OILFIELD PROCESSING
VOLUME TWO: CRUDE OIL

Contents

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	Mike Hein
Hughes Anderson	Ed Flaxbart
NATCO	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 H_2S 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:

$$°API = (141.5 / SG @ 60/60°F) - 131.5 \qquad (2\text{–}2)$$

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

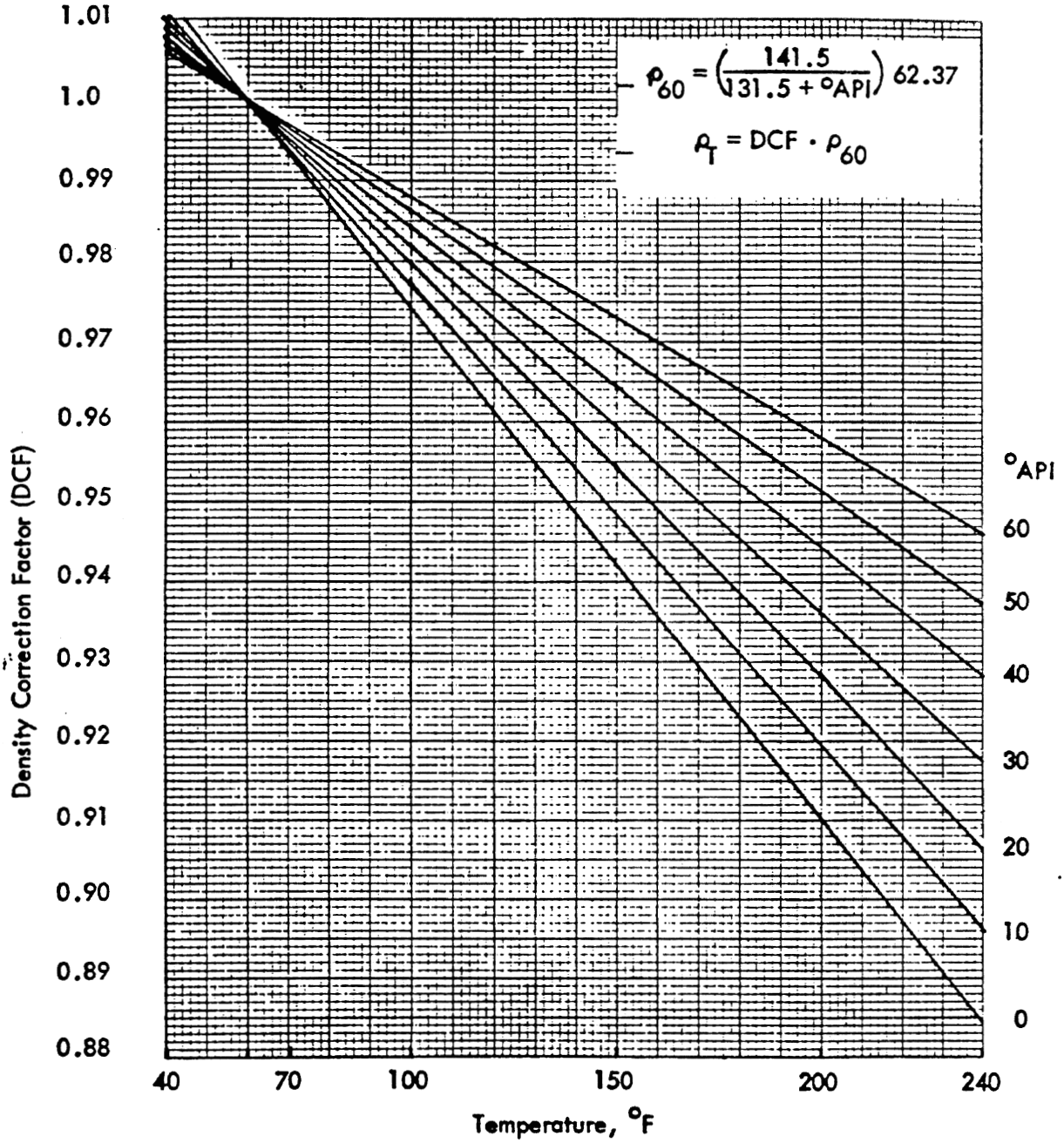

Figure 4–12 Effect of Temperature on Density of Crude Oils (Hankinson et al., 1979)

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:

$$SG_T = SG_{60}\, F/(1 + \Delta V_{wT}) \qquad (4\text{–}7)$$

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

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Table 6–1 Partial Volumes of Horizontal Cylinders

	Coefficients for Partial Volumes of Horizontal Cylinders, f (Zc)									
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