AN APPROACH FOR DETERMINATION OF THE ECONOMICALLY OPTIMAL PRODUCTION RATE FROM WATER DRIVE OIL RESERVOIRS

By

Mohamed Gamal el-din Mahfouz Ali

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In the Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
PETROLEUM ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis :

An Approach for Determination of the Economically Optimal Production Rate from Water Drive Oil Reservoirs

Key Words : Reservoir Management, Production Optimization, Economic Recovery

Summary :

Experimental design framework was used to define the sensitivities and uncertainties in the parameters that affect on fluid movement and critical rate calculations. An optimization model was built to get the optimum economic combination that achieves the highest net present value. The comparison between the optimization and critical rate correlations results', using actual field data, showed that the optimum combination (Drawdown and perforated interval), achieving the highest economic RF, is completely away from the correlations' results.

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Dedication

I would like to dedicate this thesis to my parents for sacrifices, support, and devotion. They encouraged me to do this work. Also, I would like to dedicate this thesis to my wife (for her prayers, support, and enduring patience) and my new baby "Nadeen".

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Nomenclature

A	= Cross sectional area, ft^2
A_T	= Total area of the field, ft^2
A_W	= Drainage area of a well, ft^2
c_f	= Formation compressibility, psi^{-1}
c_P	= Pore compressibility, psi^{-1}
h	= Formation thickness, ft
h_{ap}	= Oil column height above perforations, ft
h_{bp}	= Average oil column height below perforation, ft
h_O	= Oil column thickness, ft
h_p	= Perforated interval length, ft
h_t	= Total formation thickness, ft
h_{wb}	= Water breakthrough height, ft
i, *i*	= Interest rate per year, fraction
K	= Absolute reservoir permeability, md
K_g	= Effective gas permeability, md
K_h, K_H	= Horizontal oil reservoir permeability, md
K_o	= Effective oil permeability, md
K_{ro}	= Oil relative permeability at (S_{wc}), fraction
$(K_{ro})_{Sgc}$	= Oil relative permeability at critical gas saturation, fraction
$(K_{ro})_{Swc}$	= Oil relative permeability at connate water saturation, fraction
K_{rw}	= Water relative permeability at ($l-S_{or}$), fraction
$(K_{rw})_{Sorw}$	= Water relative permeability at the residual oil saturation, fraction
K_V	= Vertical oil reservoir permeability, md
L	= Wellbore penetration length from top of oil zone, ft
M	= Water/Oil mobility ratio, fraction
n_o, n_w,	= Exponents on relative permeability curves, dimensionless
n_p	= Exponent of the capillary pressure curve for the oil-water system, dimensionless
N_P	= Cumulative oil production, STB
P	= Pressure, psi
$(p_c)_{Swc}$	= Capillary pressure at connate water saturation, psi
p_{cwo}	= Capillary pressure of water-oil systems, psi
P_e	= Reservoir pressure, psi
P_{wf}	= Bottom-hole flowing pressure, psi
q_c	= Critical coning rate, STB/day
q_c^*	= Dimensionless critical coning rate, STB/day
q_{CD}	= Dimensionless critical flow rate, fraction
Q_g	= Gas flow rate, Mscf/day
Q_{gc}	= Critical gas flow rate, Mscf/day
Q_O	= Oil flow rate, STB/day
Q_{oc}	= Critical oil rate, STB/day
Q_{og}	= Critical oil flow rate in gas-oil system, STB/day
Q_{ow}	= Critical oil flow rate in oil-water system, STB/day
$Q_{SC,v}$	= Vertical well super-critical oil production rate, STB/day
q_T	= Total flow rate of the field, STB/day

q_t = Total fluid production rate, STB/day
Q_w, q_w = Water flow rate, STB/day
r_1 = Radius of the cone, ft
r_{De}, r_{eD} = Dimensionless drainage radius, ft
r_e = External or drainage radius, ft
r_w = Wellbore radius, ft
S^*_w = Effective water saturation, fraction
$\boldsymbol{S_k}$ = Net cash flow considered to be spread throughout ***k*** years, dollars
S_{nw} = Saturation of the nonwetting phase, fraction
S_{or} = Residual oil saturation, fraction
S_{orw} = Residual oil saturation in the water-oil system, fraction
S_w = Water saturation, fraction
S_{wc} = Connate water saturation, fraction
T = Reservoir temperature, ^oR
Z = Gas compressibility factor at P and T
Δg = Water-oil static pressure gradient difference, psi/ft
ΔN = Distance from the top of the formation to the top of perforated interval, ft
ΔZ = Gross perforated interval, ft
$\Delta\gamma$ = Water-Oil gravity difference, psi/ft
$\Delta\rho$ = $\rho_w - \rho_o$, density difference, lb/ft^3 or gm/cc
α'' = Dimensionless transformed variable, fraction
β_g = Gas formation volume factor, bbl/SCF
β_o = Oil formation volume factor, bbl/STB
β_w = Water formation volume factor, bbl/STB
δ = Fraction of perforated interval, fraction
δ_g = Dimensionless gas cone ratio, fraction
δ_W = Dimensionless water cone ratio, fraction
ε = Dimensionless perforated length, fraction
λ = Fraction of oil column height above perforation, fraction
μ_g = Gil viscosity, cp
μ_o = Oil viscosity, cp
μ_w = Water viscosity, cp
ρ_g = Gas density, lb/ft^3 or gm/cc
ρ_o = Oil density, lb/ft^3 or gm/cc
ρ_w = Water density, lb/ft^3 or gm/cc
ψ_g = Gas dimensionless function
ψ_w = Water dimensionless function
Φ = Porosity, fraction

Abbreviations

AFOC Annual Fixed Operating Cost
API American Petroleum Institute Standards
AQPERM Aquifer Permeability Modifier
AqRadius Aquifer Radius
BHFP Bottom Hole Flowing Pressure
DD Draw Down

FVF	Formation Volume Factor
GOC	Gas Oil Contact
GOS	Gulf of Suez
IRR	Internal Rate of Return
KzMult	Vertical Permeability Multiplier
MMBtu	Million British Thermal Unit
NPV	Net Present Value
OHC	Oil Handling Cost
OP	Oil Price
OWC	Oil Water Contact
Perf.	Perforated Interval
PERMH	Horizontal Permeability Modifier
PVT	Pressure Volume Temperature Analysis
STB	Stock Tank Barrel
STOIIP	Stock Tank Oil Initially in Place
TVDss	True Vertical Depth Subsea
VFP	Vertical Flow Performance
WHC	Water Handling Cost