

# **"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:

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Faculty of Engineering, Cairo University

Giza, Egypt

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## **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,  $\text{psi}^{-1}$

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

$C_w$  = Compressibility of the water,  $\text{psi}^{-1}$

$f$  = 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

$G_{i(\text{ext})}$  = 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,  $\text{ft}^3$

$H$  = 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  $\ln K_{ro}/K_{rg}$  vs  $S_g$  curve  
 $M_2$  = Slope of the  $\ln K_{ro}$  vs  $S_g$  curve  
 $M_3$  = Slope of the  $\ln K_{ro}/K_{rw}$  vs  $S_w$  curve  
 $M_4$  = Slope of the  $\ln K_{ro}$  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  
 $Q_{ID}$  = 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,  $r_a/r_e$   
 $r_e$  = 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  
 $R_p$  = Cumulative produced gas-oil ratio, scf/STB  
 $R_s$  = 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  
 $\sin(\Theta)$  = 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  
 $T_i$  = Initial reservoir temperature, °F  
 $t_j$  = 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  
 $\beta_g$  = Gas formation volume factor at average reservoir conditions, bbl /SCF