

Contents

1	Introduction: Basic Definitions	1
1.1	System	1
1.2	Property and Variables	2
1.3	Dimensions and Units	3
1.4	Measures of Amounts and Fractions	5
1.5	Force	6
1.6	Temperature	6
	Example 1.1 Conversion of temperature units	8
1.7	Pressure	8
	Example 1.2 Pressure calculations	10
	Example 1.3 Pressure conversions	10
	Example 1.4 Absolute pressure estimations	11
1.8	Volume	11
1.9	Energy	13
1.10	Work	14
1.11	Power	15
	Example 1.5 Power conversions	15
1.12	Heat Capacity	16
1.13	Heat	16
1.14	Internal Energy	17
1.15	Enthalpy	17
1.16	Entropy	18
1.17	State	19
	1.17.1 Saturated Liquid and Saturated Vapor States	19
	1.17.2 Partial Pressure and Saturation Pressure	21
	Example 1.6 Estimation of saturated vapor pressure	21
1.18	Steam Tables	22
	Example 1.7 Energy change during evaporation	24
	Example 1.8 Energy change during condensation	24
	Example 1.9 Quality of a saturated liquid and vapor mixture of a steam	25

1.19	Process	26
	Summary	27
	Problems	28
	References	34
2	Energy Sources	35
2.1	Energy Sources	35
2.1.1	Primary Energy Sources.	36
2.1.2	Secondary Energy Sources.	36
2.2	Nonrenewable Energy Sources.	37
2.2.1	Coal	38
2.2.2	Petroleum (Crude Oil).	39
2.2.3	Petroleum Fractions.	40
2.2.4	Natural Gas	42
2.2.5	Nuclear Energy.	43
2.3	Heating Value of Fuels	44
2.3.1	Energy Density.	44
	Example 2.1 Energy consumption by a car	45
	Example 2.2 Fuel consumption by a low and a high-mileage car	47
	Example 2.3 Daily consumption of natural gas by a city.	48
	Example 2.4 Energy consumed by a car	49
2.4	Renewable Energy Resources.	49
2.4.1	Hydroenergy	51
2.4.2	Solar Energy	51
2.4.3	Biomass and Bioenergy.	55
	Example 2.5 Gross heating value estimations.	58
2.4.4	Wind Energy	60
2.4.5	Geothermal Energy.	61
2.4.6	Ocean Energy.	62
2.5	Hydrogen	62
2.6	Electric Energy.	63
	Example 2.6 Electricity consumption of a laptop computer.	64
2.7	Magnetic Energy	64
2.8	Chemical Energy	64
	Summary	65
	Problems	67
	References	71
3	Mechanical Energy and Electrical Energy	73
3.1	Mechanical Energy	73
3.2	Kinetic Energy.	74
	Example 3.1 Calculation of the kinetic energy for a flowing fluid.	75
	Example 3.2 Kinetic energy of a car.	75

3.3	Potential Energy	76
	Example 3.3 Potential energy change of water	77
	Example 3.4 Energy of an elevator	77
3.4	Pressure Energy	78
	Example 3.5 Pressure energy of a hydraulic turbine	79
	3.4.1 Pressure Head	79
	Example 3.6 Pumping water	80
	Example 3.7 Calculation of the power needed to pump water	80
3.5	Surface Energy	80
3.6	Sound Energy	81
3.7	Electric Energy	81
	3.7.1 Electric Potential Energy	82
	3.7.2 Estimation of Electrical Energy	83
	3.7.3 Electric Power	84
	3.7.4 Capacitance	84
3.8	Various Forms of Work	85
	3.8.1 Mechanical Work	86
	3.8.2 Boundary Work	86
	Example 3.8 Expansion and compression work of an ideal gas	88
	Example 3.9 Isothermal compression work	89
	3.8.3 Fluid Flow Work	89
	3.8.4 Isentropic Process Work	90
	Example 3.10 Isentropic compression of air	91
	3.8.5 Polytropic Process Work	91
	Example 3.11 Calculation of work done by a piston on an ideal gas	92
	Example 3.12 Polytropic expansion of air	92
	3.8.6 Shaft Work	93
	Example 3.13 Estimation of shaft power	93
	3.8.7 Spring Work	93
	Example 3.14 Estimation of spring work	94
	3.8.8 Stirrer Work	94
	3.8.9 Acceleration Work	94
	3.8.10 Gravitational Work	95
	3.8.11 Electrical Work	95
	Example 3.15 Estimation of electrical work	95
3.9	Other Forms of Work	96
	Summary	96
	Problems	98
	References	104

4	Internal Energy and Enthalpy	105
4.1	Internal Energy	105
4.2	Enthalpy	108
	Example 4.1 Unit conversions of heat capacity	109
	Example 4.2 Calculation of internal energy change.	112
	Example 4.3 Calculation of internal energy change during evaporation	112
	Example 4.4 Determination of state properties	113
	Example 4.5 Heat value of a saturated liquid and vapor mixture of a steam	113
4.3	Heat	114
	4.3.1 Sensible Heat	115
	4.3.2 Latent Heat	115
	4.3.3 Heating with Phase Change	117
	Example 4.6 Calculation of heat of vaporization using Antoine equation and Clausius–Clapeyron equation.	118
	Example 4.7 Estimation of change of enthalpy with sensible and latent heat.	118
	Example 4.8 Estimation of heat of vaporization at another temperature	120
	4.3.4 Heat of Reaction.	120
	Example 4.9 Estimation of standard heat of reaction.	122
	Example 4.10 Estimation of standard heats of reaction from standard heats of formation.	122
	4.3.5 Standard Heat of Combustion.	123
	Example 4.11 Determination of standard heats of reaction.	124
	Example 4.12 Estimation of standard heats of combustion from standard heats of formation.	125
4.4	Effect of Temperature on the Heat of Reaction	125
	Example 4.13 Estimation of standard heat of reaction at a temperature other than 298 K.	126
4.5	Standard Enthalpy Changes	127
4.6	Adiabatic Flame Temperature.	127
	Example 4.14 Maximum flame temperature.	128
4.7	Air Pollution from Combustion Processes	129
4.8	Heat of Mixing	129
	Example 4.15 Estimation of partial enthalpies	131
4.9	Heat Measurements by Calorimeter.	131
	Example 4.16 Measurement of heat capacity of a metal in a calorimeter.	132
4.10	Psychrometric Diagram	133
	Example 4.17 Determination of air properties on a psychrometric chart	135

	Example 4.18 Determination of moisture from the Mollier chart	136
	Example 4.19 Determination of enthalpy and entropy from the Mollier chart	136
4.11	Heat Transfer	136
	4.11.1 Conduction Heat Transfer	136
	4.11.2 Convection Heat Transfer	137
	4.11.3 Radiation Heat Transfer	138
	Example 4.20 Estimation of radiation heat transfer	139
4.12	Exergy	139
	Summary	141
	Problems	143
	References	152
5	Energy Balances	153
5.1	Balance Equations	153
5.2	Mass Balance.	154
5.3	Energy Balance	156
	5.3.1 Unsteady State Flow Systems.	157
	5.3.2 Steady-State Flow Systems.	157
	Example 5.1 Energy balance calculations in a closed system.	158
5.4	Exergy Balance	159
	Example 5.2 Exergy loss calculations	160
5.5	Fluid Flow Processes	161
	5.5.1 Turbines, Compressors, and Pumps	161
	Example 5.3 Turbine calculations.	162
	Example 5.4 Compressor calculations.	163
	Example 5.5 Calculation of shaft work during air compression	163
	Example 5.6 Pump power calculation	164
	Example 5.7 Pump work calculations	165
	5.5.2 Nozzles and Diffusers	165
	Example 5.8 Nozzle calculations	166
	5.5.3 Mixing Chambers	166
	Example 5.9 Mixing chamber calculations.	167
	5.5.4 Throttling Valve	167
	Example 5.10 Throttling process calculations.	168
	Example 5.11 Throttling of a refrigerant	169
	5.5.5 Heat Exchangers	169
	Example 5.12 Heat exchanger calculations	170
	5.5.6 Pipe and Duct Flows	171
5.6	Energy Balance in a Cyclic Process	171

Summary	173
Problems	174
References	181
6 Energy Production	183
6.1 Energy Production	183
6.2 Electric Power Production	184
Example 6.1 Power production by an adiabatic steam turbine	185
6.3 Transmission of Energy.	186
6.3.1 Distributed Energy Resources.	187
6.4 Power-Producing Engine Cycles.	188
Example 6.2 Steam Power Production	189
Example 6.3 Steam flow rate calculation in a power plant. . .	190
6.4.1 Carnot Cycle	191
Example 6.4 Power output from a Carnot cycle	191
6.4.2 Rankine Cycle	192
Example 6.5 Analysis of a simple ideal Rankine cycle	194
6.4.3 Brayton Cycle	195
6.4.4 Stirling Engine	196
6.4.5 Combined Cycles	197
6.5 Improving the Power Production in Steam Power Plants	197
6.5.1 Modification of Operating Conditions of the Condenser and Boiler	198
6.5.2 Reheating the Steam	198
Example 6.6 Simple reheat Rankine cycle in a steam power plant	199
6.5.3 Regeneration	200
Example 6.7 Power output of ideal regenerative Rankine cycle	200
6.5.4 Reheat–Regenerative Rankine Cycle	202
Example 6.8 Ideal reheat–regenerative cycle	203
6.6 Geothermal Power Plants.	204
Example 6.9 A steam power plant using a geothermal energy source	205
6.7 Cogeneration	205
Example 6.10 Energy output in a cogeneration plant	206
Example 6.11 Estimation of process heat in a cogeneration plant	207
6.8 Nuclear Power Plants	208
6.9 Hydropower Plants	209
Example 6.12 Hydroelectric power output.	210

6.10	Wind Power Plants	210
	Example 6.13 Windmill power estimations	212
	Example 6.14 Estimation of power available from a wind turbine	213
6.11	Solar Power Plants	213
6.12	Hydrogen Production	215
	6.12.1 Hydrogen Production from Natural Gas	215
	6.12.2 Wind-Based Electrolytic Hydrogen Production	217
	6.12.3 Hydrogen Economy	217
6.13	Fuel Cells	218
	6.13.1 Direct-Methanol Fuel Cells	220
	6.13.2 Microbial Fuel Cell	221
6.14	Biomass and Bioenergy Production	222
	6.14.1 Bioethanol Production	223
	6.14.2 Biodiesel and Green Diesel Production	223
	6.14.3 Energy from Solid Waste	224
6.15	Other Energy Production Opportunities	225
6.16	Levelized Energy Cost	225
6.17	Thermoeconomics	228
	Example 6.15 Thermoeconomics of power generation	230
	Summary	231
	Problems	233
	References	238
7	Energy Conversion	241
7.1	Energy Conversion	241
7.2	Series of Energy Conversions	244
7.3	Conversion of Chemical Energy of Fuel to Heat	244
	7.3.1 Heating Value of a Fuel	245
	Example 7.1 Estimation of lower heating value from higher heating value	245
	Example 7.2 Estimating the heating values from the standard heat of combustion	246
7.4	Thermal Efficiency of Energy Conversions	247
7.5	Ideal Fluid Flow Energy Conversions	248
	Example 7.3 Maximum work (ideal work) calculations	250
	Example 7.4 Isentropic turbine efficiency	250
7.6	Lost Work	251
	Example 7.5 Estimation of lost work	252
	Example 7.6 Estimation of a minimum power required in a compressor	253
7.7	Efficiency of Mechanical Energy Conversions	253
	Example 7.7 Heat loss in an electric motor	255
	Example 7.8 Mechanical efficiency of a pump	255

7.8	Conversion of Thermal Energy by Heat Engines	256
	Example 7.9 Thermal efficiency of a heat engine	258
	Example 7.10 Fuel consumption of a car	259
7.8.1	Air-Standard Assumptions	259
7.8.2	Isentropic Processes of Ideal Gases	260
7.8.3	Conversion of Mechanical Energy by Electric Generator.	261
7.8.4	Carnot Engine Efficiency	262
7.8.5	Endoreversible Heat Engine Efficiency.	264
7.8.6	Rankine Engine Efficiency	265
	Example 7.11 Steam turbine efficiency and power output . . .	266
	Example 7.12 Estimation of thermal efficiency of a Rankine cycle	267
7.8.7	Brayton Engine Efficiency	269
	Example 7.13 Simple ideal Brayton cycle calculations with variable specific heats.	271
	Example 7.14 Thermal efficiency of an actual Brayton cycle with variable specific heats	272
	Example 7.15 Ideal Brayton cycle with constant specific heats	273
7.8.8	Otto Engine Efficiency.	274
	Example 7.16 Estimation of the efficiency of Otto engine . . .	277
	Example 7.17 Estimation of the work output of Otto engine	277
	Example 7.18 Efficiency calculations of ideal Otto engine with variable specific heats	278
	Example 7.19 Efficiency calculations of an ideal Otto cycle with constant specific heats	279
7.8.9	Diesel Engine Efficiency	281
	Example 7.20 Thermal efficiency of an ideal Diesel engine with the constant specific heats.	282
	Example 7.21 Thermal efficiency of an ideal Diesel engine with variable specific heats	283
7.8.10	Ericsson and Stirling Engine Efficiency	284
7.8.11	Atkinson Engine Efficiency	285
7.9	Improving Efficiency of Heat Engines	286
7.10	Hydroelectricity	287
	Example 7.22 Efficiency of a hydraulic turbine	288
	Example 7.23 Pumped energy in a hydropower plant	288
7.11	Wind Electricity	289
	Example 7.24 Efficiency of a wind turbine	289
7.12	Geothermal Electricity.	290
7.13	Ocean Thermal Energy Conversion.	290
7.14	Thermoelectric Effect	291

7.15	Efficiency of Heat Pumps and Refrigerators	291
7.15.1	Heat Pumps	292
Example 7.25	Heat pump calculations	294
7.15.2	Refrigerators	294
Example 7.26	Analysis of a refrigeration cycle	295
Example 7.27	Heat rejection by a refrigerator	297
Example 7.28	Coefficient of performance of a vapor- compression refrigeration cycle.	297
7.16	Efficiency of Fuel Cells	298
7.17	Energy Conversions in Biological Systems	299
7.17.1	Energy Conversion by Oxidative Phosphorylation	299
7.17.2	Energy from Photosynthesis	300
7.17.3	Metabolism	300
7.17.4	Biological Fuels	301
7.17.5	Converting Biomass to Biofuels	301
	Summary	302
	Problems	306
	References	318
8	Energy Storage	321
8.1	Energy Storage and Regulation	322
8.1.1	Water	322
8.1.2	Hydrogen.	323
8.2	Types of Energy Storage	324
8.3	Thermal Energy Storage	324
8.3.1	Solar Energy Storage.	326
8.3.2	Sensible Heat Storage	327
Example 8.1	Sensible heat storage calculations	328
8.3.3	Latent Heat Storage by Phase Changing Material.	329
Example 8.2	Heat storage calculations	332
8.3.4	Ice Storage.	333
8.3.5	Molten Salt Technology.	334
8.3.6	Seasonal Thermal Energy Storage	334
8.3.7	Seasonal Solar Thermal Energy Storage for Greenhouse Heating.	335
Example 8.3	Latent heat storage calculations	338
8.3.8	Underground Thermal Energy Storage Systems.	339
8.3.9	Aquifer Thermal Energy Storage.	339
8.3.10	Borehole Thermal Energy Systems	340
8.4	Electric Energy Storage	341
8.4.1	Hydroelectric Energy Storage	343
Example 8.4	Pumped energy in a hydropower plant	343

8.4.2	Electric Energy Storage in Battery	344
8.4.3	Rechargeable Battery for Electric Car	345
8.5	Chemical Energy Storage	347
8.5.1	Bioenergy Sources	348
8.5.2	Energy Storage in Biofuels.	348
8.5.3	Energy Storage in Voltaic Cell	349
8.6	Mechanical Energy Storage	351
8.6.1	Compressed Air Energy Storage	351
	Example 8.5 Maximum air compressed energy storage	352
	Example 8.6 Maximum air compressed energy storage in a large cavern.	353
8.6.2	Flywheel Energy Storage	354
8.6.3	Hydraulic Accumulator	354
8.6.4	Springs	354
	Summary	354
	Problems	357
	References	361
9	Energy Conservation	363
9.1	Energy Conservation and Recovery.	363
9.2	Conservation of Energy in Industrial Processes.	364
9.2.1	Energy Conservation in Power Production	364
	Example 9.1 Energy conservation by regeneration in a Brayton cycle.	365
	Example 9.2 Increasing the efficiency of a Rankine cycle by reducing the condenser pressure.	368
	Example 9.3 Maximum possible efficiency calculation in Example 9.2.	370
	Example 9.4 Increasing the efficiency of a Rankine cycle by increasing the boiler pressure.	371
	Example 9.5 Increasing the efficiency of a Rankine cycle by increasing the boiler temperature	372
	Example 9.6 Estimation of maximum possible efficiencies in Example 9.5.	373
9.2.2	Energy Conservation in the Compression and Expansion Work.	374
	Example 9.7 Energy conservation in a two-stage compression work by intercooling.	375
	Example 9.8 Compressor efficiency and power input	376
	Example 9.9 Energy conservation in expansion by replacing a throttle valve with a turbine	377
9.2.3	Conservation of Energy by High-Efficiency Electric Motors.	378

9.3	Energy Conservation in Home Heating and Cooling	379
9.3.1	Home Heating by Fossil Fuels	381
9.3.2	Home Heating by Electric Resistance	381
9.3.3	Home Heating by Solar Systems.	382
	Example 9.10 Heating a house by heat pump	383
	Example 9.11 Energy conservation in house heating by Carnot heat pump.	383
9.4	Energy Efficiency Standards.	384
9.4.1	Efficiency of Air Conditioner	385
	Example 9.12 Electricity cost of air conditioner	386
9.4.1.1	Maximum Possible Efficiency for Cooling	386
	Example 9.13 Calculating the annual cost of power for an air conditioner.	387
	Example 9.14 Saving the cost of cooling with a unit operating at a higher SEER rating.	388
9.4.2	Fuel Efficiency	388
	Example 9.15 Comparison of energy sources of electricity with natural gas for heating	389
	Example 9.16 Overall efficiency and required amount of coal in a coal-fired steam power plant	389
	Example 9.17 Required amount of coal in a coal-fired steam power plant.	391
9.4.3	Fuel Efficiency of Vehicles	392
	Example 9.18 Fuel consumption of a car	393
9.4.4	Energy Conservation While Driving	393
	Example 9.19 Fuel conservation with a more fuel-efficient car	394
9.4.5	Regenerative Braking	394
9.5	Energy Conservation in Electricity Distribution and Smart Grid	395
9.5.1	Standby Power	396
9.5.2	Energy Conservation in Lighting.	396
	Example 9.20 Conservation of energy with compact fluorescent bulbs.	397
9.5.3	Energy Harvesting	397
9.6	Exergy Conservation and Exergy	398
9.7	Energy Recovery on Utilities Using Pinch Analysis	398
9.7.1	Composite Curves.	399
	Example 9.21 Energy conservation by the pinch analysis . . .	400
	Summary	403
	Problems	405
	References	418

10	Energy Coupling	419
10.1	Energy Coupling and Gibbs Free Energy	419
10.2	Energy Coupling in Living Systems	420
10.3	Bioenergetics	421
10.3.1	Mitochondria	422
10.3.2	Electron Transport Chain and Adenosine Triphosphate (ATP) Synthesis	422
10.3.3	Active Transport	423
10.4	Simple Analysis of Energy Coupling	424
Example 10.1	Efficiency of energy conversion of photosynthesis	426
10.5	Variation of Energy Coupling	427
10.5.1	Regulation of Energy Coupling	429
10.5.2	Uncoupling	430
10.5.3	Slippages and Leaks	430
10.6	Metabolism	430
10.6.1	Catabolism	431
10.6.2	Anabolism	432
10.7	Bioenergy Sources	432
Example 10.2	Oxidation of glucose	433
Example 10.3	Daily energy expenditure	433
Example 10.4	Energy expenditure in small organisms	434
Example 10.5	Energy expenditure in an adult organism	435
	Summary	436
	Problems	438
	References	439
11	Sustainability in Energy Technologies	441
11.1	Sustainability	442
11.1.1	Sustainability and Ecology	442
11.2	Sustainability Impact Indicators	443
11.3	Energy and Global Warming	444
Example 11.1	Carbon dioxide emission from natural gas combustion	446
11.3.1	Tackling Global Warming	447
Example 11.2	Consumption of coal and emission of carbon dioxide from coal	447
Example 11.3	Reducing air pollution by geothermal heating	448
11.4	Sustainability Metrics	448
11.4.1	Carbon Tracking	449
11.4.2	Global Warming Potential	450
11.5	Sustainability in Energy Systems	450
11.5.1	Sustainable Engineering Principles in Energy Systems	451

11.6	Impact of Renewable Energy Sources on Sustainability	453
11.6.1	Wind Power-Based Electrolytic Hydrogen Production	453
11.6.2	Carbon Dioxide Capture and Compression	454
11.6.3	Sustainable Methanol Production	454
11.7	Multi-Criteria Decision Matrix on Feasibility of Energy Production	456
11.8	Sustainable Refinery Operation.	457
11.9	Thermodynamic Analysis and Sustainability.	458
11.10	Life Cycle Analysis	458
11.10.1	Life Cycle Assessment Principles	459
11.10.2	Benefits of International Organization for Standardization	461
11.10.3	Life Cycle Analysis Stages.	462
11.10.4	Life Cycle Assessment	464
11.10.5	LCA Impact Categories	467
11.11	Life Cycle Analysis of Energy Systems.	469
11.12	Economic Input–Output Life Cycle Assessment (EIO-LCA)	470
11.13	Cost of Pollution Control.	471
11.14	Environment and Exergy	471
11.14.1	Resource Depletion and Exergy	472
11.14.2	Extended Exergy Analysis	473
11.15	Ecological Cost	474
11.15.1	Index of Ecological Cost	474
11.15.2	Ecological Planning.	475
11.15.3	Coal-Fired Power Plants	476
11.15.4	Nuclear Power Plants	476
11.16	Some Projections on Energy and Environmental Protection	477
	Summary	479
	Problems	481
	References	482
	Appendix A: Physical and Critical Properties.	485
	Appendix B: Heat Capacities.	489
	Appendix C: Enthalpies and Gibbs Energies of Formation	493
	Appendix D: Ideal Gas Properties of Some Common Gases	495

Appendix E: Thermochemical Properties	501
Appendix F: Steam Tables	511
Index	613

Energy

Production, Conversion, Storage, Conservation, and
Coupling

Demirel, Y.

2016, XXVI, 616 p. 159 illus., Hardcover

ISBN: 978-3-319-29648-7