APPLIED ENHANCED OIL RECOVERY

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Dedicated to *Verona*
and *Laurence* and *Claudia* and *Olivia*.

Preface

Enhanced oil recovery is an area of great interest to those involved in and concerned with how to obtain more oil from existing oil reservoirs. Much research and development activity is being carried out, numerous technical papers are appearing, and excellent texts have been written in connection with the subject.

In teaching enhanced oil recovery (EOR), I felt the need for a textbook specifically addressed to petroleum engineering college students and to many other professionals involved in petroleum activity. This book contains thorough coverage of EOR methods describing its complex aspects in a simple and practical manner. As a textbook, the material could be taught in one four-credit-hour semester sequence with flexibility in detailing Chapters 3 through 5 (thermal methods) and 8 through 10 (miscible methods).

This book is the result of 30 years of experience in reservoir engineering, EOR studies, and projects in more than 100 oil reservoirs with a wide variety of characteristics and behaviors. The subjects are approached in a logical progression and include new advances that have occurred. The illustrative examples and case histories are in large part drawn from the technical literature, and the additional personal experience and comments are hoped to enhance the reader's understanding of the subject. The material contains practical mathematical calculations, but a conscious attempt was made to avoid the use of advanced mathematics, leaving an open door for the pursuit of deeper and more detailed knowledge through the existing texts concentrated on one particular type of EOR.

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Fargo, North Dakota — Aurel Carcoana

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Figure 5-1, from "Chemical Aspect of In-Situ Combustion," by Burger and Sahuquet, *Society of Petroleum Engineers Journal* (*SPEJ*), Vol. 12, 1972 © 1972 SPE-AIME. *Figure 5-2,* from "Laboratory Research on Wet Combustion," by Burger and Sahuquet, *Journal of Petroleum Technology,* Vol. 25, © 1973 SPE-AIME. *Figure 5-3,* from "Automation of an In-Situ Combustion Tube," by Vossoughi, S., et al., *SPEJ* August 1982, © 1982 SPE-AIME. *Figure 5-7,* from "Factors Affecting Fuel Availability and Composition," by Alexander, J. D., et al., *Journal of Petroleum Technology,* October 1962, © 1962 SPE-AIME. *Figure 5-10,* from *Combustion as a Primary Recovery Process,* by Gates, C. F., and Sklar, I., in 1985 ed. of SPE Reprint Series, No. 7, © 1985 SPE-AIME. *Figures 5-11; 5–18a, b; 5-19; 5-20; and case history,* from "Results and Difficulties of the World's Largest In-Situ Combustion Process," SPE/DOE paper 20248, by Carcoana, A., presented at the SPE/DOE Seventh Symposium on EOR, Tulsa, Oklahoma, April 1990, © 1990 SPE-AIME. *Figures 5-21 and 5-22,* from "Pressure Maintenance by In-Situ Combustion, W.

Heidelberg Unit," by Huffman et al., *Journal of Petroleum Engineers,* October 1983, © 1983 SPE-AIME. *Figure 5-24,* from "A Method for Engineering In-Situ Combustion Oil Recovery Projects," by Gates, C. F., and H. J. Ramey, Jr., *AIME Transactions,* © 1954 SPE-AIME. *Ch. 5, Example 5-1,* from *Thermal Oil Recovery,* by White, P. D., and Moss, G. T. (The Atomic H/C Ratio Calculation, pp. 72–73), © 1983 PennWell Publishing Co. *Ch. 5, Section 5–15* (*Figures 5-25 and 5-28*), from "How to Engineer an In-Situ Combustion Project," by Nelson, T. W., and McNiel, J. S., *Oil and Gas Journal,* June 5, 1961, © 1961 PennWell Publishing Co.

Table 6-1, adapted from "A Technical Survey of Polymer Flooding Projects," by Manning, R. K., et al., Report U.S. DOE/BC/10327-19, September 1983. *Figure 6-3,* from "Improved Secondary Recovery by Control of Water Mobility," by Pye, David, *Journal of Petroleum Technology,* August 1964, © 1964 SPE-AIME. *Figure 6-5,* from "Reservoir Stability of Polymer Solutions," by Knight B. L., *Journal of Petroleum Technology,* May 1973, © 1973 SPE-AIME. *Figure 6-6,* from "Factor Influencing Mobility Control by Polymer Solutions," by Jennings, R. R., et al., *Journal of Petroleum Technology,* March 1971, © 1971 SPE-AIME. *Figures 6-7 through 6-10,* from "Prediction of Oil Recovery by Waterflood," by Johnson, C. E., Jr., *AIME Transactions,* Vol. 207, 1956, © 1956 SPE-AIME. *Figure 6-11,* from *The Reservoir Engineering Aspects of Waterflooding,* by Craig, F. F., third printing, © 1980 SPE-AIME. *Figures 6-13 through 6-15, and condensed text,* from "Performance and Operation of a Successful Polymer Flood in the Sleepy Hollow Reagan Unit," by Christopher, C. A., et al., SPE/DOE paper 17395 presented at SPE/DOE Sixth Symposium on EOR, Tulsa, Oklahoma, April 1988, © 1988 SPE-AIME.

Tables 7-1 and 7-2, from "New Variations of Chemicals EOR: The ASP Process," by Ball, J., and Surkalo, H., *Proceedings of the Improved Oil Recovery Conference,* Abilene, Texas, September 1988, U.S. Department of Energy, © 1989 DOE/BC/14286-1. *Figures 7-2 through 7-4,* from "Field Trial of Caustic Flooding Process," by Graue, D. J., and Johnson, C. E., Jr., *Journal of Petroleum Technology,* December 1974, © 1974 SPE-AIME. *Figure 7-5 and text condensed,* from "An Evaluation of the Alkaline Waterflooding Demonstration Project Ranger Zone, Wilmington Field," by Dauben et al., in U.S. DOE/BC/10830-5, © 1987 US/DOE.

Figure 8-2, from *Applied Petroleum Reservoir Engineering,* by Craft, B. C., and Hawkins, M. F., p. 64, © 1959 Prentice-Hall, Inc. *Figure 8-3,* from "Carbon Dioxide Miscible Flooding: Past, Present, and Outlook for the Future," by Stalkup, F. I., *Journal of Petroleum Technology,* August 1978, © 1978 SPE-AIME. *Figure 8-6,* from *Miscible Displacement,* by Stalkup, F. I., p. 3, in SPE Monograph Series, Vol. 8, © 1984 SPE-AIME. *Figures 8-10 through 8-14 and condensed text,* from "Tertiary Application of a Hydrocarbon Miscible Flood: Rainbow Keg River 'B' Pool," by Mazzocchi et al., SPE/DOE 17355, presented at EOR Symposium, Tulsa, Oklahoma, April 1988, © 1988 SPE-

AIME. *Figures 8-15 through 8-17 and condensed text,* from "Assessment of a Vertical Hydrocarbon Miscible Flood in the Westpem Nisku D Reef," by Da Sie and Guo, SPE/DOE 17354 presented at EOR Symposium, Tulsa, Oklahoma, April 1988, © 1988 SPE-AIME. *Chapter 8 condensed text,* from *Miscible Displacement,* Ch. 2, pp. 6–16, and *Screening Criteria,* Ch. 5–7, by Stalkup, F. I., SPE Monograph Series Vol. 8, © 1984 SPE-AIME.

Figures 9-3 through 9-5, from "Commercial Scale Demonstration EOR by Micellar-Polymer Flood," Final Report prepared by Stover, D. F., Marathon Oil Co. for the U.S. DOE, AC-19-78 ET13077-130, Bartlesville, Oklahoma, 1988, © 1988 U.S./DOE. *Figure 9-6 and condensed text,* from "A Review of the Loudon Surfactant Flood Pilot Test," work performed by Dauben, D. L., under contract No. AC19-85BC 10830-8 for U.S./DOE Bartlesville, Oklahoma, 1988, © 1988 U.S./DOE. *Figure 9-7 and Figures 9-10 through 9-13, and condensed text,* from "Selection of Reservoir Amenable to Micellar Flooding—Critical Reservoir and Micellar Quantities; Screening and Evaluation," *Proceedings,* Part III and App. III, First Annual Report DOE/BC/00048-20, Bartlesville, Oklahoma, December 1980, © 1980 U.S./DOE. *Figures 9-16 and 9-17,* from "Selection of Reservoirs Amenable to Micellar Flooding," Final DOE Report performed by Goldburg, A., et al., US-DOE BC00048-29, August 1983, © 1983 U.S./DOE.

Figure 10-1, from *Fundamentals of Enhanced Oil Recovery,* by Van Poollen and Associates, p. 133, Tulsa, Oklahoma, © 1980 PennWell Publishing Co., *Figures 10-2 and 10-3,* from "Generalized Correlations of CO_2-Crude Oil System," by Simon, R., and Graue, D. J., *Journal of Petroleum Technology,* January 1965, © 1965 SPE-AIME. *Figures 10-4 and 10-8,* from "Mechanism of Oil Displacement by Carbon Dioxide," by Holm, L. W., and Josendal, V. A., *Journal of Petroleum Technology,* December 1974, lc 1974 SPE-AIME. *Figure 10-5,* adapted from *Miscible Displacement,* by Stalkup, F. I., SPE Monograph Series, Vol. 8, © 1984 SPE-AIME. *Figure 10-7,* from "Determination and Prediction of CO_2 MMP," by Yelling, W. R., et al., *Journal of Petroleum Technology,* January 1980, © 1980 SPE-AIME. *Figure 10-8,* from "Carbon Dioxide Flooding Fundamentals," by Mungan, N., *Journal of Canadian Petroleum Technology,* pp. 87–92, © 1981. *Figures 10-9 and 10-10 and Tables 10-3 and 10-4* (*adapted*), from "Performance Review of a Large-Scale CO_2-WAG Project, SACROC-Unit, Kelly-Snyder Field," by Kane, A. V., *Journal of Petroleum Technology,* February 1979, pp. 217–231, © 1979 SPE-AIME, *Figures 10-11 through 10-14 and SACROC case history,* from "Definitive CO_2 Flooding, Response in the SACROC Unit," Paper SPE/DOE 17321 presented by Langston, M. V., et al., at the SPE/DOE EOR Symposium, Tulsa, Oklahoma, April 1988, © 1988 SPE-AIME. *Figures 10-15, 10-16,* case history, and Table 10-5, from "Review of an Immiscible CO_2 Project, Tar Zone, Fault Blok V, Wilmington Field," by Spivak, A., et al, *SPE Reservoir Engineering,* May 1990, pp. 150–162, © 1990 SPE-AIME. *Example 10-2, condensed text,* from

"Carbon Dioxide Flooding," Ch. IV, in *Improved Oil Recovery,* by Mungan, N., pp. 143–145, © 1983 IOCC.

Figure 11-1, from "Improved Oil Mining: A Feasibility Study Final Report," NIPER-328 performed by Tham, M. K., et al., under Coop. Agreem. No. FC22-83FE60149, Bartlesville, Oklahoma, © 1988 U.S./DOE. *Figure 11-2,* from "Recovery of Oil from Underground Drillsites," Paper SPE 19344 presented by Streeter et al. at the 1989 SPE Eastern Regional Conference and Exhibition, October 1989, Morgantown, West Virginia, © 1989 SPE-AIME. *Figure 11-3 and condensed text,* from "Microbial-Enhanced Waterflood Field Experiment," Topical NIPER-356 Report prepared by Bryant, R. S., et al., for US-DOE under Coop. Agreem. No. FC22-83FE60149, Bartlesville, Oklahoma, © 1989 U.S./DOE. *Figures 11-4 through 11-6 and condensed text, case history,* from "Field Studies of Microbial EOR Paper SPE/DOE 20254, presented by Sheehy, A. J., at the SPE/DOE Seventh Symposium on EOR, Tulsa, Oklahoma, April 1990, © 1990 SPE-AIME.

Figure 12-3, from "Free World Oil Discovery Index," by Ivanhoe, L. B., *Oil & Gas Journal,* November 21, 1983, pp. 88–90, © 1983 PennWell Publishing Co. *Figure 12-5 and Tables 10-1 and 10-2,* from "Review of EOR Projects, Trends and Thermal EOR Technology—Topical Report," by Pautz, J. F., et al., from IIT Research Institute, NIPER-461, under Coop. Agreem. No. FC22-83FE60149, U.S. DOE Bartlesville, Oklahoma, 1990, © 1990 U.S./DOE.

Nomenclature

A	Area, acres, ft^2
a	Geothermal gradient, °F/ft
a	Well-to-well spacing, ft (Eq. 5-19)
a_s	Active surfactant retention, mg/g rock (Eq. 9-7)
B	Formation volume factor, bbl/STB
b	Surface geothermal temperature, °F (Eq. 3-10)
C	Constant (Eq. 3-6)
C	Specific heat capacity, Btu/lbm × °F or J/kg × °C.
C_a	Amount of air required to burn through a cubic foot of reservoir rock, scf/ft^3
C_u	Amount of coke deposited or fuel content, lbm/ft^3
C'_p	Injection pressure gradient, psi/ft (Eq. 9-1)
C_s	Concentration of active surfactant in the injected slug (Eq. 9-7)
C_{1,S_l}	Volume fraction of pseudocomponent 1 in phase S_l
C_{TS}	Surfactant requirements, bbl or m^3

C_{TP}	Polymer requirements, bbl or m^3
D	Depth, ft
D	Thermal diffusivity of the cap rock, ft^2/hr (Eqs. 4-1 and 4-5)
D_e	Effective diffusion coefficient for CO_2/oil or N_2/CO_2, cm^2/s (Eq. 10-7)
D_s	Surfactant retention, dimensionless (Eqs. 9-6, 9-14)
d	Tubing inside diameter, in. (Eq. 10-13)
E	Efficiency, fraction or percent
E	Expenses, $
E_D	Micellar-polymer displacement efficiency, fraction
E_r, E_R	Overall oil recovery factor, percent
F	Fluid volume, bbl
f	Fraction (such as the fraction of a flow stream consisting of a particular phase)
f	Friction factor, fraction (Eq. 10-13)
f_{hv}	Vertical heat loss, fraction (Eq. 4-11)
f_s	Steam quality, percent
$f(t_D)$	Dimensionless transient heat conduction time function (Eq. 3-10)
f_{opk}	Oil cut or the peak oil rate, volume percent (Eq. 9-20)
H	Heat of combustion, Btu/lb_m or J/kg
H_o	Heat injection rate, Btu/hr
h	Formation thickness, ft
h	Enthalpy, Btu/lb_m or J/kg
h	Differential pressure, inches of water (Eq. 3-6)
h_f	Enthalpy of saturated liquid, Btu/lb_m or J/kg
h_g	Total enthalpy, Btu/lb_m or J/kg
h_{fg}	Enthalpy of vaporization, Btu/lb_m or J/kg
K	Thermal conductivity of the cap rock, Btu/ft × hr × °F
k	Permeability, md
k	Thermal conductivity of the earth, Btu/day × ft × °F
$\overline{k}$	Mean permeability, md (Eq. 6-6)
k_s	Permeability at 84.1 percent of the cumulative samples, md
l_v	Specific latent heat (enthalpy) of vaporization, Btu/lb_m or J/kg
l_n	Natural logarithm
log	Base 10 logarithm
M	Mobility ratio, mixture
M_e	Empirical function (Eq. 9-17)

M_s	Heat capacity of steam saturated rock, Btu/ft^3 × °F
m	Mass, lb_m or kg
N	Oil in place, bbl
N_c	Capillary number
N_e	Reynolds number
n	Tubing roughness, in. (Eq. 10-13)
n	Atomic H/C ratio
P, p	pressure, psi
Q	Total heat amount, Btu or joule
Q	Total air injected, scf
Q_D	Total injection volume, pore volumes
Q_f	Net amount of heat available to formation, Btu or joule
Q_g	Steam generator heat loss, Btu or joule
Q_s	Sensible heat, Btu or joule
Q_s	Heat lost on surface lines, Btu or joule
Q_v	Latent heat of vaporization, Btu or joule
Q_w	Heat loss rate in wellbore, Btu/day (Eq. 3-10)
q	Rate, bbl/day
R	Resistance factor, ratio
R	Revenue, $
r	Radius, ft
S	Saturation, fraction
S	Saturation phase (relative amount), fraction
$S_o(S')$	Oil price (base), $/STB
T	Temperature, reservoir temperature, °F or °C
t	Time (injection), days, hours
t_{Dob}	Oil breakthrough time, porous volume (Eq. 9-18)
t_{D_s}	Time of peak oil rate, porous volume (Eq. 9-19)
U	Air flux density, scf/ft^2 × hr
U	Overall heat transfer coefficient, Btu/day × ft × °F
U_o	Idem, Btu/hr × ft × °F
u	Superficial or actual velocity, ft/day
V	Volume, bbl
V, v	Velocity, ft/day
V_{DP} or V	Permeability variation (Dykstra-Parsons)
V_b	Rate of the burning front advance, ft/day
V_o	Rate at which oil is displaced, bbl/day (Eq. 4-4)

V_{gs}	Volume occupied by gases in reservoir after pressurization, bbl (Eq. 10-3)
ν	Specific volume of saturated liquid, ft^3/lb_m
ν_g	Specific volume of saturated vapor, ft^3/lb_m
W	Flow rate of wet steam, gal/min (Eq. 3-6)
W_d	Density of dry steam, lb_m/ft^3 (Eq. 3-6)
W_o	Heat injected lost to adjacent strata, fraction (Eq. 4-2)
W_p	Cumulative water produced, bbl
X	Length of diffusion zone, ft
Y	Mole fraction in combustion gases
Z	Gas deviation factor
Z	Formation depth, ft (Eq. 3-10)
DA	Developed area, acres
ΔN	Cumulative oil produced during an interval, bbl; reserves (recoverable), bbl
ΔT	Temperature difference, °F
MD	Measured depth, ft
MP	Micellar-polymer
PV	Porous volume, bbl
RO	Recoverable oil, bbl
SG	Specific gravity
TO	Target oil, bbl
AOR	Air-oil ratio
API	American Petroleum Institute
EOR	Enhanced oil recovery
FPV	Floodable pore volume, bbl
GOR	Gas-oil ratio
NRP	Number of repeated patterns
OSR	Oil-steam ratio
SOR	Steam-oil ratio
STB	Stock tank barrels
TDS	Total dissolved solids, ppm
TDV	True vertical depth, ft
WOR	Water-oil ratio
ppg	Parts per gallon
ppm	Parts per million
CFPM	Chemical flood predictive model

CRMQ	Critical reservoir and micellar quantities
HCPV	Hydrocarbon pore volume, bbl
OOIP	Original oil in place, bbl
PECφN	Preliminary Economic Evaluation Model
ϕ	Porosity, fraction or percent
λ	Mobility, md/cp
μ	Viscosity, cp
ρ	Density, lb_m/ft^3 or g/cm^3
τ	Interfacial tension (IFT), dyne/cm

Subscripts

a	air, actual, areal
A	areal
b	burning
c	combustion, caprock
cons	consumed
cr	critic
d	dry, diffusion
D	dimensionless, displacement
e	effective, external
ext	exterior
feedw	feedwater
g	gas
h	heated
i	initial, injection
I	invasion, vertical
inj	injected