

**OILFIELD PROCESSING
VOLUME TWO: CRUDE OIL**

Contents

Preface	xi		
Chapter 1		Chapter 5	
Introduction and Scope	1	Field Processing of Crude Oil	61
Review Questions	4	Introduction	61
References	4	Design Bases	61
Chapter 2		Processing Operations	63
Characterization of Crude Oils	5	Processing Scope	65
Introduction	5	Environmental Considerations	73
Crude Oil Sampling and Analysis	16	Review Questions	76
Product Specifications	18	Problems	76
Review Questions	21	Nomenclature	77
Problems	21	References	77
Nomenclature	21	Chapter 6	
References	22	Phase Separation of Gas, Oil, and Water	79
Chapter 3		Introduction	79
Phase Behavior	25	Terminology	79
Introduction	25	Physical Description	80
Fluid Phase Behavior	25	Comparison of Separators	90
Equilibrium Calculations	27	Phase Separation Theory	91
Thermodynamics of Vapor-Liquid Equilibria	29	Design Considerations	95
Nomenclature	35	Design Examples	101
Review Questions	36	Maintenance and Troubleshooting	108
References	36	Review Questions	109
Chapter 4		Problems	109
Water-in-Crude Oil Emulsions	39	Nomenclature	110
Introduction	39	References	111
Emulsions	39	Chapter 7	
Wellhead Emulsions	41	Dehydration of Crude Oil	113
Emulsion Stability	44	Introduction	113
Settling/Rising Velocities	45	Terminology	114
Potential Emulsification Tendencies		Treating Methods	115
of Production Practices	52	Design Considerations	131
Emulsion Prevention	52	Design Examples	136
Review Questions	56	Operation and Maintenance	138
Problems	57	Review Questions	140
Nomenclature	57	Problems	141
References	58	Nomenclature	141
		References	142

Chapter 8			
Desalting of Crude Oil	145		
Introduction	145		
Process Description	146		
Design Considerations	149		
Design Procedures	150		
Operation	154		
Troubleshooting	155		
Review Questions	155		
Problems	156		
Nomenclature	156		
References	157		
Appendix 8–1	157		
Appendix 8–2	158		
Chapter 9			
Stabilization and Sweetening of Crude Oil	159		
Introduction	159		
Multistage Separation	160		
Condensate	165		
More-Complex Processing	167		
Sweetening	168		
Summary	172		
Review Questions	173		
Problems	173		
Nomenclature	173		
References	174		
Chapter 10			
Pumps	175		
Introduction	175		
General Considerations	175		
Centrifugal Pumps	176		
Positive Displacement Pumps	182		
Drivers	184		
Pump Selection	185		
Pump Design Theory	188		
Design Procedure	191		
Installation and Operation	195		
Troubleshooting	197		
Review Questions	197		
Problems	199		
Nomenclature	200		
References	200		
Chapter 11			
Measurement of Crude Oil	203		
Introduction	203		
Types of Meters	203		
Storage Tanks	206		
			Lease Automatic Custody Transfer (LACT)
		Units	213
		Turbine Meters	217
		Orifice Meters	219
		Meter Proving	221
		Mass Flowmeters	227
		Multiphase Flow Metering	229
		Meter Selection	231
		Metering Error	232
		Review Questions	234
		Problems	235
		Nomenclature	235
		References	237
		Chapter 12	
		Firetube Heaters	239
		Introduction	239
		Combustion	240
		Firetube Heaters	244
		Design	254
		Operation	263
		Review Questions	265
		Problems	266
		Nomenclature	266
		References	267
		Chapter 13	
		Transportation of Crude Oil	269
		Introduction	269
		Pipeline Design	269
		Heavy Oil Transport	281
		Pipeline Pump Selection	285
		Pipeline Operation	286
		Pipeline Construction	288
		Pipeline Cost	288
		Review Questions	288
		Problems	289
		Nomenclature	290
		References	291
		Chapter 14	
		Energy Conservation	293
		Introduction	293
		Energy Audits	295
		Fired Heaters	297
		Insulation	297
		Prime Movers	300
		Waste Heat Recovery	302
		Dehydration of Crude Oil	303
		Operating Pressure and Vapor Recovery	304

Electrical Power	306	Chapter 17	
Miscellaneous	311	Case Studies	379
Summary	313	Introduction	379
Review Questions	314	Case Study No. 1	379
Problems	314	Case Study No. 2	384
Nomenclature	315	Review Questions	388
References	316	Problems	388
		References	390
Chapter 15		Appendix 1	
Instrumentation and Process Control	319	Glossary of Terms	391
Introduction	319	Appendix 2	
Process Control Concepts	319	Material Balances	399
Feedback Control	321	Appendix 3	
Advanced Control Loops	322	Energy Balances	403
Sensing Devices	324	Appendix 4	
Control Valves	324	OPSIM	406
Controllers and Control Action	331	Introduction	406
Safety and Control Applications	334	Use of the Program	406
Control of Processing Plants	338	OPSIM Execution	409
Review Questions	347	Example Problems	411
Problems	348	Description of the Modules	416
Nomenclature	348	Structure of OPSIM	422
References	349	References	423
Chapter 16		Appendix 5	
Pressure Relief and Flaring	351	Conversion of Units	424
Introduction	351	Conversion Factors	425
Depressuring, Emergency Relief, and Flare Systems	352	Appendix 6	
General Considerations	354	Physical Properties of Fluids	426
Pressure Relief Devices	356	Index	430
Flaring	365		
Review Questions	374		
Problems	375		
Nomenclature	375		
References	376		

Preface

Oilfield Processing is the second book in the three-volume series on the various surface unit operations commonly used in production facilities. Natural gas was covered in Volume 1 which was published in 1991. Oilfield waters (both produced and injection) will be covered in Volume 3.

Hopefully, this book will serve three needs. First, in the form of typed notes, the current material has been used as a text for a senior-level, petroleum engineering design course on surface production and processing. The authors do appreciate the numerous suggestions from the University of Tulsa seniors who have used these notes.

Second, this book material has been used in short courses for engineers and foremen working in field handling of crude oil. It is hoped that this book will help engineers in other disciplines learn petroleum production concepts.

Third, this book should serve as a refresher and handbook for all engineers interested in field handling of crude oil.

The mathematical background required to use this book has been kept to a minimum to make it easily readable and immediately useful. Where advantageous, current computer simulation has been identified but computer expertise is not required.

The authors were shocked and deeply saddened by the sudden death of Nelda Whipple on May 21, 1991. Nelda typed and retyped numerous drafts of Volume 1 and the early versions of much of Volume 2. We miss her very much.

The authors express their gratitude and thanks to the University of Tulsa for providing the opportunity and environment to write this book. The University of Tulsa enjoys many long-standing and close relationships with the petroleum industry. In fact, so many petroleum industry engineers helped so much that it is impossible to document every kindness.

Nevertheless, the authors are pleased to thank the following friends and companies for providing up-to-date information and for reviewing drafts:

Coastal Chemical Company	Don Ballard Bill Manning
Conoco Inc.	Albert Peck Scott Dalton Garvin Fryar Bob Gibson Gene Morrison Joe Provine Harry Sharkis Duane Wilson Wayne Wilson
Flow Con Hughes Anderson NATCO	Mike Hein Ed Flaxbart B. E. Harrell Floyd Prestridge Gary Sams Harry Wallace Ken Warren
The Pro Quip Corp.	Ron Key Don Love
Radco Inc.	Reed Melton Shannon Melton
T. H. Russell Company	Tom Russell

While all these friends were exceedingly helpful, some contributions demand individual recognition. Dr. Bill Manning coauthored Chapter 12. Professor Kerry Sublette's critiques of Chapters 4, 7, and 8 were tantamount to coauthorship as were Al Peck's suggested revisions for Chapter 15 and Bob Gibson's review of Chapter 16.

The authors have collectively and individually taught numerous short courses worldwide for Amoco Production, OGCI, Rike Service Inc., and Texaco. This experience proved invaluable, as did Professor Thompson's 15-year experience with Crest Engineering and Furlow-Philbeck Engineering.

The senior author thanks the University of Tulsa and the College of Engineering and Applied Sciences for granting him a sabbatical leave during the 1993 fall semester to work on this volume.

Chapter 1

Introduction and Scope

As produced, wellhead fluids—crude oil, natural gas, and brine—must be processed before sale, transport, reinjection, or disposal. Therefore, oil and gas production involve a number of surface unit operations between the wellhead and the point of custody transfer or transport from the production facilities (Figure 1–1). Collectively these operations are called field handling or oilfield processing. Accordingly *oilfield processing* is defined as the processing of oil and/or gas for safe and economical storage and/or transport by pipeline, tanker, or truck. Oilfield processing also includes *water treatment*, whether produced waters for disposal and/or reinjecting, or additional injection waters used for formation flooding or reservoir-pressure maintenance.

The present work is Volume 2 in a two-volume treatise on *Oilfield Processing of Petroleum*. Process descriptions, design methods, operating procedures, and troubleshooting are covered in detail and nearly every chapter concludes with review questions and practical numerical problems. Volume 1 discussed oilfield processing of natural gas in detail (Manning and Thompson, 1991). The present Volume 2 describes oilfield processing of crude oil.

In this volume “conditioning,” “processing,” and “handling” are used synonymously to refer to all oilfield operations.

“Separation,” “dehydration,” “desalting,” “sweetening,” and “stabilization” describe specific operations as follows:

- Separation: Separating the vapor, oil, and water phases of a produced wellhead stream.
- Dehydration: Removing water droplets or S & W or B S & W from crude oil (sometimes called treating).

- Desalting: Reducing the salt content of a crude oil by diluting the entrained/emulsified water and then dehydrating.
- Sweetening: Removing H₂S and other sulfur compounds.
- Stabilization: Removing the most volatile components of a crude oil to reduce the Reid vapor pressure (RVP), or more correctly the bubblepoint pressure.

As shown in Figure 1–1, the *scope* of oilfield processing of crude oil starts at the wellhead and ends with a pipeline, storage tank, or tanker. As is also shown in Figure 1–1, oilfield processing generally consists of two distinct categories of operations:

1. Separation of the gas-oil-brine wellstream into its individual phases.
2. Removal of impurities from the separated phases to meet sales/transportation/reinjection specifications and/or environmental regulations.

Obviously, the selection and operation of field-handling equipment depend very strongly on the *volume* and *characteristics* of the *streams produced* at the *wellhead*. Accordingly, Volume 2 starts with three chapters describing crude oils:

- Chapter 2—Characterization of Crude Oils
- Chapter 3—Phase Behavior of Crude Oil
- Chapter 4—Water-in-Crude-Oil Emulsions

A similar description of natural gas is available in Volume 1.

In every situation the actual processing scheme depends not only on the wellhead stream, but also on product selection and delivery specifications. Therefore, overall crude oil processing considerations such as design basis and processing scope and objectives are reviewed next in Chapter 5. Natural gas processing schemes are discussed in Volume 1.

Review Questions

1. What are the three main objectives of crude oil processing?
2. Name the principle types of petroleum fluids produced from subsurface reservoirs.
3. Define: natural gas, crude oil, condensate, solution gas, separator gas, formation-volume factor, shrinkage, GOR, wet gas, dry gas, sweet crude (versus sour crude).
4. Define: conventional crude, heavy crude, extra-heavy crude, natural bitumen, oil or tar sands, and shale.
5. List the constituents of crude oil as produced at the wellhead.
6. List the parameters commonly used to characterize crude oil.
7. List the major types of hydrocarbons found in crude oil.
8. What is an isomer?
Draw structures for the five hexane (C_6H_{14}) isomers.
9. Define characterization factor.
10. List the constituents in crude oil that can cause problems.
Identify the potential problems caused by each constituent.
11. What types of solids can be found in crude oils?
How do asphaltenes and resins differ?
12. What can happen when the reservoir pressure falls below the bubblepoint of the original reservoir fluid?
13. How do subsurface and surface sampling of crude oils differ?
Identify one major difficulty in sampling a crude oil for custody transfer.
14. List the commonly used crude-oil pipeline specifications.
Identify the tests used to define these specifications.
15. Describe the Reid vapor pressure test (RVP).
Why is the RVP used much more frequently than a true vapor pressure or bubblepoint pressure?
16. The RVP (in psia) is obtained by reading a gage pressure. True or false? If true, explain.
Why is the RVP always less than the TVP?
17. What tests are involved in a complete assay of a crude oil?

Problems

1. One thousand barrels (bbl) of a 30°API crude oil are blended with five hundred barrels (bbl) of a 20°API crude. Estimate the °API of the resulting blend. State all assumptions. [See Ashcroft *et al.* (1991) for information on volume shrinkage when crude oils are blended.]
2. Barrios (1989) reports the following water measurements on crude oil:

Centrifuge method (ASTM D 4007)	0.050 %
Water by distillation (ASTM D 4006)	0.208 %
Karl Fischer method	0.226 %

Which method is the most accurate? Estimate the loss in revenue if the centrifuge method is used in the custody transfer of 100,000 bopd. Who loses—the buyer or the seller?

Nomenclature

ANSI = American National Standards Institute formerly “ASA” and “USAS”

API = American Petroleum Institute

°API = liquid specific gravity scale defined by:

$$^{\circ}\text{API} = (141.5 / \text{SG} @ 60/60^{\circ}\text{F}) - 131.5 \quad (2-2)$$

ASTM = American Society for Testing and Materials

bopd = barrels of oil per day

BS&W = basic sediment and water

bwpd = barrels of water per day

bsto = barrels of stock tank oil

CF = characterization factor (see UOP K) (2-1)

cP = centipoise

EOR = enhanced oil recovery

FVF or B_o = formation volume factor for crude oil

GOR = gas oil ratio

MMS = Minerals Management Service

OCS = Offshore Continental Shelf

ppmv = parts per million by volume

res bbl = barrels of reservoir fluid

RVP = Reid vapor pressure

SF = shrinkage, reciprocal of FVF or B_o

S&W = sediment and water

SG = specific gravity (2-1)

T_b = normal (*i.e.*, at 1 standard atm) boiling point

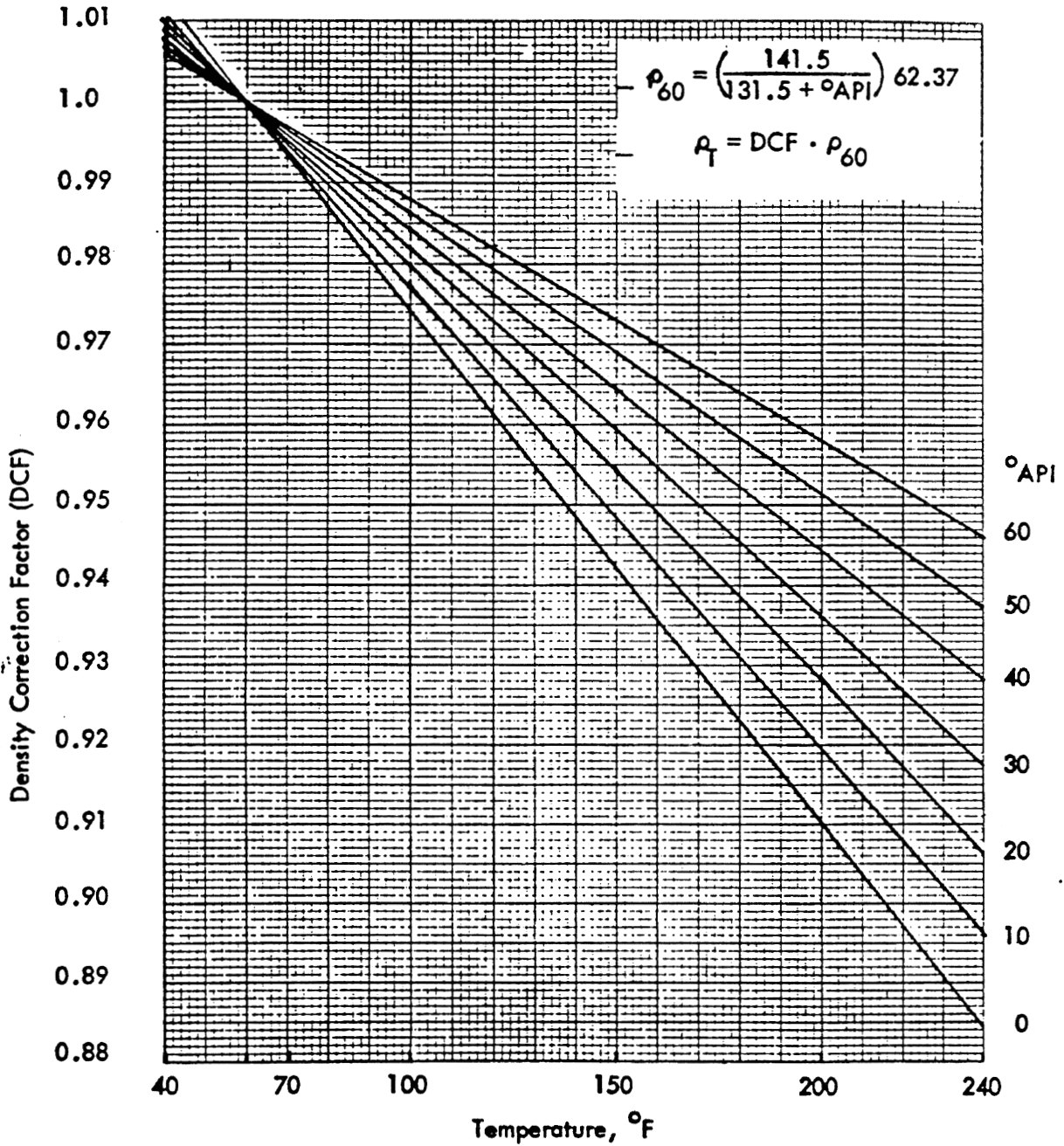


Figure 4-12 Effect of Temperature on Density of Crude Oils (Hankinson et al., 1979)

the water and crude decreases. As discussed in Chapter 7, this limits the temperature to which very heavy crudes should be heated in heater-treaters.

Brine. McCain reports the density of brine at 60°F and 1 atm as a function of total dissolved solids (Figure 4-13). Changes in brine density with temperature can be estimated by:

$$SG_T = SG_{60} F / (1 + \Delta V_{wT}) \quad (4-7)$$

where, ΔV_{wT} is read from Figure 4-14. The effect of pressure is minor; increasing the pressure 2,000 psi increases the density approximately 0.2% (McCain, 1990, p. 448).

Patton (1977) provides another approach (Figure 4-15).

Component	Flow (lbmol/day)
H2O	116.2
N2	618.7
CO2	598.3
C1	6,522.7
C2	2,795.3
C3	2,597.0
iC4	467.3
nC4	1,475.8
iC5	698.7
nC5	818.7
nC6	232.0
H2S	262.6
NBP 140	364.5
NBP 175	1,631.8
NBP 225	1,657.2
NBP 273	1,895.9
NBP 324	1,222.4
NBP 374	914.9
NBP 450	1,362.8
NBP 550	1,110.4
NBP 645	1,019.8
NBP 750	599.4
NBP 892	971.0
NBP 1096	754.9
Wellstream pressure	60 psig
Wellstream temperature	75.6°F

Nomenclature

API = American Petroleum Institute
 bopd = barrels of oil per day
 BTEX = benzene, toluene, ethyl benzene, xylenes
 bwpd = barrels of water per day
 CAAA = Clean Air Act Amendments
 DOT = Department of Transportation
 ECT = Environmental Control Technology
 EOR = enhanced oil recovery
 EPA = Environmental Protection Agency
 GLR = gas-liquid ratio
 GOM = Gulf of Mexico
 GOR = gas-oil ratio
 GOSP = gas-oil separation plant
 LACT = lease automatic custody transfer
 LNG = liquefied natural gas
 LTL = Letter to Lessees and Operators
 MMS = Minerals Management Service
 NGL = natural gas liquids (condensate)
 NORM = naturally occurring radioactive materials
 NPDES = National Pollution Discharge Elimination System
 OCS = Outer Continental Shelf

RCRA = Resource Conservation and Recovery Act
 RP = Recommended Practice
 scf = standard cubic feet
 SDWA = Safe Drinking Water Act
 S&W = sediment and water
 TEG = triethylene glycol (liquid desiccant for natural gas)
 VRU = vapor recovery unit
 UIC = Underground Injection Control
 WMT = waste-management technology
 WOR = water-oil ratio

References

- Anonymous (1991), "EPA Aims to Cut Offshore Platform Discharges," *Oil & Gas Journal*, Vol. 89, No. 10, p. 48 (March 18).
- Anonymous (1992), "EPA Tightens Enforcement on Use of Unlined Pits," *Oil & Gas Journal*, Vol. 90, No. 42, p. 36 (October 19).
- Anonymous (1993), "EPA Drafts Tougher Injection Well Rules," *Oil & Gas Journal*, Vol. 91, No. 24, p. 11 (June 14).
- API RP 14E (1991), "Recommended Practice for Design and Installation of Offshore Production Platform Piping Systems", 5th ed., American Petroleum Institute, 1220 L Street, N.W., Washington, DC 20005 (October 1).
- API BUL E2 (1992), "Bulletin on Management of Naturally Occurring Radioactive Materials (NORM) in Oil & Gas Production," 1st ed., American Petroleum Institute, 1220 L Street, N.W., Washington, DC 20005 (April 1).
- Arnold, Kenneth E. (1983), "Design Concepts for Offshore Produced-Water Treating and Disposal Systems," *Journal of Petroleum Technology*, Vol. 35, No. 2, pp. 276–283 (February).
- Blanscet, D. I. and M. W. Lewellen (1981), "Consolidation and Automation of the Conroe Field Facilities following Unitization," *Journal Petroleum Technology*, Vol. 33, No. 5, pp. 771–778 (May).
- Bleakley, W. B. (1971), "Ekofisk goes on production," *Oil & Gas Journal*, Vol. 69, No. 22, pp. 54–58 (May 31).
- Clark, Norman J. (1960), *Elements of Petroleum Reservoirs*, SPE of AIME, Dallas, Texas.
- Colyer, R. S., and J. Meyer (1991), "Understand the Regulations Governing Equipment Leaks," *Chemical Engineering Progress*, Vol. 87, No. 8, pp. 22–30 (August).
- Curzon, J. E. (1984), "Construction starts on Ekofisk waterflood," *Oil & Gas Journal*, Vol. 82, No. 47, pp. 81–84 (November 19).

Table 6-1 Partial Volumes of Horizontal Cylinders

Zc	Coefficients for Partial Volumes of Horizontal Cylinders, f (Zc)									
	0	1	2	3	4	5	6	7	8	9
.00	.000000	.000053	.000151	.000279	.000429	.000600	.000788	.000992	.001212	.001445
.01	.001692	.001952	.002223	.002507	.002800	.003104	.003419	.003743	.004077	.004421
.02	.004773	.005134	.005503	.005881	.006267	.006660	.007061	.007470	.007886	.008310
.03	.008742	.009179	.009625	.010076	.010534	.010999	.011470	.011947	.012432	.012920
.04	.013417	.013919	.014427	.014940	.015459	.015985	.016515	.017052	.017593	.018141
.05	.018692	.019250	.019813	.020382	.020955	.021533	.022115	.022703	.023296	.023894
.06	.024496	.025103	.025715	.026331	.026952	.027578	.028208	.028842	.029481	.030124
.07	.030772	.031424	.032081	.032740	.033405	.034073	.034747	.035423	.036104	.036789
.08	.037478	.038171	.038867	.039569	.040273	.040981	.041694	.042410	.043129	.043852
.09	.044579	.045310	.046043	.046782	.047523	.048268	.049017	.049768	.050524	.051283
.10	.052044	.052810	.053579	.054351	.055126	.055905	.056688	.057474	.058262	.059054
.11	.059850	.060648	.061449	.062253	.063062	.063872	.064687	.065503	.066323	.067147
.12	.067972	.068802	.069633	.070469	.071307	.072147	.072991	.073836	.074686	.075539
.13	.076393	.077251	.078112	.078975	.079841	.080709	.081581	.082456	.083332	.084212
.14	.085094	.085979	.086866	.087756	.088650	.089545	.090443	.091343	.092246	.093153
.15	.094061	.094971	.095884	.096799	.097717	.098638	.099560	.100486	.101414	.102343
.16	.103275	.104211	.105147	.106087	.107029	.107973	.108920	.109869	.110820	.111773
.17	.112728	.113686	.114646	.115607	.116572	.117538	.118506	.119477	.120450	.121425
.18	.122403	.123382	.124364	.125347	.126333	.127321	.128310	.129302	.130296	.131292
.19	.132290	.133291	.134292	.135296	.136302	.137310	.138320	.139332	.140345	.141361
.20	.142378	.143398	.144419	.145443	.146468	.147494	.148524	.149554	.150587	.151622
.21	.152659	.153697	.154737	.155779	.156822	.157867	.158915	.159963	.161013	.162066
.22	.163120	.164176	.165233	.166292	.167353	.168416	.169480	.170546	.171613	.172682
.23	.173753	.174825	.175900	.176976	.178053	.179131	.180212	.181294	.182378	.183463
.24	.184550	.185639	.186729	.187820	.188912	.190007	.191102	.192200	.193299	.194400
.25	.195501	.196604	.197709	.198814	.199922	.201031	.202141	.203253	.204368	.205483
.26	.206600	.207718	.208837	.209957	.211079	.212202	.213326	.214453	.215580	.216708
.27	.217839	.218970	.220102	.221235	.222371	.223507	.224645	.225783	.226924	.228065
.28	.229209	.230352	.231498	.232644	.233791	.234941	.236091	.237242	.238395	.239548
.29	.240703	.241859	.243016	.244173	.245333	.246494	.247655	.248819	.249983	.251148
.30	.252315	.253483	.254652	.255822	.256992	.258165	.259338	.260512	.261687	.262863
.31	.264039	.265218	.266397	.267578	.268760	.269942	.271126	.272310	.273495	.274682
.32	.275869	.277058	.278247	.279437	.280627	.281820	.283013	.284207	.285401	.286598
.33	.287795	.288992	.290191	.291390	.292591	.293793	.294995	.296198	.297403	.298605
.34	.299814	.301021	.302228	.303438	.304646	.305857	.307068	.308280	.309492	.310705
.35	.311918	.313134	.314350	.315566	.316783	.318001	.319219	.320439	.321660	.322881
.36	.324104	.325326	.326550	.327774	.328999	.330225	.331451	.332678	.333905	.335134
.37	.336363	.337593	.338823	.340054	.341286	.342519	.343751	.344985	.346220	.347455
.38	.348690	.349926	.351164	.352402	.353640	.354879	.356119	.357359	.358599	.359840
.39	.361082	.362325	.363568	.364811	.366056	.367300	.368545	.369790	.371036	.372282
.40	.373530	.374778	.376026	.377275	.378524	.379774	.381024	.382274	.383526	.384778
.41	.386030	.387283	.388537	.389790	.391044	.392298	.393553	.394808	.396063	.397320
.42	.398577	.399834	.401092	.402350	.403608	.404866	.406125	.407384	.408645	.409904
.43	.411165	.412426	.413687	.414949	.416211	.417473	.418736	.419998	.421261	.422525
.44	.423788	.425052	.426316	.427582	.428846	.430112	.431378	.432645	.433911	.435178
.45	.436445	.437712	.438979	.440246	.441514	.442782	.444050	.445318	.446587	.447857
.46	.449125	.450394	.451663	.452932	.454201	.455472	.456741	.458012	.459283	.460554
.47	.461825	.463096	.464367	.465638	.466910	.468182	.469453	.470725	.471997	.473269
.48	.474541	.475814	.477086	.478358	.479631	.480903	.482176	.483449	.484722	.485995
.49	.487269	.488542	.489814	.491087	.492360	.493633	.494906	.496179	.497452	.498726

Source: *GPSA*, 1987: Vol I, p. 6-21, Fig. 6-22