''An Integrated Model Predicts the Performance of Combination Drive Reservoirs ''

By

Mohamed Halafawi Yehia Mohamed

A Thesis Submitted To

Department of Mining, Petroleum, and Metallurgical Engineering,

Faculty of Engineering, Cairo University

In partial fulfillment of the Requirements for the Degree of

Master of Science in Petroleum Engineering

Under Supervision of:

Prof. Dr. Abdel-Waly Abdallah Abdel-Waly

Petroleum Engineering Professor, Cairo University

Faculty of Engineering, Cairo University

Giza, Egypt

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Acknowledgement

I thank the Almighty God for giving me the help, strength, and towards accomplishing all my academics endeavors and realizing my personal dreams.

I would like to thank my supervisor, and mentor ***Prof. Dr. Abdel-Waly Abdallah Abdel-Waly*** for giving me this opportunity. My deepest appreciation is for his motivation, guidance, and sound advice throughout the entire program.

Finally, I would like to thank all members of my family, especially my parents for their prayers and patience.

Abstract

Depletion performance of combination drive oil reservoirs is highly influenced by changes in reservoir rock and fluid data, relative permeability data, and PVT data of reservoir.

Future prediction of combination drive oil reservoirs is therefore difficult due to the long term and huge equations, and the sensitivity of data especially the PVT data and relative permeability curve.

In this thesis, an integrated analytical model was constructed with a computer program to simulate the combination drive oil reservoirs performance. It has coupled the general material balance equation with water Influx equations, water-Invaded pore volume equations, gas- invaded pore volume equations, oil and gas saturation equations, and fluids contacts equations for petroleum reservoirs. All these equations are solved simultaneously and with reservoir depletion stages.

The different equations used in the integrated model have been programmed so that it can be utilized in history match mode to estimate original fluids in place, aquifer parameters, and saturation distribution of oil, gas, and water. The model also estimates fluids contacts level, and effective recovery factor during gas movement from higher to lower level and water aquifer movement from lower to higher level towards oil zone in all reservoir depletion stages.

The model has been validated using published cases for various oil reservoirs conditions. It has been shown a good match between the results of published cases and the integrated model ones for these reservoirs. After validating the integrated model, it has been used to simulate an Egyptian Combination Drive Reservoir. The

reservoir production history has been matched and the future production performance for this reservoir was carried out.

In this study, it was noted that the model is capable to predict reservoir performance under water or gas injection or both.

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Nomenclatures

A = Area of the reservoir, acres

B = aquifer constant, bbl/psi

BGOC = Bottom gas-oil contact, ft sub sea

BWOC = Bottomwater-oil contact, ft sub sea

C_f = Compressibility of the aquifer formation, psi^{-1}

C_t = Total (water plus formation) compressibility, Psi^{-1}

C_w = Compressibility of the water, psi-1

f = Encroachment angle, degree

f_g = Fraction of gas in the flowing stream in the reservoir, fraction

f_w = Fraction of water in the flowing stream in the reservoir, fraction

G = Initial gas-cap gas, scf

G_{fg} = Cumulative free gas produced from un-invaded oil zone to end of period, Mcf at std. condition

G_i = Cumulative injected gas at standard conditions, SCF

$G_{i(ext)}$ = Cumulative gas injected in excess of that produced from the beginning of pressure maintenance operations to end of the period, Mcf at std. condition

GOC = Gas-oil contact, ft sub sea

GOR= Instantaneous gas-oil ratio, scf/STB

G_p = Cumulative gas produced, scf

G_{pc} = Cumulative gas production from the gas cap, SCF

G_x = Total volume of gas in any segment at end of period, ft^3

H = Formation thickness, ft

h = Thickness of reservoir, ft

h_w = aquifer thickness, ft

k_{rg}= Relative permeability of the reservoir rock to gas

K_{ro} = Relative permeability of the reservoir rock to oil

K_{ro}/K_{rg} = Ratio of the relative permeabilities of the reservoir rock to oil and gas

K_{ro}/K_{rw} = Ratio of the relative permeabilities of the reservoir rock to oil and water

K_{rw} = Relative permeability of the reservoir rock to water

m = Ratio of initial gas-cap-gas reservoir volume to initial reservoir oil volume, bbl/bbl

M_1 = Slope of the In K_{ro}/K_{rg} vs Sg curve

M_2 = Slope of the In K_{ro} vs S_g curve

M_3 = Slope of the In K_{ro}/K_{rw} vs S_w curve

M_4 = Slope of the In K_{ro}vs S_w curve

N = original oil-in-place, STB

N_p = Cumulative oil produced, STB

N_{pg} = Oil production from the gas-invaded zone, STB

t = Total elapsed time since initial days production,days

OGIP = original free gas-in-place in standard conditions, SCF

OGOC = original gas-oil contact, ft sub sea

OOIP = original oil-in-place at surface conditions, STB

OWOC = original water-oil contact, ft sub sea

P_b = Bubble point pressure, psi

P_D = dimensionless pressure

$P_{D'}$ = first derivative of dimensionless pressure

P_i= Initial reservoir pressure, psi

P_{owc} = pressure at the original OWC, psi

P_{owf} = pressure at the oil/water front, psi

P_r = reservoir pressure, psi

PV = pore volume of the reservoir, res bbl

PV_{BOTTOM} = pore volume from the bottom to the top of the reservoir, res bbl

PV_{BWOC} = pore volume from bottom water-oil contact to top of reservoir, res bbl

PV_{GOC} = pore volume from gas-oil contact to top of reservoir, res bbl

PV_{OGOC} = pore volume from original gas-oil contact to top of reservoir, res bbl

PV_{OWOC} = pore volume from original water-oil contact to top of reservoir, res bbl

PV_{WOC} = pore volume from water-oil contact to top of reservoir, res bbl

Q_{tD} = dimensionless flow rate

Q_{Tx} = Total volume of fluid invading any segment during period, ft^3

r_a = radius of the aquifer, ft

r_D = dimensionless radius, ra/re

r_e = radius of the reservoir, ft

R_{gc} = Current gas/oil contact radius,ft

R_{gi} = Initial gas/oil contact radius, ft

R_o = Original oil reservoir radius, ft

R_{oc} = Current oil/water contact radius

Rp = Cumulative produced gas-oil ratio, scf/STB

Rs = current gas solubility, scf/STB

R_{si}= Original dissolved gas-oil ratio, SCF/STB

S_g = gas saturation, fraction

S_{gc} = critical gas saturation, fraction

S_{go} = Gas saturation in oil zone, fraction

S_{gr} = Residual gas saturation in the shrinking zone, fraction

S_{grg} = Residual gas saturation in the gas-invaded zone, fraction

S_{grw} = Trapped gas saturation in the water-invaded zone, fraction

S_{gt} = trapped gas saturation, fraction

Sin (Ө)= Sine of the angle of formation dip

S_{org} = Residual oil saturation in the gas-invaded zone, fraction

S_{orgw} = residual oil saturation to oil displacement followed by water displacement, fraction

S_{orw} = Trapped oil saturation in the water-invaded zone, fraction

S_{orwg} = residual oil saturation to gas displacement followed by water displacement, fraction

S_{wa} = Average water saturation in the water- invaded zone, fraction

S_{wi} = initial or connate water saturation (S_{wc}), fraction

t = Time, days

t_D = dimensionless time

Ti = Initial reservoir temperature, ^oF

t_j = cumulative elapsed time at end of jth interval, days

V_g = reservoir volume of remaining gas at a given reservoir pressure, res bbl

V_o = reservoir volume of remaining oil at a given reservoir pressure, res bbl

W_e = Cumulative water influx, bbl

W_i = initial volume of water in the aquifer, bbl

$W_{i(ext)}$ = Cumulative water injected in excess of that produced from the beginning of pressure maintenance operation to end of the period, bbl

W_{inj}= Cumulative water injected, STB

WOC = water-oil contact,ft sub sea

W_p = cumulative water production, STB

β_g = Gas formation volume factor at average reservoir conditions, bbl /SCF