac{P_A - P_B}{\gamma_{Hg}} = \frac{(20\ psig - 18\ psig)(144\ in^2/ft^2)}{(845\ lb_f/ft^3)}$$

$$h = 0.34\ ft$$

2.12 PRESSURE = FORCE/AREA

FORCE = PRESSURE × AREA

$$= \left(250\ \frac{lb_f}{in^2}\right)(\pi)\left(\frac{1\ ft^2}{4}\right)(144\ in^2/ft^2)$$

$$= 28,274\ lb_f$$

2.13 (a.) 14.8 psiv

(b.) 14 in. Hg VACUUM

2.14 (a.) 14.7 psi = 29.9389... in Hg

(b.) 460 mm Hg = 61.3... kPa

(c.) 300 in. Hg = 147.3 psi

(d.) 50 psi = 344.75 kPa

(e.) 20 kPa = 2.9008 psi

(f.) 20 inches WG = 0.722 psig

(g.) 50 cm WG = 4.903 kPa

2.15 $p = p_g + p_a$

$= 955 \text{ psig} + 14.4 \text{ psi}$

$p = 969.4 \text{ psia}$

2.16 $p = p_a - p_{gv} = 100.4 - 80$

$p = 20.4 \text{ kPa}$

PROBLEMS FROM SECTIONS 2.9 AND 2.10 ARE INTENDED TO HELP STUDENTS UNDERSTAND THERMAL EQUILIBRIUM AND TEMPERATURE MEASUREMENTS.

2.17 BLOCKS A AND B ARE NOT IN THERMAL EQUILIBRIUM. THEY WOULD BE IN THERMAL EQUILIBRIUM IF THEY WERE AT THE SAME TEMPERATURE.

2.18 COPPER-CONSTANTAN THERMOCOUPLE WILL GENERATE AN EMF (VOLTAGE) IN DIRECT PROPORTION TO THE JUNCTION TEMPERATURE. THE MAXIMUM VOLTAGE WILL BE OBSERVABLE AT 400°F AND FROM TABLE 2-3 THIS WOULD BE 9.523 MILLIVOLTS.

2.19 IRON-CONSTANTAN THERMOCOUPLE HAS A MEASURED EMF OF 8.700 mV. FROM TABLE 2-3 THE TEMPERATURE MAY BE FOUND BY LINEAR INTERPOLATION

$$\frac{T-177}{148.9-177} = \frac{8.700-9.483}{7.947-9.483} = .50977$$

$$\underline{T = 177 - 14.325 = 162.675°C}$$

2.20 WE MAY WRITE $T_N = mT_c + b$

WHERE m AND b ARE CONSTANTS. THEN WE SUBSTITUTE VALUES, $T_N = 0$ WHEN $T_c =$ 28.5°C AND $T_N = 100$ WHEN $T_c = 690°C$.

$$0 = m(28.5) + b$$

$$100 = m(690) + b$$

SOLVING THESE TWO EQUATIONS FOR m AND b: $m = 0.1512$ AND $b = -4.308$

SO THAT

$$T_N = 0.1512T_c - 4.308$$

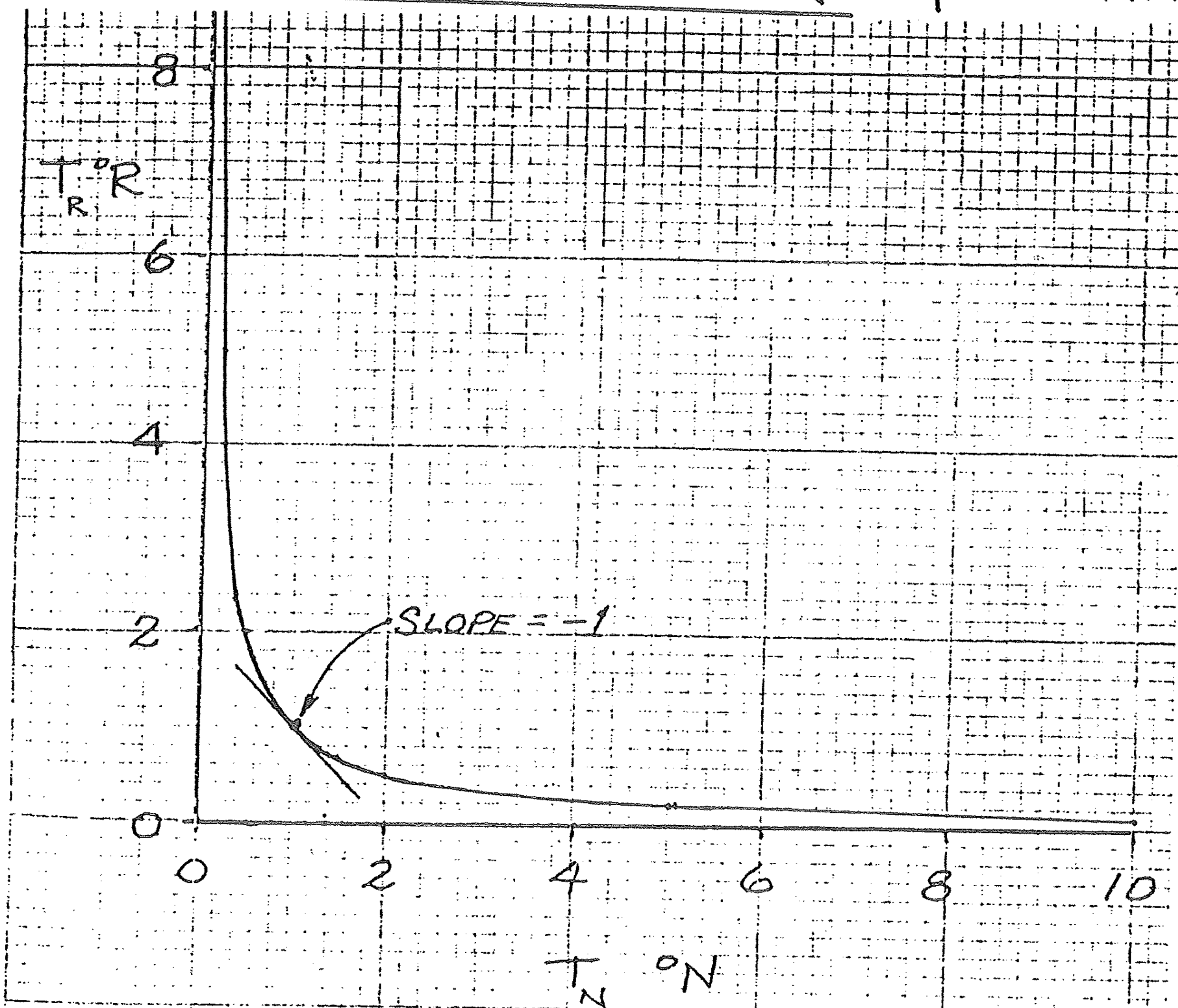
ALSO $T_c = T - 273$ WHERE T IS IN KELVIN DEGREES. AT ABSOLUTE ZERO; $T = 0$ SO

$$T_N = .1512(T-273) - 4.308$$

$\underline{T_N = -45.58°N}$ AT ABSOLUTE ZERO.

2.21 SLOPE AT $T_D = 1°D$:

SLOPE = -1 °D/°R (SEE GRAPH)



2.22 $T_L = \text{LOG } T°R = \text{LOG } T_R$. ALSO $T_R = \frac{9}{5} T_K$ SO THAT

$$T_L = \text{LOG}\left(\frac{9}{5} T_K\right) = \text{LOG } \frac{9}{5} + \text{LOG } T_K$$

OR

$$T_L = 0.255\ldots + \text{LOG } T_K$$

2.23 (a.) $140°F = 600°R$

(b.) $88°F = 548°R$

(c.) $230°F = 110°C$

(d.) $87\,K = 156.6°R$

2.24 (a.) $412°F = 872°R = 484\,K$

(b.) $32°F = 492°R = 273\,K$

(c.) $117°C = 390\,K = 702°R$

(d.) $72°C = 345\,K = 621.°R$

2.25 USING TABLE 2-3, THE emf IN mV FOR A COPPER-CONSTANTIN THERMOCOUPLE IS 3.967 mV AT 200°F. A THERMOPILE IS A GROUP OF THERMOCOUPLES CONNECTED IN SERIES. THUS THE emf FOR 8 THERMOCOUPLES IS

$$emf = 8 \times 3.967\,mV$$
$$= 31.736\,mV$$

THE PROBLEMS OF SECTION 2.11 ARE INTENDED TO GIVE A BETTER UNDERSTANDING OF ENERGY: KINETIC, POTENTIAL, AND INTERNAL.

2.26 (a.) KINETIC ENERGY $= \frac{1}{2} m \bar{V}^2$

$$KE = \left(\frac{1}{2}\right)(45{,}000\ kg)\left(1000\ \frac{km}{h}\right)^2\left(\frac{1h}{3600s}\right)^2$$

AND 1000 m (10^3 m) = 1 km SO THAT

$$KE = \left(1736\ \frac{kg\text{-}km^2}{s^2}\right)\left(10^6\ \frac{m^2}{km^2}\right) = \underline{1.736 \times 10^6\ kJ}$$

(b.) POTENTIAL ENERGY $= mgz$

$$= (45{,}000\ kg)\left(9.81\ \frac{m}{s^2}\right)(3000\ m)$$

$$\underline{PE = 13.2435 \times 10^5\ kJ}$$

2.27 (a.) ZERO (0), SINCE $\bar{V}$ APPEARS TO BE ZERO.

(b.) $KE = \frac{1}{2} m \bar{V}^2 = \frac{1}{2}\left(\frac{W}{g}\right)\bar{V}^2$

$$= \left(\frac{1}{2}\right)\left(\frac{170\ N}{9.8\ m/s^2}\right)\left(140{,}000\ \frac{m}{h}\right)^2\left(\frac{1h}{3600s}\right)^2$$

$$\underline{KE \cong 13{,}100\ kJ}$$

2.28 (a.) THE WOOD WILL FALL 40 meters. THUS

$$\Delta PE = mg(\Delta z) = (1 kg)(9.8 \frac{m}{s^2})(40 m)$$
$$= \underline{392 J}$$

(b.) THE STEEL WILL SINK AND THEREFORE FALL 60 meters.

$$\Delta PE = (1 kg)(9.8 m/s^2)(60 m) = \underline{588 J}$$

2.29 THE ENERGY SUPPLIED BY THE PUMP MUST BE EQUAL TO THE INCREASE IN POTENTIAL ENERGY OF THE WATER, WHICH IS

$$\Delta pe = \Delta PE/m = g(\Delta z)$$
$$= (9.8 m/s^2)(75 m) = \underline{735 J/kg}$$

2.30 $ke = \frac{1}{2}\bar{V}^2 = (\frac{1}{2})(24 \frac{m}{s})^2 = \underline{288 J/kg}$

2.31 $KE = \frac{1}{2}m\bar{V}^2 = \frac{1}{2}(1 kg)(60 \frac{m}{s})^2 = \underline{1800 J}$

2.32 (a.) TOTAL ENERGY = AKE + KE + PE + U

$$= \underline{305 kJ}$$

(b.) TOTAL MECHANICAL ENERGY = AKE + KE + PE

$= \underline{270 \text{ kJ}}$

2.33 (a.) POTENTIAL ENERGY, $PE = mgz/g_c$

AND $g = 32.09 \text{ ft/s}^2$ FROM TABLE B.2

THE BALLOON MASS IS

$$m = \frac{g_c}{g} W = \left(\frac{32.17}{31.7}\right)\left(\frac{10}{16} \text{lb}_f\right) = 0.634 \text{ lb}_m$$

THEN

$$PE = mgz/g_c = \frac{(0.634 \text{ lb}_m)(32.09 \text{ ft/s}^2)(5000 \text{ ft})}{(32.17 \text{ ft·lb}_m/\text{lb}_f\text{·s}^2)}$$

$\underline{PE = 3162.1 \text{ ft-lb}_f}$

(b.) AT SEA LEVEL $g = 32.108$ FROM TABLE B.2. THEN, WITH $z = -1000$ ft

$$PE = \frac{(0.634 \text{ lb}_m)(32.108 \text{ ft/s}^2)(-1000 \text{ ft})}{(32.17 \text{ ft·lb}_m/\text{lb}_f\text{·s}^2)}$$

$= \underline{-632.778 \text{ ft-lb}_f}$

(c.) <u>zero</u>, SINCE RELEASE POINT WAS ASSUMED TO BE ELEVATION OF ZERO POTENTIAL ENERGY.

2.34 TOTAL ENERGY = KE + PE + U

$= 28\ BTU + 2\ BTU + 150\ BTU$

$= 180\ BTU.$

2.35 $ke = \frac{1}{2g_c}\bar{V}^2 = \frac{(70\ mi/hr)^2(1.47\ ft/s/mi/hr)^2}{(2)(32.17\ ft\cdot lbm/lbf\cdot s^2)}$

$ke = 164.5..\ ft\ lbf/lbm$

2.36 TOTAL ENERGE, $E = KE + PE + U$

$= (10\ lbm)(500\ BTU/lbm) + (10\ lbm)(100\ BTU/lbm)$

$+ 15{,}000\ BTU$

$E = 21{,}000\ BTU$

$e = \frac{E}{m} = 2{,}100\ BTU/lbm$

2.37 DIFFERENCE IN ENERGY $= \Delta PE = \frac{gh}{g_c}$

$\Delta PE = 50\ ft\text{-}lbf/lbm$ MORE AT (1) THAN AT (2)

2.38 $ke = \frac{1}{2g_c}\bar{V}^2 = \frac{(2\ ft/s)^2}{2(32.17\ ft\cdot lbm/lbf\cdot s^2)}$

$= 0.062\ ft\cdot lbf/lbm$

2.39 $pe = 150 \text{ ft}\cdot\text{lbf/lbm}$ AT (1)

$= 100 \text{ ft}\cdot\text{lbf/lbm}$ AT (2)

PROBLEMS IN SECTION 2.12 ARE INTENDED TO GIVE A BETTER UNDERSTANDING OF EFFICIENCY.

2.40 EFFICIENCY, $\eta = \dfrac{\text{OUTPUT}}{\text{INPUT}} = 0.92$

THE INPUT IS $140{,}000 \dfrac{\text{BTU}}{\text{GAL}} \times 100 \text{ GAL}$

$= 14{,}000{,}000 \text{ BTU}.$

THE EXPECTED OUTPUT IS

$\text{OUTPUT} = (0.92)(14{,}000{,}000 \text{ BTU})$

$= 12{,}880{,}000 \text{ BTU}.$

2.41 $\eta = \dfrac{\text{OUTPUT}}{\text{INPUT}} = 0.08$ AND OUTPUT = 2.5 kW

SO THAT $\text{INPUT} = \dfrac{2.5 \text{ kW}}{0.08} = 31.25 \text{ kW}$

ALSO

$\text{INPUT} = (1000 \text{ W/m}^2)(\text{AREA OF PANEL})$

AND

$\text{AREA OF PANEL} = \dfrac{31.25 \text{ kW}}{1000 \text{ W/m}^2} = 31.25 \text{ m}^2$

2.42 $\eta = \frac{\text{OUTPUT}}{\text{INPUT}} = 0.70$

THE INPUT IS THE POTENTIAL ENERGY OF THE WATER: 60 lbf·ft/lbm AND THE RATE IS 60 × 1,000,000 ft·lbf/min

$= 60{,}000{,}000$ ft-lbf/min

$= 1{,}000{,}000$ ft·lbf/s $= 1818.18\ldots$ hp

$= 1356.36\ldots$ kW

THE OUTPUT IS THEN

OUTPUT $= (0.70)(1356.36 \text{ kW})$

$= 949.45 \text{ kW}$

2.43 EFFICIENCY, $\eta = \frac{\text{OUTPUT}}{\text{INPUT}}$

OUTPUT $= 200$ MW $= 200{,}000$ kW

INPUT $= 30{,}000 \frac{\text{kJ}}{\text{kg}} \times 1.6 \times 10^6 \frac{\text{kg}}{\text{day}}$

$= 48 \times 10^9$ kJ/day $= 2 \times 10^9$ kJ/hr

$= 555{,}555\ldots$ kW

SO $\eta = \frac{200{,}000 \text{ kW}}{555{,}555 \text{ kW}} = 36\%$ (.36)

2.44 EFFICIENCY $= \frac{\text{OUTPUT}}{\text{INPUT}} = \eta$

OUTPUT $= 5$ kW

INPUT $= 180{,}000 \frac{\text{BTU}}{\text{GAL}} \times 0.4 \frac{\text{GAL}}{\text{hr}}$

$$\text{INPUT} = 72{,}000 \ \frac{\text{BTU}}{\text{hr}} = 20 \ \frac{\text{BTU}}{\text{s}}$$

$$= 21.1 \text{ kW}$$

SO THAT

$$\eta = \frac{5 \text{ kW}}{21.1 \text{ kW}} = \underline{23.7\ \%}$$

2.45 $$\text{EFFICIENCY} = \frac{\text{OUTPUT}}{\text{INPUT}} = \eta$$

$$\text{INPUT} = 3800 \text{ J}$$

$$\text{OUTPUT} = 3600 \text{ W}\cdot\text{s} = 3600 \text{ J}$$

So

$$\eta = \frac{3600 \text{ J}}{3800 \text{ J}} = \underline{94.7\%}$$

2.46 FOR 100 WIND GENERATORS PRODUCING 250 kW EACH,

$$\text{TOTAL POWER} = 100 \times 250 \text{ kW}$$

$$= 25 \text{ MW}$$

FOR 38% EFFICIENCY

$$\eta = \frac{\text{OUTPUT}}{\text{WIND POWER}} = 0.38$$

AND

$$\text{WIND POWER} = \frac{25 \text{ MW}}{0.38}$$

$$\underline{= 65.789 \text{ MW}}$$

PROBLEMS OF SECTION 2.13 ARE INTENDED TO PROVIDE ADDITIONAL PRACTICE IN HANDLING UNITS.

2.47 FROM THE DEFINING EQUATION FOR THE REYNOLDS NUMBER

$$\mu = \frac{\rho \bar{V} D}{Re}$$

AND Re IS UNITLESS, ρ IS DENSITY, $\bar{V}$ IS VELOCITY, AND D IS A DIAMETER OR LENGTH. IN SI:

$$\mu = \left(\frac{kg}{m^3}\right)\left(\frac{m}{s}\right)(m) = \underline{kg/m \cdot s}$$

IN ENGLISH UNITS

$$\mu = \left(\frac{lbm}{ft^3}\right)\left(\frac{ft}{s}\right)(ft) = \underline{lbm/ft \cdot s}$$

2.48 (a.) UNITS FOR χ ARE $\underline{\frac{kJ}{kg \cdot s}}$ OR $\underline{\frac{BTU}{lbm \cdot s}}$.

(b.) χ UNITS ARE $\frac{kJ}{kg \cdot K}$ OR $\frac{kJ}{kg \cdot °C}$ IN SI

$\frac{BTU}{lbm °R}$ OR $\frac{BTU}{lbm °F}$ IN ENGL.

(c.) χ UNITS ARE $\underline{kJ}$ OR $\underline{BTU}$.

(d.) χ UNITS ARE $\underline{kJ \cdot kg/m^6}$ OR $\underline{\frac{BTU \cdot lbm}{ft^6}}$

(e.) χ UNITS ARE $\underline{\frac{kJ}{kg \cdot K}}$ OR $\underline{\frac{BTU}{lbm \cdot {}^\circ R}}$

2.49 IN SI, THE LEFT SIDE HAS UNITS OF kg/m^4. THE RIGHT SIDE:

$$\frac{(kg/m^3)(m^2/s^2)}{(m)(kg \cdot m/s^2 \cdot N)}\left[\frac{kg/m \cdot s}{(m)(m/s)(N/m^2)}\right] = kg/m^4$$

SO THE UNITS ARE THE SAME. IN ENGLISH UNITS THE LEFT SIDE HAS UNITS OF lbm/ft^4. THE RIGHT SIDE:

$$\frac{(lbm/ft^3)(ft^2/s^2)}{(ft)(lbm \cdot ft/lbf \cdot s^2)}\left[\frac{lbm/ft \cdot s}{(ft)(ft/s)(lbf/ft^2)}\right] = lbm/ft^4$$

WHICH GIVES THE SAME UNITS AS THE LEFT SIDE.

2.50 (a.) UNITS OF $C = \left(\frac{N}{m^2}\right)\left(\frac{m^3}{kg}\right)^{1.7} = \frac{N \cdot m^{3.1}}{kg^{1.7}}$ (SI)

$$= \left(\frac{lbf}{ft^2}\right)\left(\frac{ft^3}{lbm}\right)^{1.7} = \frac{lbf \cdot ft^{3.1}}{lbm^{1.7}} \quad \text{(ENGLISH)}$$

2.50 (CONT.)

(b.) $$\left(\frac{N}{m^2}\right)\left(\frac{m^3}{kg}\right)^{1.3} = \frac{N\cdot m^{1.9}}{kg^{1.3}} \quad \text{(SI)}$$

$$\left(\frac{lbf}{ft^2}\right)\left(\frac{ft^3}{lbm}\right)^{1.3} = \frac{lbf\cdot ft^{1.9}}{lbm^{1.3}} \quad \text{(ENGLISH)}$$

(c.) $$\left(\frac{N}{m^2}\right)\left(\frac{m^3}{kg}\right)\Big/\left(\frac{m^3}{kg}\right)^{2.3} = \frac{N\cdot kg^{1.3}}{m^{5.9}} \quad \text{(SI)}$$

$$\left(\frac{lbf}{ft^2}\right)\left(\frac{ft^3}{lbm}\right)\Big/\left(\frac{ft^3}{lbm}\right)^{2.3} = \frac{lbf\cdot lbm^{1.3}}{ft^{5.9}} \quad \text{(ENGL.)}$$

(d.) N/m^2 (Pa) OR lbf/ft^2

OR lbf/in^2 (psi)

(e.) K OR °R

Chapter 3 Discussion Questions

Section 3-1

3.1 *Work* is energy crossing a system boundary due to a force acting through a distance.

3.2 A volume change is due to a boundary moving and this is due to a force or pressure, thus we call this *boundary work*.

Section 3-2

3.3 Power is the time rate of doing work.

3.4 A kilowatt hour can describe power summed or integrated over a time period and this is work.

Section 3-3

3.5 *Heat* is energy crossing the boundary of a system due to a temperature difference and not a force acting through a distance.

3.6 The *calorie* is an amount of energy that could raise the temperature of one (1) gram of water by one (1) degree celsius.

3.7 *Heat Transfer* is the time rate of *heat*.

Section 3-4

3.8 Both friction and viscous effects are not reversible and thus work done against them is irreversible work.

Section 3-5

3.9 Heat and work have the same units of energy and both are energy in transition or crossing the system boundary.

2.50 (CONT.)

(b.) $$\left(\frac{N}{m^2}\right)\left(\frac{m^3}{kg}\right)^{1.3} = \frac{N\cdot m^{1.9}}{kg^{1.3}} \quad (SI)$$

$$\left(\frac{lbf}{ft^2}\right)\left(\frac{ft^3}{lbm}\right)^{1.3} = \frac{lbf\cdot ft^{1.9}}{lbm^{1.3}} \quad (ENGLISH)$$

(c.) $$\left(\frac{N}{m^2}\right)\left(\frac{m^3}{kg}\right) \Big/ \left(\frac{m^3}{kg}\right)^{2.3} = \frac{N\cdot kg^{1.3}}{m^{5.9}} \quad (SI)$$

$$\left(\frac{lbf}{ft^2}\right)\left(\frac{ft^3}{lbm}\right) \Big/ \left(\frac{ft^3}{lbm}\right)^{2.3} = \frac{lbf\cdot lbm^{1.3}}{ft^{5.9}} \quad (ENGL.)$$

(d.) N/m^2 (Pa) OR lbf/ft^2

OR lbf/in^2 (psi)

(e.) K OR °R

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Section 3-6

3.10 The three types of systems are *isolated, closed*, and *open*.

Section 3-7

3.11 Work and heat cannot be stored in a system or stored in the surroundings. Thus, being transitional phenomena, they are not properties of a system.

CHAPTER 3

THE PROBLEMS IN SECTION 3.1 PROVIDE PRACTICE IN DETERMINING WORK INVOLVING LINEAR AND ROTATING MOTION, SPRINGS, PISTON-CYLINDERS, AND OTHERS.

3.1 WORK = FORCE × DISTANCE, SINCE THE FORCE IS CONSTANT. THEN

$$\text{WORK} = (20\ \text{N})(20\ \text{m}) = 400\ \text{N-m}$$
$$= \underline{400\ \text{J}}$$

3.2

$$\text{WORK} = W \times \Delta z = mg(\Delta z)$$
$$= (30\ \text{kg})(9.8\ \text{m/s}^2)(20\ \text{m})$$
$$= \underline{5880\ \text{J}}$$

3.3

$$\text{WORK} = W \times \Delta z = \frac{g}{g_c} m \Delta z$$
$$= \left(\frac{31.8\ \text{ft/s}^2}{32.17\ \text{ft}\cdot\text{lbm}/\text{lb}_f\cdot\text{s}^2}\right)(30\ \text{lbm})(3\ \text{ft})$$
$$= \underline{88.96\ \text{ft-lb}_f}$$

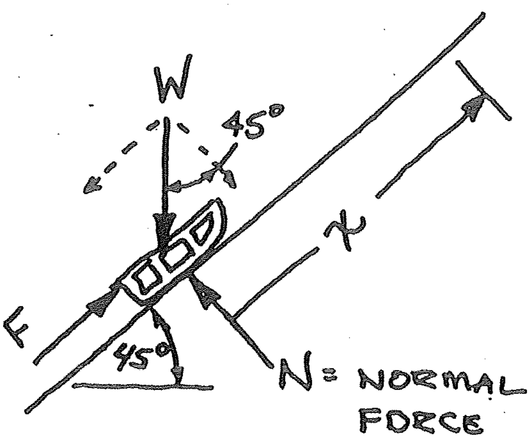
3.4 THE WORK DONE TO PUSH A SLED UP AN INCLINE OF 45° AND WHICH IS FRICTIONLESS IS F_x SHOWN IN THE FREE

BODY DIAGRAM.

$F = W \sin 45°$
$= (80\,lbf)(.707)$
$= 56.56\ lbf$

SO THAT, THE WORK IS

$WK = Fx$
$= (56.56\ lbf)(70\,ft)$
$= 3959.2\ ft\text{-}lbf$



FREE-BODY DIAGRAM

3.5 FOR A LINEAR SPRING $F = bx$
WHERE $b = 100\ lb_f/in$ AND $x = \frac{3}{8}$ in.
THEN

$$F = 100 \times \frac{3}{8} = 37.5\ lb_f.$$

THE WORK DONE TO COMPRESS THE SPRING FROM ITS FREE LENGTH IS

$$WK = \frac{1}{2} bx^2$$
$$= \frac{1}{2}\left(100\ \frac{lb_f}{in}\right)\left(\frac{3}{8} in\right)^2 = 7.03..\ in\text{-}lb_f$$

3.6 ASSUMING THE DEFLECTION OF THE SPRING WAS FROM ITS FREE LENGTH

$$WK = \frac{1}{2} bx^2 = 1.8\ J$$

AND SINCE $b = 180\,N/cm$,

$$x = \sqrt{\frac{2\,Wk}{b}} = \sqrt{\frac{2 \times 1.8\,N\cdot m \times 100\,cm/m}{180\,N/cm}}$$

$$\underline{x = 1.414\ldots\ cm}$$

3.7 $Wk = \frac{1}{2} b (x_2^2 - x_1^2)$ WHERE

$b = 140\,lbf/in$, $x_1 = 1\,in$, AND $x_2 = 2\,in$

THEN

$$Wk = \frac{1}{2}\left(140\,\frac{lbf}{in}\right)\left(2^2_{in} - 1^2_{in}\right)$$

$$\underline{= 210\ in\text{-}lbf}$$

3.8 FORCE AT PRE-TENSION $= bx_1$

$$= (6.4\,kN/m)(2\,cm)(1/100\,cm/m)$$

$$= 0.128\,kN = \underline{128\,N}$$

FORCE AFTER EXTENSION TO 8 cm MORE

$$= (6.4\,kN/m)(10\,cm)(1/100\,cm/m)$$

$$= 0.64\,kN = \underline{640\,N}$$

$$Wk = \frac{1}{2} b (x_2^2 - x_1^2) = \frac{1}{2}(6.4)(100 - 4)\left(\frac{1}{10^4}\right)$$

$$= .03072\,kJ = \underline{30.72\,J}$$

3.9 (a.) $Wk = Fx$ WHERE
$F = ma/g_c$ $a = \Delta V/\Delta t$. IF a IS CONSTANT, AND $x = \frac{1}{2}at^2$.

$$a = \frac{60\,mph}{10\,s} \times \frac{1.47\,ft/s}{mph} = 8.82\,ft/s^2$$

$$x = \frac{1}{2}\left(8.82\,\frac{ft}{s^2}\right)(10s)^2 = 441\,ft$$

$$F = (3000\,lbm)(8.82\,ft/s^2)/(32.17\,ft\text{-}lbm/lb_f \cdot s^2)$$

$$= 822.5\ldots\,lbf$$

THEN

$$Wk = (822.5\,lbf)(441\,ft) = \underline{362{,}722\,ft\text{-}lbf}$$

(b.) IF $t = 15\,s$, INSTEAD OF $10\,s$.

$$a = \frac{60}{15} \times 1.47 = 5.88\,ft/s^2$$

$$x = \frac{1}{2}(5.88)(15)^2 = 661.5\,ft$$

$$F = (3000\,lbm)(5.88\,ft/s^2)/(32.17)$$

$$= 548.3\ldots\,lbf$$

AND

$$Wk = (548.3\,lbf)(661.5\,ft)$$

$$\underline{Wk = 362{,}700\,ft\text{-}lbf}$$ (SAME AS (a.))

3.10 ZERO WORK SINCE NO VOLUME CHANGE OCCURS.

3.11 ZERO WORK SINCE NO VOLUME CHANGE OCCURS, BOUNDARY WORK THAT IS. THERE WILL BE WORK DONE TO STRETCH THE ROD.

3.12 WORK FROM (1) TO (3) IS ZERO AND WORK FROM (3) TO (4) IS AREA UNDER CURVE (3-4). THUS:

$$Wk = (6\ kPa)(0.15\,m^3 - 0.05\,m^3)$$
$$= \underline{0.6\ kJ}$$

3.13 WK FROM (2) TO (4) IS ZERO AND WK FROM (1) TO (2) IS AREA UNDER CURVE (1-2). THUS:

$$Wk = (14\ kPa)(0.15\,m^3 - 0.05\,m^3)$$
$$= \underline{1.4\ kJ}$$

3.14 THE WORK DONE BY THE PISTON WILL BE THE SAME AS THE BOUNDARY WORK; $WK = \sum p\delta V$, AND SINCE THE

PRESSURE IS CONSTANT, TH. WORK IS $Wk = p\Delta V$. THE VOLUME CHANGE IS

$$\Delta V = \pi (\text{DIAMETER})^2 \left(\tfrac{1}{4}\right)(\text{STROKE})$$

$$= \pi (.08\,m)^2 \left(\tfrac{1}{4}\right)(0.20\,cm) = .001\ m^3$$

THEN

$$Wk = (14000\ kPa)(.001\ m^3)$$

$$= 14.0\ kJ$$

3.15 $Wk = p\Delta V$ SINCE PRESSURE IS A CONSTANT. THEN, WORK OF ATMOSPHERE IS, $Wk = (100\ kPa)(+3\ m^3)$

$$= 300\ kJ$$

3.16 THE WORK DONE ON THE ATMOSPHERE IS DONE AT CONSTANT PRESSURE (ATMOSPHERIC PRESSURE) AND SO

$$Wk = p\Delta V = p(V_2 - V_1)$$

FROM EXAMPLE 3-5 $V_2 = 696.9\ ft^3$ AND $V_1 = 523.6\ ft^3$. THEN

$$Wk = \left(14.7\ \frac{lbf}{in^2}\right)(696.9\ ft^3 - 523.6\ ft^3)$$

$$= 2547.51\ lb_f \cdot ft^3/in^2.$$

CONVERTING UNITS AND REDUCING:

$$Wk = 2547.51 \times 144\ \frac{in^2}{ft^2} = 366{,}841.44\ ft\cdot lbf$$

3.17 WORK IS DONE ON THE ENGINE BY THE ATMOSPHERE. SINCE THE WORK IS DONE AT CONSTANT PRESSURE,

$$Wk = p\Delta V = \left(14.6\ \frac{lbf}{in^2}\right)\left(6\ in^3\right)$$

$$= \underline{87.6\ in\text{-}lbf}$$

3.18 SINCE THE WORK IS DONE AT CONSTANT TORQUE:

$$Wk = T\theta$$

$$\theta = 100\ rev \times 2\pi\ rad/rev = 628.3\ rad.$$

THEN

$$Wk = (75\ N\cdot m)(628.3\ rad) = \underline{47{,}122.5\ N\cdot m}$$

3.19 SINCE WORK IS DONE AT CONSTANT TORQUE:

$$Wk = T\theta$$

$$\theta = (25^\circ)\left(\frac{2\pi}{360}\ \frac{rad}{^\circ}\right) = 0.436\ rad.$$

$$Wk = (120\ ft\cdot lbf)(0.436\ rad.)$$

$$= \underline{52.32\ ft\text{-}lbf}$$

3.20 FOR A PROCESS WHERE $pV = C$ THEN $p_1 V_1 = p_2 V_2$ AND

$$V_2 = V_1\,(p_1/p_2)$$

3.20 OR (CONT.)

$V_2 = (0.5\,m^3)(200\,kPa / 1600\,kPa)$

$= .0625\,m^3$

FOR BOUNDARY WORK, $\Sigma p\delta V$, WHEN $pV = C$, THE RESULT IS

$Wk = C \ln V_2/V_1 = p_1V_1 \ln V_2/V_1$

OR,

$= p_2V_2 \ln V_2/V_1$

THEN

$Wk = (1600\,kPa)(.0625\,m^3) \ln\left(\frac{.0625\,m^3}{0.5\,m^3}\right)$

$= -207.9\ldots\,kJ$

NEGATIVE SIGN INDICATES WORK IS DONE ON THE SYSTEM.

ALTERNATELY:

USING CALCULUS:

$$Wk = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} C\,\frac{dV}{V} = C\int_{V_1}^{V_2} \frac{dV}{V}$$

$= C \ln V_2/V_1$

$= p_1V_1 \ln V_2/V_1 = -207.9\ldots\,kJ$

3.21 FOR THE PROCESS WHERE $pV = C$, WE HAVE $p_1 V_1 = p_2 V_2$

$$p_2 = p_1 V_1 / V_2 = (500\,\text{psia})\left(\frac{1.4\,\text{in}^3}{15\,\text{in}^3}\right)$$

$$= 46.67\ldots\,\text{psia}$$

THE BOUNDARY WORK, FOR $pV = C$, IS

$$Wk = C \ln V_2/V_1 = C \ln p_1/p_2$$

WHERE $C = p_1 V_1 = p_2 V_2$.

THEN

$$Wk = (500\,\text{psia})(1.4\,\text{in}^3) \ln\left(\frac{500\,\text{psia}}{46.67\,\text{psia}}\right)$$

$$= 1660.05\ldots\,\text{in-lbf}$$

ALTERNATIVELY, USING CALCULUS:

$$Wk = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} C\frac{dV}{V} = C\int_{V_1}^{V_2} \frac{dV}{V}$$

$$= C \ln V_2/V_1 = p_1 V_1 \ln V_2/V_1$$

$$Wk = 1660.1\ldots\,\text{in}\cdot\text{lbf}$$

3.22 FOR THE POLYTROPIC PROCESS

$$p_1 V_1^n = p_2 V_2^n = C$$

$$p_2 = p_1 (V_1/V_2)^n$$

$$P_2 = (6\,MPa)\left(\frac{.02\,m^3}{1.0\,m^3}\right)^{1.35} = \underline{\underline{.0305\,MPa}}$$

FOR THE BOUNDARY WORK OF A POLYTROPIC PROCESS, EQN (3-17)

$$Wk = \frac{1}{1-n}(P_2V_2 - P_1V_1)$$

$$= \frac{1}{1-1.35}(30.5\,kPa \times 1.0\,m^3 - 6000\,kPa \times .02\,m^3)$$

$$\underline{\underline{= 255.7\cdots kJ}}$$

ALTERNATIVELY, USING CALCULUS:

$$Wk = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} \frac{C}{V^n}\,dV = C\int_{V_1}^{V_2} V^{-n}\,dV$$

$$= C\left(\frac{1}{1-n}\right)\left(V_2^{\,1-n} - V_1^{\,1-n}\right)$$

$$= \frac{1}{1-n}(P_2V_2 - P_1V_1)$$

$$\underline{\underline{Wk = 255.7\cdots kJ}}$$

3.23 FOR THE POLYTROPIC PROCESS $P_1V_1^{\,n} = P_2V_2^{\,n}$, SOLVING FOR n:

$$\left(\frac{V_1}{V_2}\right) = \frac{P_2}{P_1} \text{ AND } n \log\frac{V_1}{V_2} = \log\frac{P_2}{P_1}$$

$$n = \left[\log\frac{P_2}{P_1}\right] \Big/ \left[\log\frac{V_1}{V_2}\right]$$

$$= \left[\log\frac{120}{14.6}\right] \Big/ \left[\log\frac{0.330}{0.057}\right] = \underline{1.199..}$$

THE BOUNDARY WORK IS GIVEN BY EQUATION (3-12):

$$Wk = \frac{1}{1-n}\left(P_2 V_2 - P_1 V_1\right)$$

$$= \frac{1}{-0.199}\left(120\ \text{lbf/in}^2 \times .057\ \text{ft}^3/\text{lbm} \times 144\ \frac{\text{in}^2}{\text{ft}^2}\right.$$

$$\left. - 14.6 \times .330 \times 144\right)$$

$$\underline{= -1463\ \text{ft-lbf/lbm}}$$

NEGATIVE WORK MEANS THAT THE WORK IS INTO THE SYSTEM.

3.24 THE SIMPLEST, YET SUFFICIENT, APPROXIMATION OF THE WORK IS THE AREA UNDER CURVE 1-2 USING A TRAPEZOID AND A RECTANGLE:

THE TRAPEZOID IS

$$A = \frac{1}{2}\ \text{base} \times (\text{sum of two sides})$$

$$= \frac{1}{2}\left(4.75 - 2\ \text{cm}^3\right)\left(300 + 133\ \text{kPa}\right)$$

$= 595.375 \text{ kPa}\cdot\text{cm}^3 = .595375 \text{ J}$

THE RECTANGLE IS

$A = \text{base} \times \text{height} = (300 \text{kPa})(12 - 4.75 \text{cm}^3)$

$= 2175 \text{ kPa}\cdot\text{cm}^3 = 2.175 \text{ J}$

THUS

$Wk = 2.770375 \text{ J}$

3.25 THE WORK OF THE PROCESS 1-2 CAN BE APPROXIMATED AS THE AREA UNDER THE CURVE. THIS AREA CAN BE ESTIMATED BY ADDING SMALL TRAPEZOIDAL AREAS, OR BY USING PROGRAM AREA WITH A PC COMPUTER. AS A FIRST APPROXIMATION, SELECTING THE FOLLOWING POINTS:

P (psi)	V (ft³)	δV	P_ave δV (psi·ft³)
48.0	0.1		
		0.1	4.70
46.0	0.2		
		0.1	3.85
31.0	0.3		
		0.1	2.55
20.0	0.4		
		0.1	1.875
17.5	0.5		
			12.975

THUS, $Wk \approx 12.975 \frac{\text{lbf}}{\text{in}^2}\cdot\text{ft}^3$

AND, CONVERTING,

$$Wk \approx 12.975 \times 144 = \underline{1868.4 \text{ ft-lbf}}$$

BETTER ESTIMATES CAN BE MADE BY USING MORE POINTS

3.26 THE WORK OF PROCESS 1-2 MAY BE APPROXIMATED AS THE AREA UNDER THE FORCE-DISPLACEMENT DIAGRAM. THE ESTIMATION MAY BE MADE BY SELECTING SMALL TRAPEZOIDS AND ADDING THE TOTAL. AS ONE APPROXIMATION, SELECT x AND F VALUES AS FOLLOWS:

x (mm)	F (kN)	δx	$F\delta x$
10	1.0		
		2.5	7.1875
12.5	4.75		
		2.5	12.0625
15	4.90		
		5.0	22.0
20	3.90		
		10.0	32.5
30	2.60		
		10.0	21.75
40	1.75		
		10.0	14.25
50	1.10		
		10.0	9.25
60	0.75		

IF THE VALUES $x - F$ ARE ENTERED IN THE PROGRAM AREA USING A PERSONAL COMPUTER, THE AREA IS FOUND TO BE 102, IDENTICAL TO THAT OF THE SUM OF THE $F\delta x$ TERMS INDICATED ABOVE. THEN

$$Wk \approx 117 \text{ kN}\cdot\text{mm} = 0.117 \text{ kN-m}$$

$$= 0.117 \text{ kJ}$$

3.27 THE WORK INVOLVED IN THE PROCESS WHERE VOLUME CHANGED FROM V_1 TO V_2 AND PRESSURE ALSO CHANGED ACCORDING TO FIG. 3-15 CAN BE ESTIMATED AS THE AREA UNDER THE CURVE. AS ONE APPROXIMATION, USING THE FOLLOWING DATA:

$V(in^3)$	$P(psia)$
5.0	20.0
7.5	38.0
10.0	44.0
15.0	48.0
20.0	55.0
25.0	77.5

THE AREA UNDER THE CURVE IS THEN ESTIMATED AS A SUM OF TRAPEZOID AREAS, AS IN THE SOLUTIONS TO 3.25 & 3.26 ABOVE. USING THE PROGRAM AREA AND A PERSONAL COMPUTER, OR BY USING $A = \sum p \delta V$, THE SOLUTION IS:

$$A = 993.75 \text{ in-lb}_f \quad \text{OR}$$

$$= 82.8125 \text{ ft-lb}_f$$

3.28 THE WORK DONE IN ROTATING A TURNTABLE HAVING A VARYING TORQUE WITH ANGULAR DISPLACEMENT MAY BY ESTIMATED AS THE AREA UNDER THE CURVE; i.e.

$$Wk \cong \sum T \delta \theta$$

AND, AS A SUGGESTED SET OF DATA POINTS FROM FIG. 3-16:

T (N·m)	θ (degrees)
35	0
58	120

64	165
62	195
53	240
40	300
37.5	330
37.5	360

USING TRAPEZOIDAL AREA SUMS OR COMPUTER PROGRAM AREA WITH A PERSONAL COMPUTER,

$Wk \approx 17,880$ N·m·degrees

$= 312.06..$ N·m

3.29 THE WORK DONE IN ROTATING A SYSTEM THROUGH 120° WITH A VARYING TORQUE GIVEN IN FIG. 3-17 CAN BE APPROXIMATED BY THE AREA UNDER THE CURVE, USING $Wk = \Sigma T\delta\theta$ AND THE FOLLOWING SUGGESTED DATA :

T (ft-lbf)	θ (degrees)	δθ	Tδθ
0	0		
		20	950
95	20		
100	25	5	487.5

80	50	25	2250
75	60	10	775
70	70	10	725
74	90	20	1440
82	120	30	2340

$$\Sigma T \delta\theta = 8967.5$$

THE RESULT IS OBTAINED BY THE METHOD OF SUM OF TRAPEZOID AREAS OR THE COMPUTER PROGRAM AREA WITH A PERSONAL COMPUTER:

$$Wk \approx 8967.5 \text{ ft}\cdot\text{lbf}\cdot\text{degrees}$$

$$= 156.5 \text{ ft}\cdot\text{lbf}$$

3.30 USING CALCULUS

$$Wk = \int_{x_1}^{x_2} F\,dx = \int_{x_1}^{x_2} bx^2\,dx = \frac{b}{3}\left(x_2^3 - x_1^3\right)$$

$$= \frac{1}{3}\left(50\,\frac{\text{lbf}}{\text{in}^2}\right)\left(1\,\text{in}^3 - 27\,\text{in}^3\right)$$

$$Wk = -433.3\ldots \text{ in}\cdot\text{lbf}$$

3.31 USING CALCULUS

$$Wk = \int_{V_1}^{V_2} p\,dV$$

HERE $p = \frac{(18.5\ kPa \cdot m^{4.5})}{V^{1.5}}$

SO

$$Wk = (18.5\,kPa \cdot m^{4.5}) \int_{V_1}^{V_2} \frac{dV}{V^{1.5}}$$

$$= \frac{(18.5\,kPa \cdot m^{4.5})}{(1-1.5)} \left(V_2^{-0.5} - V_1^{-0.5} \right)$$

$$= \frac{18.5\,kPa \cdot m^{4.5}}{-0.5} \left(\frac{1}{\sqrt{3m^3}} - \frac{1}{\sqrt{2m^3}} \right)$$

$$\underline{Wk = 4.80\ldots\ kPa \cdot m^3 = 4.80\ldots\ kJ}$$

3.32 USING CALCULUS

$$Wk = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} 3V^3 dV - \int_{V_1}^{V_2} 0.3V\,dV$$

$$= \frac{3\,bar/m^9}{4}\left(V_2^4 - V_1^4\right) - \frac{0.3\,bar/m^3}{2}\left(V_2^2 - V_1^2\right)$$

$$= \frac{3}{4}\left(1.6^4 - 2.6^4\right) - \frac{0.3}{2}\left(1.6^2 - 2.6^2\right)$$

$$\underline{Wk = -28.728\ bar \cdot m^3 = -2872.8\ kJ}$$

3.33 USING CALCULUS

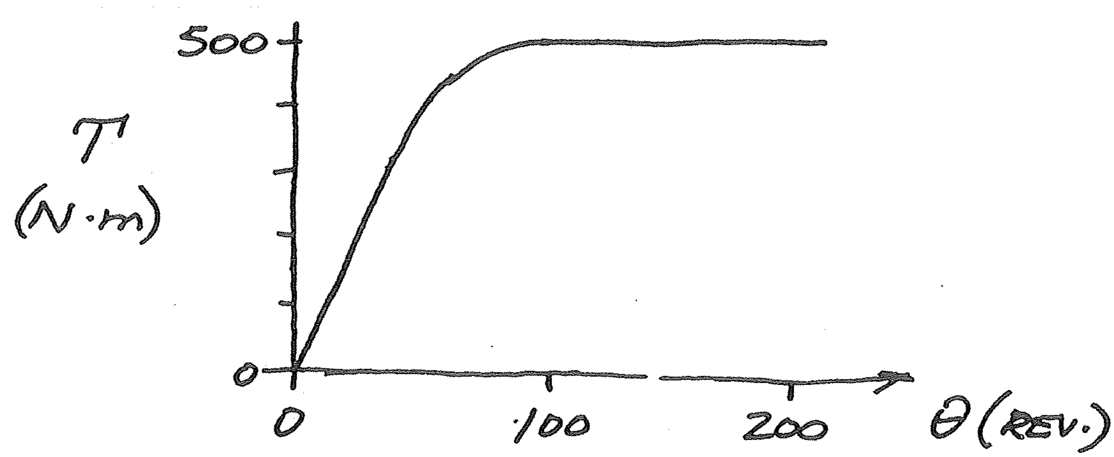
$$Wk = \int T\,d\theta$$

THE INTEGRATION NEEDS TO BE SEPARATED INTO TWO INTERVALS:

$T = 10\,\theta - 0.05\,\theta^2$ (J) $\quad \theta_1 = 0$ REV. TO $\theta_2 = 100$ REV.

$T = 500$ J $\quad \theta_2 = 100$ REV. TO $\theta_3 = 200$ REV.

GRAPHICALLY, WE DETERMINE THE AREA UNDER THE CURVE SHOWN:



$$Wk = \int_{\theta_1}^{\theta_2} T\,d\theta + \int_{\theta_2}^{\theta_3} T\,d\theta$$

$$= \int_{\theta_1}^{\theta_2} 10\,\theta\,d\theta - \int_{\theta_1}^{\theta_2} (0.05)\,\theta^2\,d\theta + \int_{\theta_2}^{\theta_3} 500\,d\theta$$

$$=\left(\frac{10}{2}\right)\left(\theta_2^2-\theta_1^2\right)-\left(\frac{0.05}{3}\right)\left(\theta_2^3-\theta_1^3\right)+500\left(\theta_3-\theta_2\right)$$

$$=\frac{10\ \text{J/REV}}{2}\left(100\ \text{REV}\right)^2-\frac{0.05\ \text{J/REV}^2}{3}\left(100\ \text{REV}\right)^3$$

$$+\left(500\ \text{J}\right)\left(200-100\ \text{REV}\right)$$

$$=83{,}333.3\cdots\ \text{J-REV.}$$

SINCE 2π RADIANS = 1 REV

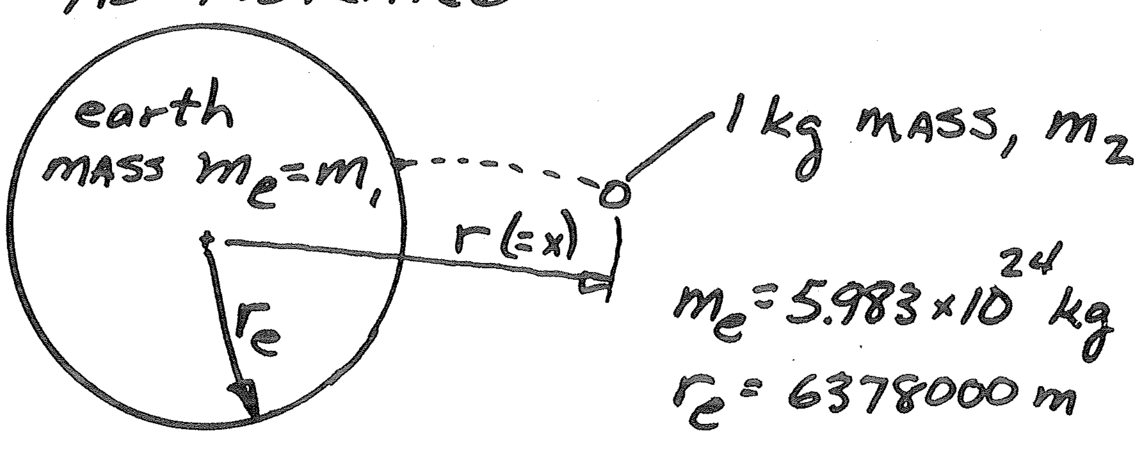
AND 1000 J. = 1 kJ

WE FIND

$$\underline{Wk = 523.6\cdots\ kJ}$$

3.34 $Wk = \int F\,dx$ IN THIS CASE,

FOR LAUNCHING 1 kg MASS, $dx = dr$ AS INDICATED



$m_e = 5.983 \times 10^{24}$ kg

$r_e = 6378000$ m

AND 3.34 (CONT.) $F = G_u \dfrac{m_e m_2}{r^2}$ SO THAT

$$Wk = \int_{r_e}^{\infty} F\,dx = G_u m_e m_2 \int_{r_e}^{\infty} \frac{dr}{r^2}$$

$$= G_u m_e m_2 \left[-\frac{1}{r}\right]_{r_e}^{\infty} = \frac{G_u m_e m_2}{r_e}$$

FROM CHAPTER 2:

$$G_u = 6.67 \times 10^{-11}\, m^3/kg.s^2$$

SO

$$Wk = \frac{(6.67 \times 10^{-11}\, m^3/kg.s^2)(5.983 \times 10^{24}\, kg)(1\, kg)}{(6.378 \times 10^{6}\, m)}$$

$\underline{Wk = 6.2569 \times 10^{7}\, J}$ FOR 1 kg MASS

99.5% OF THIS WORK IS DONE FROM EARTH'S SURFACE TO SOME DISTANCE r_o. THIS WORK

$$6.2569 \times 10^{7}\, J \times .995 = 6.2256 \times 10^{7}\, J$$

IS:

$$6.2256 \times 10^{7}\, J = G_u m_e m_2 \left[\frac{1}{r_e} - \frac{1}{r_o}\right]$$

SUBSTITUTING VALUES FOR G_u, m_e, m_2, AND r_e:

$$.1560046 \times 10^{-6} = \frac{1}{6.378 \times 10^{6}\ m} - \frac{1}{r_0}$$

GIVES

$$r_0 = 1.2749 \times 10^{6}\ km$$

NOW, SINCE $r_e = 6.378 \times 10^{6}\ m$

THE DISTANCE OUT FROM THE EARTH'S SURFACE IS

$$r_0 - r_e = 1.2685 \times 10^{6}\ km$$

THE PROBLEMS IN SECTION 3.2 WILL HELP THE STUDENT IN UNDERSTANDING HOW POWER IS THE RATE OF DOING WORK.

3.35 $\dot{W}k\ (\text{POWER}) = \frac{Wk}{\Delta t} = \frac{750\ \text{JOULES}}{7\ s}$

$$= 107.1\ W$$

3.36 $\dot{W}k = \dfrac{Wk}{\Delta t} = \dfrac{80{,}000 \text{ ft-lbf}}{2.3 \text{ s}}$

$= 34{,}782.6 \dfrac{\text{ft-lbf}}{\text{s}}$

USING THE CONVERSION $550 \dfrac{\text{ft-lbf}}{\text{s}} = 1 \text{ hp}$

$\therefore \dot{W}k = 63.24 \text{ hp}$

3.37 $Wk = \dot{W}k(\Delta t) = (380 \text{ W})(2 \times 3600 \text{ s})$

$= 2{,}736{,}000 \text{ J} = 2{,}736 \text{ kJ}$

3.38 $Wk = \dot{W}k(\Delta t) = \left(125 \times 550 \dfrac{\text{ft-lbf}}{\text{s}}\right)(30 \times 60 \text{ s})$

$= 123{,}750{,}000 \text{ ft-lbf}$

3.39 $\dot{W}k = F \cdot \bar{V}$ WHERE $\bar{V} = 20 \text{ m/s}$

$F = 628 \text{ N}$

THEN

$\dot{W}k = 12{,}560 \dfrac{\text{N}\cdot\text{m}}{\text{s}} = 12{,}560 \text{ W}$

3.40 $\dot{W}k$ = THRUST × VELOCITY

$= (7{,}000{,}000 \text{ lbf})(100 \text{ ft/s})$

$= 700{,}000{,}000 \dfrac{\text{ft-lbf}}{\text{s}} = 1{,}272{,}727 \text{ hp}$

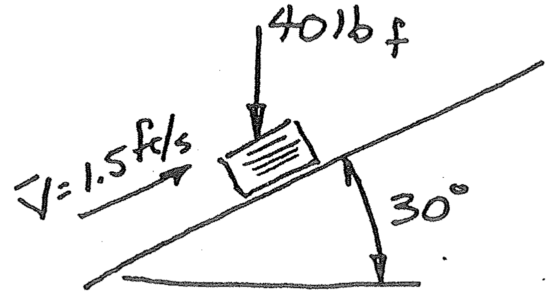
3.41 ASSUME ONE BOX IS ON THE CONVEYOR AT ANY ONE TIME SO THAT THE POWER REQUIRED IS

$$\dot{W}k = F \cdot \bar{V} \qquad \text{WHERE } \bar{V} = 1.5 \, m/s$$
$$F = 2N$$

THEN

$$\dot{W}k = 3 \, N \cdot m/s = \underline{3 \, W}$$

3.42 THE POWER REQUIRED TO MOVE 40 lbf HAY BALES UP A CONVEYOR AT 1.5 ft/s IS $\dot{W}k = F \cdot \bar{V}$



WHERE

$$F = (40 \, lb_f) \sin 30° = 20 \, lbf$$
$$\bar{V} = 1.5 \, ft/s$$

THUS,

$$\dot{W}k = 20 \times 1.5 = 30 \, ft\text{-}lbf/s$$
$$= \underline{0.0545.. \, hp}$$

3.43 FOR A ROTATING MACHINE

$$\dot{W}k = \frac{2\pi}{60} T \cdot N$$

WHERE $N = 1200$ rpm. THEN

$$T = \frac{60}{2\pi}\frac{\dot{W}k}{N} = \frac{60}{2\pi}\left(\frac{\tfrac{1}{2}\,hp \times 550\,\frac{ft\cdot lbf}{s\cdot hp}}{1200\,rpm}\right)$$

$$\underline{T = 2.188\ ft\text{-}lbf}$$

3.44 $\dot{W}k = \frac{2\pi}{60} T N$ WHERE

$T = 70\ N\cdot m$, $N = 600\ rpm$

THEN

$$\dot{W}k = \frac{2\pi}{60}(70\ N\cdot m \times 600\ rpm)$$

$$= 4398.2\ J = \underline{4.3982\ kJ}$$

3.45 $\dot{W}k = \frac{2\pi}{60} T N$ SO THAT

$$T\ (\text{TORQUE}) = \frac{60\,\dot{W}k}{2\pi N}$$

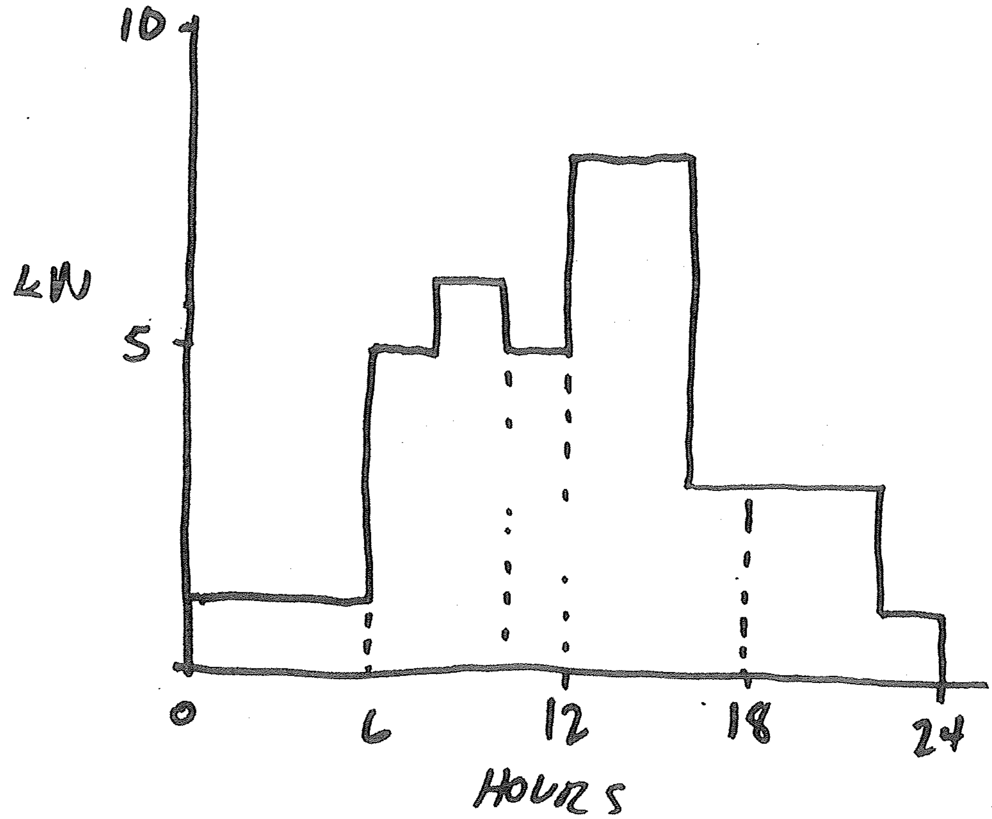
$$T = \frac{60\,(160\ kJ/s)}{2\pi\,(1800\ rpm)} = \underline{0.849\ kN\cdot m}$$

3.46 $\dot{W}k = \frac{2\pi}{60} T N$ SO THAT

$$T = \frac{60}{2\pi}\frac{\dot{W}k}{N} = \frac{60}{2\pi}\left(\frac{3.5\,hp \times 550\,\frac{ft\cdot lbf}{s\cdot hp}}{3200\,rpm}\right)$$

$$\underline{T = 5.744\ ft\cdot lbf}$$

3.47 THE DAILY ELECTRIC POWER IS:



THE TOTAL, DAILY ENERGY IS THE AREA UNDER THE GRAPH

$$E = \sum \dot{W}_k \, \delta t$$

USING RECTANGULAR AREAS:

$$E = (1\text{ kW})(6\text{ hr}) + (5\text{ kW})(2\text{ hr}) + (6\text{ kW})(2\text{ hr}) + (5)(2) + (8)(4) + (3\text{ kW})(6\text{ hr}) + (1)(2)$$

$$E = 90\text{ kW-hr}$$

3-48 $F = 15000 - 500V$

$$\dot{W}k = FV = 15000V - 500V^2$$

THE MAXIMUM POWER OCCURS WHEN

$$\frac{d\dot{W}k}{dV} = 0$$

DIFFERENTIATING:

$$\frac{d\dot{W}k}{dV} = \frac{d}{dV}(15000V - 500V^2)$$

$$= 15000 - 1000V = 0$$

THEN

$V = 15\,m/s$ AT MAXIMUM POWER. THE MAXIMUM POWER IS:

$$\dot{W}k = 15000(15) - 500(15)^2$$

$$= 112{,}500 \;\; W$$

3-49 $T = 5.15 - 2\times10^{-4}N^2$

$$\dot{W}k = TN = 5.15N - 2\times10^{-4}N^3$$

THE MAXIMUM POWER OCCURS WHEN

3.49 (CONT.) $\frac{d\dot{W}k}{dN} = 0$

DIFFERENTIATING:

$$\frac{d\dot{W}k}{dN} = \frac{d}{dN}\left(5.15N - 2\times10^{-4}N^3\right)$$

$$= 5.15 - 6\times10^{-4}N^2$$

AND

$$N^2 = 8583.3 \ldots\ldots$$

$$\underline{N = 92.646 \ldots \quad \text{RAD/s}}$$

THE MAXIMUM POWER IS:

$$\dot{W}k_{max} = 5.15(92.646\ldots) - 2\times10^{-4}(92.646\ldots)^2$$

$$= 318.086\ldots \ \text{ft}\cdot\text{lbf/s}$$

$$\underline{= 0.578\ldots \ \text{hp}}$$

THE PROBLEMS OF SECTION 3.3 ARE INTENDED TO GIVE A BETTER UNDERSTANDING OF HEAT, HEAT TRANSFER (OR RATE OF HEAT PER UNIT TIME), AND HOW THESE TWO CONCEPTS ARE RELATED.

3.50 HEAT, $Q = \dot{Q}\Delta t$ IF $\dot{Q}$ IS A CONSTANT RATE. THEN

$$Q = \left(80\ \frac{BTU}{s}\right)(\Delta t) = 7000\ BTU$$

SO THAT

$$\Delta t\ (\text{time}) = \frac{7000\ BTU}{80\ BTU/s} = \underline{87.5\ s}$$

3.51 HEAT LOSS, $Q = \dot{Q}\Delta t$ IF $\dot{Q}$ IS A CONSTANT RATE OF HEAT LOSS. THEN

$$Q = \left(1.2\ \frac{J}{s}\right)\left(24\ hr \times 3600\ \frac{s}{hr}\right)$$

$$Q = 103{,}680\ J = \underline{103.68\ kJ}$$

3.52 HEAT TRANSFER $\dot{Q} = \frac{\delta Q}{\delta t}$ AND IF $\dot{Q}$ IS CONSTANT $\dot{Q} = Q/\Delta t$. THEN

$$\Delta t = Q/\dot{Q} = \frac{20{,}000\ BTU}{670\ BTU/s} = 29.85\ s$$

3.53 $Q = \dot{Q}\Delta t$ WHEN $\dot{Q}$ IS CONSTANT.

THEN

$$Q = (700\ W/m^2)(1\ m^2)(1\ hr \times 3600\ s/hr)$$

$$= 2{,}520{,}000\ J = \underline{2{,}520\ kJ}$$

3-54 HEAT GAIN $= 200{,}000\ \frac{BTU}{hr} \times 12\ hr$

$$= 2{,}400{,}000\ BTU$$

HEAT LOSS $= 20{,}000\ \frac{BTU}{hr} \times 12\ hr$

$$= 240{,}000\ BTU$$

<u>NET HEAT GAIN = 2,160,000 BTU</u>

AVERAGE HEAT GAIN RATE, $\dot{Q}_{GAIN}$ IS

$$\dot{Q}_{GAIN} = \frac{2{,}160{,}000\ BTU}{24\ HR.}$$

$$= \underline{90{,}000\ \frac{BTU}{hr}}$$

THE PROBLEMS IN SECTION 3.4 ARE INTENDED TO GIVE AN APPRECIATION OF IRREVERSIBLE WORK AND HOW TO CALCULATE IT.

3.55 THE TORQUE OF 1.6 N·m IS DONE TO OVERCOME FRICTION AND IT REPRESENTS IRREVERSIBLE TORQUE. THE WORK IS

$$Wk = T\Theta = (1.6\ N\cdot m)\left(360^\circ \times \frac{2\pi}{360}\right)$$

$$= 10.05\ N\cdot m = \underline{10.05\ J}$$

3.56 IRREVERSIBLE POWER $= \frac{2\pi}{60} TN$

$$= \frac{2\pi}{60}(7\ in\text{-}oz)(800\ rpm)$$

$$= 586.43\ in\text{-}oz/s$$

SINCE 16 oz = 1 lbf, WE HAVE

$$\dot{W}k_{irr} = \frac{586.43}{16} = 36.65\ in\text{-}lbf/s$$

$$= \underline{3.054\ ft\text{-}lbf/s} = \underline{.00555\ hp}$$

3.57 THE TORQUE OF 30 N-m NEEDED TO DRIVE THE BLENDER IS ALL IRREVERSIBLE. THUS, THE POWER IS

$$\dot{W}k_{irr} = \frac{2\pi}{60} TN = \frac{2\pi}{60}(30\ N\cdot m)(720\ rpm)$$

$$= 2261.9\ N\cdot m/s$$

$$= \underline{2261.9\ W}$$

3.58 IF SLIPPAGE REQUIRES 2% OF THE POWER, THEN

$$\text{SLIPPAGE POWER} = (.02)(32\ hp)$$

$$\dot{W}k_{SP} = 0.64\ hp = 352\ \frac{ft \cdot lbf}{s}$$

AND

$$\dot{W}k_{SP} = (F_{SP})(\bar{V}) = 352\ \frac{ft\text{-}lbf}{s}$$

WHERE $\bar{V} = 55\ mph = 80.7\ ft/s$

$$\therefore \quad F_{SP} = (\text{SLIPPAGE FORCE}) = \frac{352\ ft\text{-}lbf/s}{80.7\ ft/s}$$

$$= \underline{4.36\ lbf}$$

3.59 $\dot{W}k_{irr} = F \cdot \bar{V} = (100\ lbf)(4.4\ ft/s)$

$$= 440\ ft\text{-}lbf/s$$

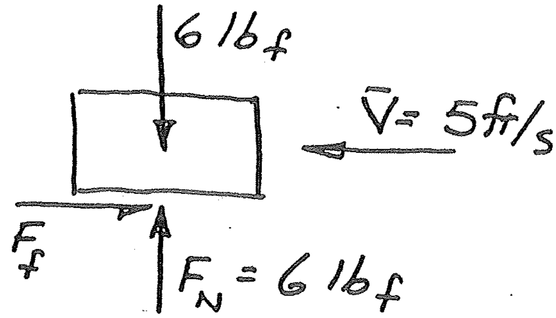
$$= \underline{0.8\ hp}$$

3.60 $\dot{W}k_{irr} = F \times \bar{V} = (30\ kN)(7\ m/s)$

$$= 210\ kJ/s = \underline{210\ kW}$$

3.61 $\dot{W}k_{irr} = F_f \bar{V}$

WHERE



$$F_f = 0.3\ F_N$$

$$= 1.8\ lb_f$$

SO THAT $\dot{W}k_{irr} = (1.8\ lb_f)(5\ ft/s)$

$= \underline{9\ ft\text{-}lbf/s}$

3.62 IRREVERSIBLE POWER DUE TO DYNAMIC FRICTION IS $(10\ kW)(.002) = 20\ W$

THEN

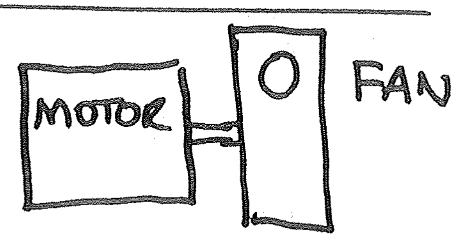
$$\dot{W}k_{irr} = \frac{2\pi}{60} T_{irr} N = 20\ W$$

SO THAT

$$T_{irr} = \left(\frac{20\ N\cdot m/s}{1200\ rpm}\right)\left(\frac{60}{2\pi}\right)$$

$$= \underline{0.159\ N\cdot m}$$

3.63



$\dot{W}k_{motor} = 150\ hp$

$$\eta_{fan} = 85\% = \frac{\dot{W}k_{fan,rev}}{\dot{W}k_{input}}$$

$\dot{W}k_{input} = \dot{W}k_{motor} = 150\ hp$

SO $\dot{W}k_{fan,rev} = 150\ hp \times .85 = \underline{127.5\ hp}$

$\dot{W}k_{fan,irrev} = \underline{22.5\ hp}$

3.64 THE BILLIARD BALL IS GIVEN KINETIC ENERGY AND THIS ENERGY IS DISSIPATED AS IRREVERSIBLE WORK AGAINST ROLLING RESISTANCE.

$$\frac{1}{2} m \bar{V}^2 = F_f \cdot x$$

OR

$$\frac{1}{2} \frac{W}{g} \bar{V}^2 = F_f \cdot x$$

THEN

$$\frac{1}{2}\left(\frac{4N}{9.81\,m/s^2}\right)\left(0.4\,\frac{m}{s}\right)^2 = \left(F_f\right)\left(20m\right)$$

SOLVING FOR

ROLLING RESISTANCE, $F_f = 1.63\,mN$

PROBLEM 3.65 GIVES SOME PRACTICE IN CONVERTING ENERGY, WORK, POWER, AND HEAT UNITS.

3.65 (a.) 17 BTU/lbm = 13,226 ft-lbf/lbm
(b.) 3350 ft-lbf = 4.3.. BTU
(c.) 2×10^6 in-oz = 13.389.. BTU
(d.) 27.8 kJ = 27,800 N·m (J)
(e.) 3000 MW = 3×10^9 J/s

Chapter 4 Discussion Questions

Section 4-1

4.1 *Mass flow rate* is the time rate at which mass flows past a stationary plane, or boundary of an open system.

4.2 *Volume flow rate* is the time rate at which a volume of fluid flows past a stationary plane or boundary of an open system..

Section 4-2

4.3 *Steady flow* means that the flow rate is constant in time.

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Section 4-2

4.3 *Steady flow* means that the flow rate is constant in time.

Section 4-3

4.4 *Uniform flow* means that the properties of a flowing fluid are same throughout, including in the system from which or to which they are flowing.

4.5 The *filling process* is a process where fluid only flows into a system.

4.6 The *emptying process* is a process where fluid only flows out of a system.

Section 4-4

4.7 By convention, in engineering and technology work obtained from a system is described as positive work. Thus, work into a system needs to be negative.

Section 4-5

4.8 The *first law of thermodynamics* is usually considered to be the conservation of energy. Sometimes the law is interpreted to mean that energy is a property of a system.

Section 4-6

4.9 An *isolated system* is a system that cannot loss or gain either mass or energy.

4.10 *Adiabatic* means no heat or heat transfer can occur.

Section 4-7

4.11 *Flow energy* is the energy used to account for fluid flow across a system boundary. It can be calculated by the product of pressure times volume or for specific flow energy, by the product of pressure times specific volume.

4.12 *Enthalpy* is internal energy plus flow energy, or U + pV.

Section 4-8

4.13 An *open system* is one that allows for mass and energy to cross the boundary.

4.14 *Shaft work* is work transmitted through a rotating shaft, often a boundary of an open system.

4.15 *Open system work* is closed system work minus the difference in flow work between out flow and in flow.

CHAPTER 4

THE PROBLEMS FROM SECTIONS 4.1 AND 4.2 ARE INTENDED TO HELP UNDERSTAND THE CONSERVATION OF MASS APPLIED TO STEADY FLOW SYSTEMS AND TO BE ABLE TO FIND MASS FLOW RATES

4.1 ASSUME STEADY-FLOW SO THAT

$$A_1 \rho_1 \bar{V}_1 = A_2 \rho_2 \bar{V}_2$$

ASSUME THAT WATER IS INCOMPRESSIBLE SO THAT $\rho_1 = \rho_2$ AND THEN

$$A_1 \bar{V}_1 = A_2 \bar{V}_2$$

NOW $d_2 = \frac{1}{2} d_1$ AND $A_1 = \pi d_1^2/4$

$A_2 = \pi d_2^2/4$ SO $A_2 = \pi (d_1)^2/16 = A_1/4$

THEN $\bar{V}_2 = (A_1/A_2)\bar{V}_1 = 4\bar{V}_1$

$$\bar{V}_2 = 4(3\,m/s) = \underline{12\,m/s}$$

4.2 $\dot{m} = \rho A \bar{V}$ AND FOR A ROUND TUBE $A = \pi d^2/4$ SO THAT

$$\dot{m} = \rho \pi d^2 \bar{V}/4 .$$

THEN

$$d = \sqrt{\frac{4\dot{m}}{\pi \rho \bar{V}}} = \sqrt{\frac{4(1\,kg/s)}{\pi(793\,\frac{kg}{m^3})(5\,m/s)}}$$

WHERE

$\rho = 793\,kg/m^3$ FROM TABLE 2-1

THEN

$$\underline{d = .0179\,m = 1.79\,cm}$$

4.3 (a.) ASSUME STEADY FLOW. THE MASS FLOW OF AIR AT A IS

$$\dot{m}_A = \rho_A A_A \bar{V}_A = (0.48\,\tfrac{kg}{m^3})(0.1\,m^2)(240\,m/s)$$

$$\underline{= 11.52\,kg/s}$$

(b.) AT B $\dot{m}_B = \dot{m}_A$ BY STEADY FLOW AND

$$\bar{V}_B = \frac{\dot{m}_B}{\rho_B A_B} = \frac{11.52\,kg/s}{(1.12\,kg/m^3)(.05\,m^2)}$$

$$\underline{\bar{V}_B = 205.7\,m/s}$$

4.4 THE SPECIFIC KINETIC ENERGY IS $\frac{1}{2}\bar{V}^2 = ke$

THEN, USING MASS FLOW RATE, $\dot{m} = \rho A \bar{V}$,

$$\bar{V} = \dot{m}/A\rho = \dot{V}/A = 4\dot{V}/\pi d^2$$

WHERE

$$\dot{V} = \text{VOLUME FLOW RATE} = \dot{m}/\rho .$$

THUS $$\bar{V} = \frac{(1.0\,m^3/min)(4)(10000\,cm^2/m^2)}{\pi\,(4\,cm)^2(60\,s/min)}$$

$$= 13.26\ m/s \qquad \text{AND}$$

$$ke = \frac{1}{2}(13.26\,m/s)^2 = \underline{87.95\ J/kg}$$

4.5 FOR PIPE A:

$$\dot{m} = \rho A \bar{V} \quad \text{OR} \quad \dot{V} = A\bar{V}$$

USING FOR $\bar{V} = 6\,m/s$ AND FOR $A = \pi d_A^2/4$ WE HAVE

$$1.5\,\frac{m^3}{min} = \pi\,\frac{d_A^2}{4}(6\,m/s)$$

OR $$d_A = \sqrt{\frac{4 \times 1.5\,m^3/min}{\pi \times 6\,m/s \times 60\,s/min}} = \underline{.073\ m}$$

FOR PIPE B:

$$\dot{V} = A\bar{V} = \pi\,\frac{d_B^2}{4}\,\bar{V} = 2.5\,m^3/min$$

THEN $$d_B = \sqrt{\frac{4 \times 2.5\,m^3/min}{\pi \times 6\,m/s \times 60\,s/min}} = \underline{.094\ m}$$

FOR PIPE C: ASSUME WATER IS INCOMPRESSIBLE SO THAT THE DENSITY IS THE SAME. THEN WE CAN WRITE

$$\dot{V}_A + \dot{V}_B = \dot{V}_C = 1.5\,\frac{m^3}{min} + 2.5\,\frac{m^3}{min} = 4\,\frac{m^3}{min}$$

AND $\pi \frac{d_C^2}{4} \bar{V}_C = 4\,\frac{m^3}{min}$ SO THAT

$$d_C = \sqrt{\frac{4 \times 4\,m^3/min}{\pi \times 6\,m/s \times 60\,s/min}} = \underline{0.119\,m}$$

4.6 ASSUME STEADY FLOW

$$\rho_A A_A \bar{V}_A = \rho_B A_B \bar{V}_B$$

THEN

$$\bar{V}_A = \frac{\rho_B A_B \bar{V}_B}{\rho_A A_A} = \frac{\rho_B \bar{V}_B}{\rho_A}$$

SINCE $A_B/A_A = 1$ (OR $A_B = A_A$). THEN

$$\bar{V}_A = \frac{(0.64\,kg/m^3)(30\,m/s)}{1.2\,kg/m^3} = \underline{16\,m/s}$$

4.7 FOR THE PIPE

$$\dot{m} = \rho A \bar{V} = \rho \pi \frac{d^2}{4} \bar{V} = 40{,}000\,kg/hr$$

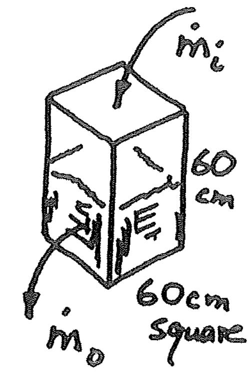
THEN

$$d = \sqrt{\frac{4 \times 40{,}000\,kg/hr}{\pi \times 1000\,\frac{kg}{m^3} \times 24\,\frac{m}{s} \times 3600\,s/hr}}$$

$d = .024\,m$. SELECT $\underline{d = 2.5\,cm}$

4.8 $\dot{m}_i = \dot{m}_o$ + ACCUMULATION RATE.

THE ACCUMULATION MUST BE THE AMOUNT OF WATER NEEDED TO FILL THE TANK:



$$\text{ACCUMULATION} = (.3m)(.6m)(.6m)\rho = \rho(.108\,m^3)$$

ASSUME $\rho = 1000\ kg/m^3$ SO THAT ACCUMULATION = 108 kg. THE ACCUMULATION RATE IS,

$$\text{ACCUM. RATE} = \frac{108\,kg}{2\,min} = 54\,\frac{kg}{min} = 0.9\,\frac{kg}{s}$$

SINCE $\dot{m}_o = 1.0\ kg/s$, THE INLET FLOW IS

$$\dot{m}_i = 1.0\,\frac{kg}{s} + 0.9\,\frac{kg}{s} = \underline{1.9\ kg/s}$$

4.9 $$\text{ACCUMULATION RATE} = \dot{m}_{IN} - \dot{m}_{OUT}$$

$$= 13\,\frac{kg}{s} + 9\,\frac{kg}{s} + \frac{20\,kg/min}{60\,s/min} - 23\,\frac{kg}{s}$$

$$= -0.667\,\frac{kg}{s} \quad \text{(LOSS IN MASS)}$$

4.10 $\dot{m} = \rho A \bar{V}$. THUS

$$\bar{V} = \frac{\dot{m}}{\rho A} = \frac{4\dot{m}}{\rho \pi d^2} = \frac{4 \times 600\ lbm/min}{(62.4\,\frac{lbm}{ft^3})(\pi)(0.5\,ft)^2}$$

$$\underline{\bar{V} = 48.97\ ft/min}$$

4.11 ASSUME STEADY FLOW CONDITIONS

(a.) $\dot{m}_A = \dot{m}_B = \dot{m}_C = \underline{60\ lbm/s}$

(b.) $\bar{V}_B = \frac{\dot{m}_B}{\rho_B A_B} = \frac{4\dot{m}_B}{\rho \pi d_B} = \frac{(4)(60\ \frac{lbm}{s})(144\ in^2/ft^2)}{(54.9\ \frac{lbm}{ft^3})(\pi)(4\ in^2)}$

WHERE $\rho = 54.9\ \frac{lbm}{ft^3}$ FROM TABLE 2-1

THEN

$\bar{V}_B = \underline{50.1\ ft/s}$

(c.) $\bar{V}_C = \frac{\dot{m}_C}{\rho A_C} = \frac{4\dot{m}_C}{\rho \pi d_C^2} = \frac{(4)(60)(144)}{(54.9)(\pi)(25)}$

$\bar{V}_C = \underline{8.015\ ft/s}$

4.12 ASSUME STEADY FLOW CONDITIONS

(a.) $\dot{m}_A = \dot{m}_B = \dot{m}_C = \rho A \bar{V} = \dot{m}$

AT STATION A, $\bar{V}_A = 400\ ft/s$ SO

$\dot{m} = \left(0.045\ \frac{lbm}{ft^3}\right)\left(\pi \frac{d_A^2}{4}\right)\left(400\ ft/s\right)$

$= (0.045)(\pi/4)(5\ in)^2(400) / 144\ in^2/ft^2$

$\underline{\dot{m} = 2.45\ lbm/s}$

(b.) $\bar{V}_B = \frac{\dot{m}_B}{\rho_B A_B} = \frac{4\dot{m}_B}{\rho_B \pi d_B^2}$

$$\bar{V}_B = \frac{4 \times 2.45\ lbm/s \times 144\ in^2/ft^2}{\left(0.060\ \frac{lbm}{ft^3}\right)(\pi)(2\ in)^2}$$

$$= \underline{1875\ ft/s}$$

(c.) $$\bar{V}_c = \frac{4\dot{m}_c}{\rho_c \pi d_c^2} = \frac{4 \times 2.45\ lbm/s \times 144\ in^2/ft^2}{0.050\ \frac{lbm}{ft^3} \times \pi \times 25\ in^2}$$

$$= \underline{360\ ft/s}$$

4.13 ASSUME STEADY FLOW CONDITIONS

THEN

$$\dot{m}_a + \dot{m}_f = \dot{m}_{a/f} = 2\ lbm/min$$

ALSO

$$\dot{m}_f = .04\,\dot{m}_a$$ (.04 lbm fuel per 1 lbm air)

THEN

$$1.04\,\dot{m}_a = 2\ lbm/min$$

AND

$$\dot{m}_a = \frac{2\ lbm/min}{1.04} = \underline{1.923\ \frac{lbm}{min}}$$

ALSO $\dot{m}_f = \underline{.0769\ lbm/min}$

4.14 ASSUME STEADY FLOW CONDITIONS. THEN, SINCE THE TUBES HAVE A UNIFORM AREA,

$$\rho_1 \bar{V}_1 = \rho_2 \bar{V}_2 \quad \text{AND} \quad \bar{V}_2 = \bar{V}_1 \rho_1 / \rho_2$$

$$\bar{V}_2 = (10\ ft/s)(62.5\ lbm/ft^3)/(61.8\ lbm/ft^3)$$

$$= \underline{10.11\ ft/s}$$

4.15 $\dot{m}_{air} = \rho \dot{V} = (0.06\ \frac{lbm}{ft^3})(30{,}000\ ft^3/min)$

$$= 1800\ lbm/min$$

$$\dot{m}_{fuel} = 0.02 \times 1800\ lbm/min = 36\ lbm/min$$

SINCE 0.02 lbm FUEL IS MIXED WITH EACH 1 lbm AIR.

∴ ASSUMING STEADY FLOW,

$$\dot{m}_{exhaust} = \dot{m}_{air} + \dot{m}_{fuel} = 1836\ lbm/min$$

AND

$$\dot{m}_{exhaust} = \rho_{gases} A_{exh} \bar{V}_{exh}$$

THEN

$$\bar{V}_{exh} = \frac{\dot{m}_{exhaust}}{\rho_{gases} A_{exh}} = \frac{1836\ lbm/min}{(.01\ \frac{lbm}{ft^3})(1\ ft^2)}$$

$$= 183{,}600\ ft/min$$

$$= \underline{3060\ ft/s}$$

4.16 $\dot{m} = \rho A \bar{V} = \rho \pi \frac{d^2}{4} \bar{V}$ AND THEN

$$d = \sqrt{\frac{4\dot{m}}{\bar{V}\rho\pi}} = \sqrt{\frac{4 \times 260\ lbm/min}{(100\ ft/s)(78\ \frac{lbm}{ft^3})(\pi)(60\ s/min)}}$$

$d = .0266\ ft \approx \underline{.32\ inches}$

4.17 ACCUMULATION = $\dot{m}_{in} \Delta t$

WHERE Δt = TIME REQUIRED TO FILL BALLOON

ALSO

ACCUMULATION = BALLOON VOLUME x AIR DENSITY.

$$= (0.5\ ft^3)\left(\frac{1\ lbm}{12\ ft^3}\right) = .0417\ lbm$$

THEN

$$\Delta t = \frac{.0417\ lbm}{0.01\ lbm/s} = \underline{4.17\ s}$$

4.18 ASSUME AIR IS INCOMPRESSIBLE, THEN

$\dot{V}_{IN}$ = RATE OF INCREASE IN CYLINDER VOLUME

$$\dot{V}_{IN} = \dot{V}_A = \bar{V}_A A_A = \bar{V}_A (1\ in^2)$$

THE RATE OF INCREASE IN CYLINDER VOLUME IS $\bar{V} A_B = (100\ ft/s)\pi \frac{(3\ in)^2}{4}$

THEN

$$\bar{V}_A = \frac{(100\ ft/s)\pi \frac{(3\ in)^2}{4}}{1\ in^2} = \underline{706.8\ \frac{ft}{s}}$$

THE PROBLEMS FROM SECTION 4.3 GIVE FURTHER PRACTICE IN CONSERVATION OF MASS

APPLIED TO UNIFORM FLOW SUCH AS IN FILLING AND EMPTYING OF SYSTEMS.

4.19 $\dot{m}_{in} = \dot{m}_{system}$

ASSUME $\dot{m}_{in}$ IS CONSTANT AND THEN

$$\dot{m}_{in} = \frac{\rho_{OIL} V_{TANK}}{\Delta t} = \frac{\left(920 \frac{kg}{m^3}\right)\left(5 m^3\right)}{45 \, min}$$

$$= 102.2\ldots \; kg/min$$

4.20 $m = \dot{m}_{in} \Delta t = \left(500 \frac{lbm}{s}\right)\left(30 s\right)$

$= 15{,}000 \; lbm$

4.21 SINCE MASS FLOW RATE VARIES WITH TIME FROM START-UP,

$m = \sum \dot{m} \delta t$ WHERE δt IS A SMALL AMOUNT OF TIME CHANGE. WE MAY VISUALIZE m AS THE AREA UNDER THE CURVE OF FIG. 4-25. FOR AN APPROXIMATE SOLUTION, SELECT THE FOLLOWING DATA FROM FIG 4-26:

$\dot{m}$ (lbm/s)	t (s)
0	0
26.0	0.5
48.0	1.0
66.2	1.5
77.0	2.0
82.5	2.5
82.5	3.0

THEN, USING SUM OF TRAPEZOID AREAS OR THE COMPUTER PROGRAM AREA WITH A PERSONAL COMPUTER, THE RESULT OF $\sum \dot{m}\,\delta t$ IS

$$\underline{m = 170.475 \text{ lbm}}$$

4.22 $m = \dot{m}\Delta t$ SINCE $\dot{m}$ IS CONSTANT IN TIME. THEN

$$m = \left(25 \frac{kg}{s}\right)\left(20 \text{min} \times 60 \frac{s}{\text{min}}\right)$$

$$\underline{= 30{,}000 \text{ kg}}$$

4.23 MASS OF MILK DRAINED $= \sum \dot{m}\,\delta t$ SINCE $\dot{m}$ VARIES WITH TIME. THIS CAN BE VISUALIZED AS THE

AREA UNDER THE CURVE OF FIG. 4-7. AS AN EXAMPLE, USING THE FOLLOWING DATA FROM FIG 4-7:

$\dot{m}$ (kg/min)	t (min)
30.5	25.0
25.0	27.5
19.5	30.0
12.5	32.5
8.0	35.0
5.0	37.5
3.0	40.0
2.0	42.5
1.5	45.0

THEN, USING A SUM OF TRAPEZOID AREAS OR THE COMPUTER PROGRAM AREA WITH A PERSONAL COMPUTER, THE RESULT IS

$$m = \sum \dot{m}\,\delta t = \underline{227.5\ kg}$$

4.24 FOR STEADY STATE:

$$\dot{m}_{in} = \dot{m}_{OUT}$$

SINCE THE SPECIFIC GRAVITIES ARE GIVEN (S.G.) WE MAY WRITE THE

CONSERVATION OF MASS AS

$$(SG)_{CRUDE}\dot{V}_{IN} = (SG)_{HEAVY\ BOTTOM}\dot{V}_{HB} + (SG)_{GREASE}\dot{V}_{GR.}$$

$$+ (SG)_{HEAVY\ OIL}\dot{V}_{HEAVY\ OIL} + (SG)_{LIGHT\ OIL}\dot{V}_{LIGHT\ OIL}$$

$$+ (SG)\dot{V}_{KEROSENE} + (SG)\dot{V}_{GASOLINE}$$

OR, SINCE $(SG)_{CRUDE} = 1.00$

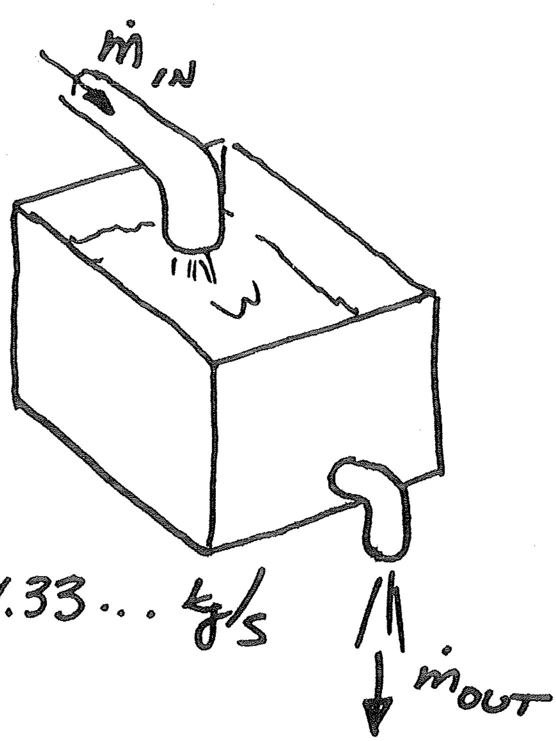
$$\dot{V}_{IN} = (1.10)(25\ gpm) + (0.95)(10\ gpm)$$

$$+ (0.88)(110\ gpm) + (0.84)(250)$$

$$+ (0.81)(65) + (0.73)(500)$$

$$= 761.45\ gpm$$

4.25 FOR THE TANK SHOWN:



$\dot{m}_{in} = 3\ kg/s$ WATER

$\dot{m}_{OUT} = 80\ kg/min$ WATER

$= \frac{80}{60}\ kg/s = 1.33\ldots\ kg/s$

4.25 THEREFORE:

(CONT.) $\dot{m}_{IN} - \dot{m}_{OUT} = 1.667 \text{ kg/s}$ $\quad \dot{m}_{OUT}$

$= \text{RATE OF ACCUMULATION}$

$= \dfrac{\delta m_{SYSTEM}}{\delta t}$

a.) <u>TANK IS FILLING</u>

b.) NOW

$$\frac{\delta m_{system}}{\delta t} = 1.667 \text{ kg/s}$$

SINCE TANK BEGINS AS 1/3 FULL THE MASS REQUIRED TO FILL TANK IS:

$$\Delta m_{SYSTEM} = \text{VOLUME} \times \text{WATER DENSITY}$$

$$= V \times \rho_{H_2O}$$

$$= \frac{2}{3}(\text{TANK VOLUME})(\rho_{H_2O})$$

$$= \frac{2}{3}(2m \times 2m \times 1.5m)(\rho_{H_2O})$$

$$= \frac{2}{3}(6m^3)(998 \text{ kg/m}^3)$$

$\Delta m_{system} = 3992\ kg$

AND THE TIME REQUIRED TO FILL THE TANK, ASSUMING THE RATE OF ACCUMULATION IS CONSTANT, AT 1.667 kg/s, IS

$$\delta t = \Delta t = \frac{\Delta m_{sys.}}{(\delta m / \delta t)} = \frac{3992\ kg}{1.667\ kg/s}$$

$$\Delta t \cong 2395\ s = 39.9\ min.$$

4.26 FROM EXAMPLE 4.10, THE TIME IS

$$t = 47.6\left(\sqrt{m_{sys,t}} - \sqrt{m}\right)$$

OR

$$\sqrt{m} = \sqrt{m_{sys,t}} - t/47.6$$

SINCE $m_{sys,t} = 2000\ kg$

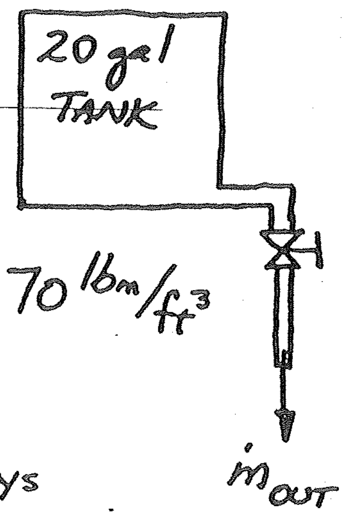
WE HAVE $\sqrt{m} = \sqrt{2000} - t/47.6$

OR

$$m = 2000 - 1.879t + 4.41\times10^{-4}t^2$$

THIS GIVES THAT $m=0$ (TANK EMPTY) $t = 2128$ s (35.4 min). THE PLOT IS SHOWN IN THE FIGURE.

4.27 20-gal TANK FULL OF ETHYL GLYCOL



$\rho = 70\ lbm/ft^3$

$m_{FULL} = 20\,gal \times .1337\ ft^3/gal \times 70\ lbm/ft^3$

$= 187.18\ lbm$

$$\dot{m}_{OUT} = 0.5\, m_{sys} = -\frac{dm_{sys}}{dt}$$

SO

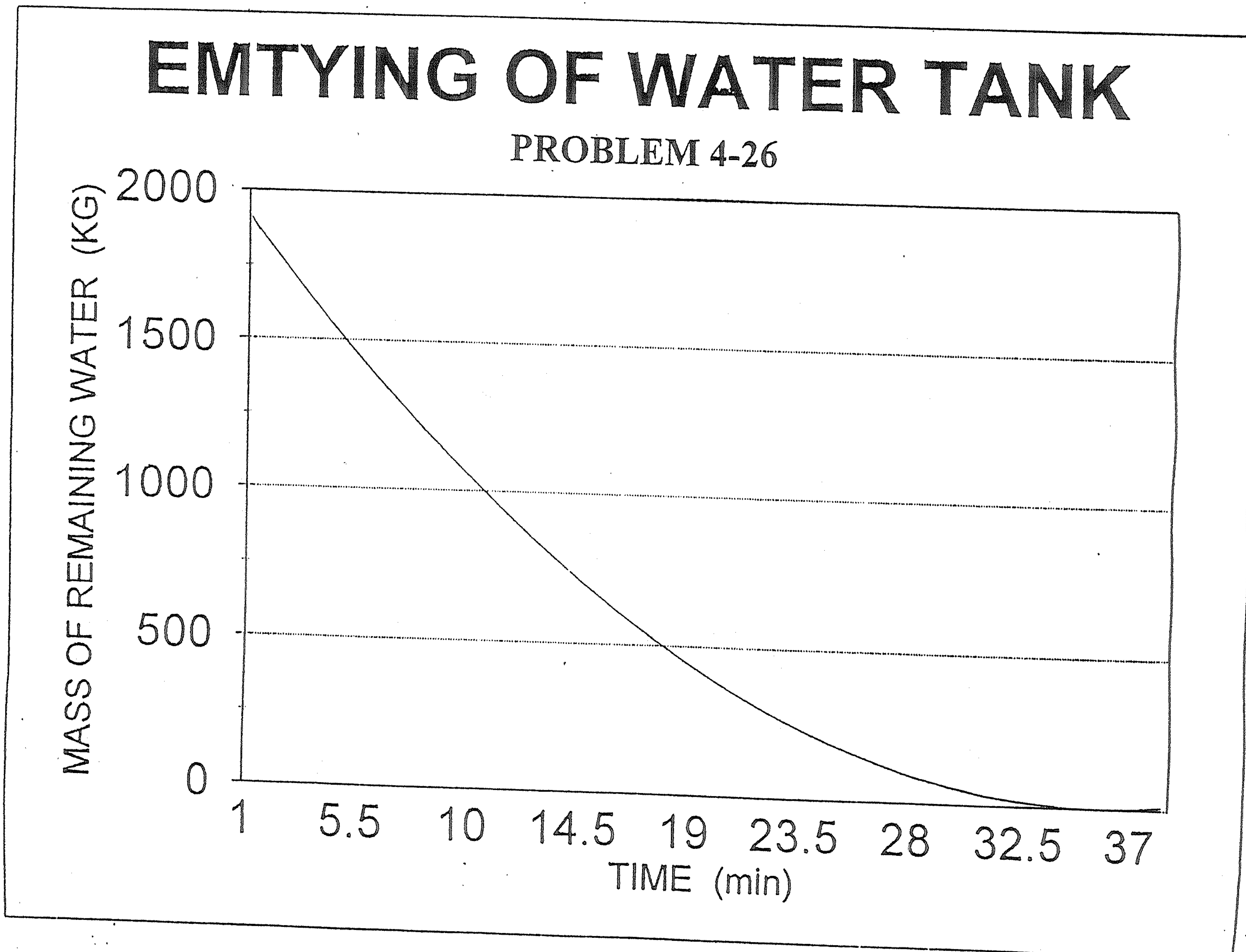
$$0.5\, dt = -\frac{dm_{sys}}{m_{sys}}$$

FOR $m_{sys} = 187.18\ lbm$ AT $t=0$

AND $m_{sys} = 137.18\ lbm$ AT t,

WE HAVE

$$0.5\int_0^t dt = -\int_{187.18}^{137.18} \frac{dm_{sys}}{m_{sys}} = -\ln\frac{137.18}{187.18}$$


EMTYING OF WATER TANK
PROBLEM 4-26
MASS OF REMAINING WATER (KG)
2000
1500
1000
500
0
1
5.5
10
14.5
19
23.5
28
32.5
37
TIME (min)

AND

$$0.5t = -\ln \frac{137.18}{187.18}$$

SO

$$\underline{t = 0.62 \text{ min}}$$

ALSO

$$0.5t = -\ln m/187.18$$

FOR ANY TIME t. THIS CAN BE WRITTEN

$$e^{-0.5t} = \frac{m}{187.18}$$

OR

$$\underline{m = 187.18 e^{-0.5t}}$$

4.28 WE HAVE FOR THIS SYSTEM THAT

$$\dot{m}_{OUT} = 0.1 m^{3/4}$$

WHERE m IS THE MASS OF THE SYSTEM. ALSO

$$-\dot{m}_{OUT} = \frac{dm}{dt} = -0.1 m^{3/4}$$

SEPARATING VARIABLES GIVES:

$$m^{-3/4} dm = -0.1\, dt$$

THEN, INTERGRATING FROM

$m_i = 300\,kg$ AT $t = 0$

TO $m_f = 150\,kg$ AT t

GIVES THAT

$$4\left(m_f^{1/4} - m_i^{1/4}\right) = -0.1t$$

OR

$$4\left(150^{1/4} - 300^{1/4}\right) = -0.1t$$

$$\underline{t = 26.486\ldots\ s}$$

THE PROBLEMS FROM SECTIONS 4.4 AND 4.5 PROVIDE PRACTICE IN THE USE OF CONSERVATION OF ENERGY TO CLOSED SYSTEMS.

4.29 $Q - Wk = \Delta E$ SO THAT

$$Wk = Q - \Delta E$$

$$= 40\,kJ - (30\,kJ) = \underline{+10\,kJ}$$

<u>OUTPUT WORK</u>

4.30 $Q - Wk = \Delta E = \Delta U$ IF ALL ENERGY CHANGES ARE ASSUMED TO BE INTERNAL THEN

$$\Delta U = -(-200\,N\cdot m) = \underline{200\ J}$$

4.31 ASSUME ALL ENERGY CHANGE IS INTERNAL. THEN

$$\Delta u = q - wk_{cs} = 62.5\,\frac{kJ}{kg} - 60\,\frac{kJ}{kg}$$

$$= 2.5\,\frac{kJ}{kg}$$ SO THAT

$$\Delta U = m\Delta u = (2\,kg)\left(2.5\,\frac{kJ}{kg}\right) = \underline{5\ kJ}$$

4.32 $m = 0.01\ kg$, $Q = -10\,kJ$, $Wk_{cs} = 20\,kJ$. SO

$$\Delta U = Q - Wk_{cs} = -10\,kJ - 20\,kJ$$

$$= -30\,kJ.$$

THEN

$$\Delta u = \frac{\Delta U}{m} = \frac{-30\,kJ}{0.01\,kg} = \underline{-3000\,\frac{kJ}{kg}}$$

4.33 FOR A CLOSED CONTAINER, ASSUME VOLUME IS CONSTANT AND THEN $\dot{W}k_{cs} = 0$. ALSO, SINCE $\dot{Q} = 150\,\frac{kJ}{s}$

THEN $\dot{U} = \dot{Q} - \dot{W}k_{cs} = \underline{150\ kJ/s}$.

ALSO

$$\dot{u} = \frac{\dot{U}}{m} = \frac{150\ kJ/s}{100\ kg} = 1.5\ kJ/kg \cdot s$$

$$= \underline{1.5\ \frac{kW}{kg}}$$

4.34 $Wk_{cs} = Q - \Delta U = -20\ BTU - (-20\ BTU)$

$\underline{Wk_{cs} = 0}$

4.35 $q = \Delta u + wk_{cs} = 0.75\ \frac{BTU}{lbm} + 778\ \frac{ft\text{-}lbf}{lbm}$

$$= 0.75\ \frac{BTU}{lbm} + \frac{778}{778}\ \frac{BTU}{lbm} = \underline{1.75\ \frac{BTU}{lbm}}$$

4.36 FOR $Q = 0$

OUTPUT $= Wk = -\Delta U = -(-16.8\ BTU)$

$\underline{Wk = 16.8\ BTU.}$

4.37 $\Delta u = q - wk_{cs} = 8\ \frac{BTU}{lbm} - 6224\ \frac{ft\text{-}lbf}{lbm}$

$$= 8\ \frac{BTU}{lbm} - \frac{6224}{778}\ \frac{BTU}{lbm} = \underline{0\ \frac{BTU}{lbm}}$$

4.38 $\dot{W}k_{cs} = 10\ hp$, $\dot{U} = -10\ BTU/s$

$$= -10 \times 1.41\ hp = -14.1\ hp$$

so $\dot{Q} = \dot{U} + \dot{Wk}_{cs} = -14.1 hp + 10 hp$

$= -4.1 hp$ (COOLING)

4.39 $\Delta E = Q - Wk$ AND $Q = -10$ BTU.

$Wk = 100$ W-hr $= 100 \times 3.414$ BTU

USING CONVERSION 3414 BTU/hr = 1 kW FROM TABLE B.22. THIS IS

3.414 BTU/hr = 1 W or

3.414 BTU = 1 W-hr. THEN

$\Delta E = -10$ BTU $- 341.4$ BTU

$= -351.4$ BTU

THE PROBLEMS OF SECTION 4.5 ARE INTENDED TO GIVE PRACTICE IN APPLYING THE FIRST LAW OF THERMODYNAMICS TO CLOSED SYSTEMS INVOLVING REVERSIBLE AND IRREVERSIBLE PROCESSES

4.40 (a.) SINCE $Q = 0$, $Wk_{cs} = -\Delta U$

OR $Wk_{cs} = -24$ kJ (INPUT)

(b.) HERE THE WORK IS ALL IRREVERSIBLE, $Wk_{irr} = -24$ kJ

$Wk_{cs,rev} = 0$

(c.) $\underline{Q = 0}$

(d.) $wk_{cs} = wk_{irr} = \frac{Wk_{irr}}{m} = \frac{-24\ kJ}{3\ kg}$

$= -8\ kJ/kg$

$\underline{q = 0}$

4.41 $\Delta U = Q - Wk = -1\ kJ - (-20\ kJ)$

$\underline{= 19\ kJ}$

4.42 FOR THE CONSTANT PRESSURE PROCESS

$Wk = p\Delta V = \left(75 \frac{lbf}{in^2}\right)\left(2 ft^3\right)\left(144 \frac{in^2}{ft^2}\right)$

$\underline{= 21{,}600\ ft\text{-}lbf}$

4.43 FOR THE HEAT ENGINE UNDER STEADY STATE $\dot{U} = 0$ SO THAT

$\dot{Q} = \dot{W}k = \underline{100{,}000\ W = 100\ kW}$

PROBLEMS OF SECTION 4.6 ARE INTENDED TO SHOW APPLICATIONS OF CONSERVATION OF ENERGY TO ISOLATED SYSTEMS.

4.44 HERE $Q = Wk = 0 = \Delta E$

AFTER COMING TO REST ON THE BOTTOM THE $KE = 0$ AND $\Delta PE =$

$-(1\,kg)(9.8\,m/s^2)(1\,m) - (1\,kg)(9.8\,m/s^2)(2\,m)$
$= -29.4\,J$. THEN

$$\Delta E = \Delta U + \Delta KE + \Delta PE = 0$$

AND $\Delta U = -\Delta KE - \Delta PE$

$$= -(-20\,J)(2) - (-29.4\,J)$$
$$= \underline{69.4\,J}$$

4.45 (a.) THE SAME, <u>3000 BTU</u> AND <u>30 lbm</u>

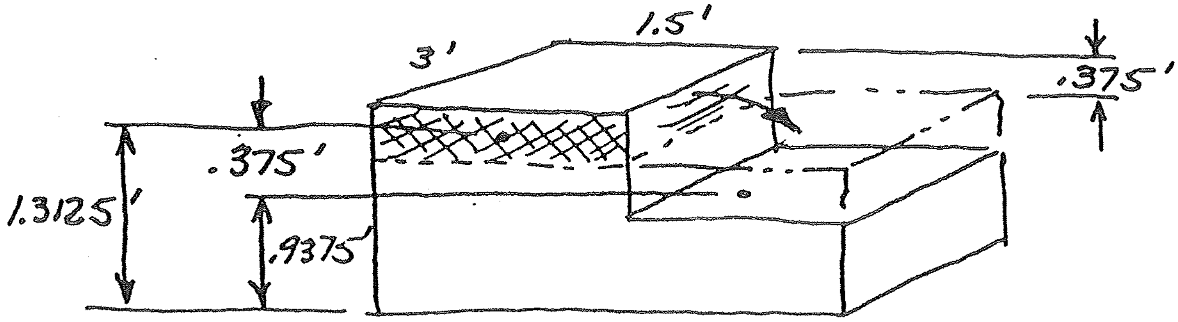
(b.) THE SAME, <u>3000 BTU</u> AND <u>30 lbm</u>

NO CHANGES AS LONG AS THE SYSTEM IS ISOLATED.

4.46 ASSUME POTENTIAL ENERGY CAN BE CONVERTED TO INTERNAL ENERGY. THEN

$$\Delta U = -\Delta PE = -mg\Delta z/g_c$$

THE GRAINS OF SAND MAY SEEK A LOWER ELEVATION AS SHOWN:



THUS, THE GRAINS OF SAND THAT WILL MOVE LOWER HAVE A MASS,

$$m = \left(38\,\frac{lbm}{ft^3}\right)(.375\,ft)(3\,ft)(1.5\,ft)$$

$$= 64.125\ lbm.$$

THE HEIGHT CHANGE, Δz, IS $-.375$ ft SO, ASSUMING $g = 32.17\ ft/s^2$

$$\Delta U = -\frac{(64.125\ lbm)\left(32.17\,\frac{ft}{s^2}\right)(-.375\,ft)}{\left(32.17\,\frac{ft\cdot lbm}{lbf\cdot s^2}\right)}$$

$$= 24.04\ldots\ ft\cdot lbf$$

PROBLEMS FROM SECTION 4.7 ARE INTENDED TO SHOW HOW TO DETERMINE FLOW WORK AND ENTHALPY.

4.47 FLOW WORK (OR FLOW ENERGY) $= pv$

$$= \left(1000\,\frac{kN}{m^2}\right)\left(0.232\,\frac{m^3}{kg}\right)$$

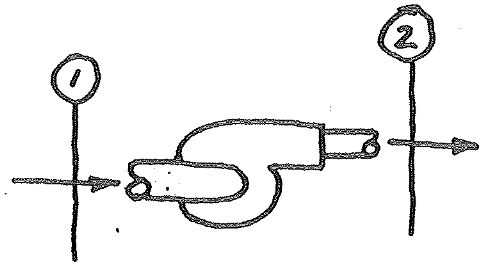
$$= 232\ kJ/kg$$

4.48 ASSUME WATER DENSITY IS $62.5\ lbm/ft^3$ AND $g = 32.17\ ft/s^2$. THEN

$$\text{FLOW WORK} = pv = \left(60\,\frac{lbf}{in^2}\right)\left(144\,\frac{in^2}{ft^2}\right)\left(\frac{1\,ft^3}{62.5\,lbm}\right)$$

$$= \underline{138.24 \ \frac{ft\text{-}lbf}{lbm}} = \underline{0.177.. \ \frac{BTU}{lbm}}$$

4.49 THE CHANGE IN FLOW WORK PER UNIT TIME IS GIVEN BY



$$p_2 v_2 \dot{m} - p_1 v_1 \dot{m} = p_2 \frac{\dot{m}}{\rho_2} - p_1 \frac{\dot{m}}{\rho_1}$$

$$= \left(14.8 \ \frac{lbf}{in^2}\right)\left(144 \ \frac{in^2}{ft^2}\right)\left(\frac{0.1 \ lbm/s}{42 \ lbm/ft^3}\right)$$

$$- \left(14.0 \ \frac{lbf}{in^2}\right)\left(144 \ \frac{in^2}{ft^2}\right)\left(\frac{0.1 \ lbm/s}{42 \ lbm/ft^3}\right)$$

$$= \underline{0.274.. \ ft\text{-}lbf/s}$$

4.50 (a.) $p\dot{V} = pv\dot{m}$. FROM PROBLEM 4.47 THE FLOW WORK pv IS 232 kJ/kg SO THAT

$$pv\dot{m} = \left(232 \frac{kJ}{kg}\right)\left(20 \frac{kg}{s}\right)$$

$$= 4640 \ kJ/s = \underline{4640 \ kW}$$

(b.) $p\dot{V} = p\bar{V}A$ WHERE $\bar{V} = 30$ ft/s

$$A = \pi \frac{d^2}{4} = \pi\left(\frac{2}{12} ft\right)^2 / 4 = .0218 \ ft^2$$

AND THEN

$$p\bar{V}A = \left(60 \ \frac{lbf}{in^2}\right)\left(144 \ \frac{in^2}{ft^2}\right)\left(30 \ \frac{ft}{s}\right)\left(.0218 \ ft^2\right)$$

$\rho \bar{V} A = \underline{5655} \ \frac{ft\text{-}lbf}{s} = \underline{10.28 \ hp}$

4.51 $\quad pv = \left(200 \frac{kN}{m^2}\right)\left(0.755 \frac{m^3}{kg}\right) = \underline{151 \ kJ/kg}$

$h = u + pv = 1405.6 + 151 = \underline{1556.6 \ \frac{kJ}{kg}}$

$H = mh = \underline{3113.2 \ kJ}$

4.52 $\quad pv = \left(200 \frac{kN}{m^2}\right)\left(1.36 \frac{m^3}{kg}\right) = \underline{272 \ kJ/kg}$

$h = u + pv = \underline{3111 \ kJ/kg}$

$H = mh = \underline{21,777 \ kJ}$

4.53 $\quad pv = \left(101 \frac{kN}{m^2}\right)\left(\frac{1}{1.3 \frac{kg}{m^3}}\right) = \underline{77.69 \ \frac{kJ}{kg}}$

$h = u + pv = \underline{257.692 \ kJ/kg}$

$H = mh = \underline{19326.9 \ kJ}$

4.54 $\quad pv = \left(20 \frac{lbf}{in^2}\right)\left(144 \frac{in^2}{ft^2}\right)\left(\frac{1 \ ft^3}{0.1 \ lbm}\right)$

$= 28800 \ ft\text{-}lbf/lbm = \underline{37.0.. \ BTU/lbm}$

$h = u + pv = \underline{157.0.. \ BTU/lbm}$

$H = mh = \underline{157.0 \ BTU}$

4.55 $pv = \left(200 \frac{lbf}{in^2}\right)\left(144 \frac{in^2}{ft^2}\right)\left(\frac{1 ft^3}{0.1 lbm}\right)$

$= 288,000 \ lb_f\text{-}ft/lbm = \underline{370.2 \frac{BTU}{lbm}}$

$h = u + pv = \underline{1370.2 \ BTU/lbm}$

$H = mh = \underline{1370.2 \ BTU.}$

4.56 $pv = \left(112 \frac{lbf}{in^2}\right)\left(144 \frac{in^2}{ft^2}\right)\left(0.7 \frac{ft^3}{lbm}\right)$

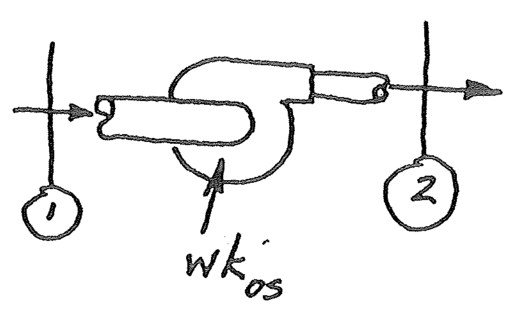
$= 11,289.6 \frac{ft\text{-}lbf}{lbm} = \underline{14.51 \frac{BTU}{lbm}}$

$h = u + pv = \underline{137.44 \ BTU/lbm}$

$H = mh = \underline{1374.4 \ BTU}$

PROBLEMS FROM SECTION 4.8 ADDRESS APPLICATIONS OF THE FIRST LAW OF THERMODYNAMICS TO STEADY STATE OPEN SYSTEMS.

4.57 (a.) FOR THE ADIABATIC PUMP, $q = 0$ AND THEN



$$-wk_{os} = h_2 - h_1 \quad \text{OR} \quad wk_{os} = h_1 - h_2$$

$$wk_{os} = 160 - 170\ \frac{kJ}{kg} = \underline{-10\ \frac{kJ}{kg}\ \text{(INPUT)}}$$

(b.) APPROXIMATELY

$$wk_{os} \approx -v_{ave}\Delta p = v_{ave}(p_1 - p_2)$$

$$-10\ \frac{kJ}{kg} \approx (v_{ave})(1\ kPa - 1200\ kPa)$$

OR $v_{ave} \approx .00834\ m^3/kg$

$$\rho_{ave} \approx \underline{119.9\ kg/m^3}$$

4.58 FOR STEADY FLOW OF THE NOZZLE

$$h_A + \frac{\bar{V}_A^2}{2} = h_B + \frac{\bar{V}_B^2}{2} \quad \text{AND THEN}$$

$$h_B = h_A + \frac{\bar{V}_A^2 - \bar{V}_B^2}{2}$$

ALSO $\rho_A A_A \bar{V}_A = \rho_B A_B \bar{V}_B$

AND FOR INCOMPRESSIBLE FLUIDS

$\rho_A = \rho_B$ SO THAT

$$A_A \bar{V}_A = A_B \bar{V}_B \quad \text{OR} \quad \bar{V}_B = \frac{A_A}{A_B}\bar{V}_A$$

$$\bar{V}_B = (3)(\bar{V}_A) = 45\ m/s$$

THEN,

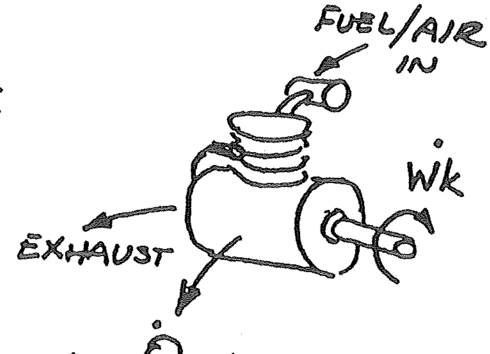
$$h_B = 3278\ \frac{kJ}{kg} + \frac{(15\,m/s)^2 - (45\,m/s)^2}{2}$$

$$= 3278\ \frac{kJ}{kg} - 900\ \frac{m^2}{s^2} = 3278\ \frac{kJ}{kg} - 0.9\ \frac{kJ}{kg}$$

$$= \underline{3277.1\ kJ/kg}$$

4.59 FOR STEADY STATE

$$\dot{m}(h_{exh} - h_{f/a}) = \dot{Q} - \dot{W}k$$



THEN

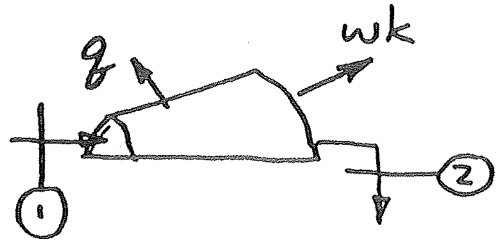
$$h_{exh} = h_{f/a} + \frac{\dot{Q}}{\dot{m}} - \frac{\dot{W}k}{\dot{m}}$$

$$= 2600\ \frac{kJ}{kg} + \frac{-40\ kJ/min}{0.73\,kg/min} - \frac{(20\,hp)(.746\ \frac{kW}{hp})(60\ \frac{s}{min})}{0.73\ kg/min}$$

$$= 2545.2\ \frac{kJ}{kg} - 1226.3\ \frac{kJ}{kg}$$

$$= \underline{1318.9\ kJ/kg}$$

4.60 FOR STEADY FLOW, STEADY STATE



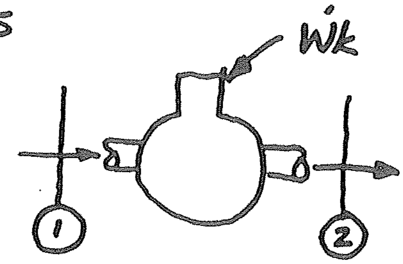
$$h_2 - h_1 = q - wk$$

$$h_2 = h_1 + q - wk$$

$$h_2 = 1530\ \frac{BTU}{lbm} + \left(-8\ \frac{BTU}{lbm}\right) - 290\ \frac{BTU}{lbm}$$

$$h_2 = \underline{1232\ BTU/lbm}$$

4.61 ASSUME NO HEAT LOSSES OR GAINS. THEN, FOR STEADY STATE

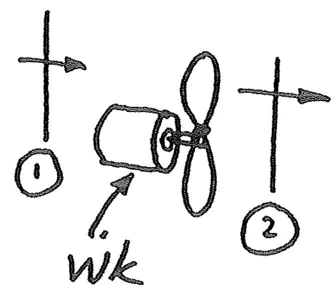


$$\dot{m}(h_2 - h_1) = -\dot{W}k$$

$$\left(3000\ \frac{lbm}{min}\right)\left(230\ \frac{BTU}{lbm} - 118\ \frac{BTU}{lbm}\right) = 336{,}000\ \frac{BTU}{min}$$

$$\dot{W}k = -336{,}000\ \frac{BTU}{min} = -5600\ \frac{BTU}{s} = -7896\ hp$$

4.62 THE FAN GIVES AIR KINETIC ENERGY. FOR STEADY STATE AND NO HEAT TRANSFER



$$-\dot{w}k = \dot{m}\ \frac{\bar{V}_2^2 - \bar{V}_1^2}{2g_c}$$

NEGLECT $\bar{V}_1$, THEN

$$\frac{1}{4}hp = \dot{m}\ \frac{\bar{V}_2^2}{2g_c} = \left(40\ \frac{lbm}{min}\right)\left(\frac{\bar{V}_2^{\ 2}}{2 \times 32.17\ \frac{ft \cdot lbm}{lbf \cdot s^2}}\right)$$

$$\frac{1}{4}hp \times 33000\frac{ft}{hp \cdot min} = 0.6217\ \bar{V}_2^2$$

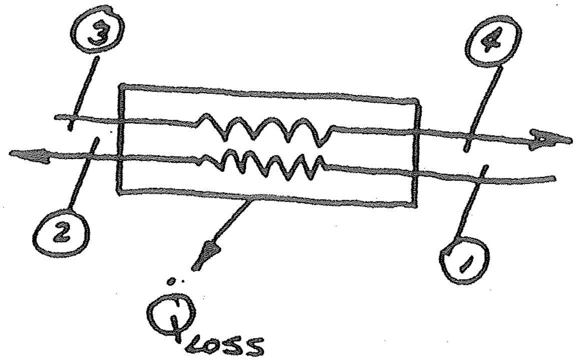
$$\therefore\ V_2 = \sqrt{13270\ ft^2/min^2} = 115.2\ ft/min$$

$$= 1.92\ ft/s$$

4.63 FOR THE HEAT EXCHANGER, OPERATING AT STEADY STATE AND NEGLECTING KINETIC AND POTENTIAL ENERGY CHANGES:

4.63 (CONT.)

$$\dot{m}_A(h_1 - h_2) = \dot{m}_B(h_4 - h_3) + \dot{Q}_{LOSS}$$



OR

$$(2\ \text{lbm/s})(85\ \text{BTU/lbm}) = (10\ \text{lbm/s})(h_4 - h_3) + 2\ \frac{\text{BTU}}{\text{s}}$$

AND

$$h_4 - h_3 = \Delta h = \frac{170\ \text{BTU/s} - 2\ \text{BTU/s}}{10\ \text{lbm/s}}$$

$$\underline{\Delta h = 16.8\ \text{BTU/lbm}}$$