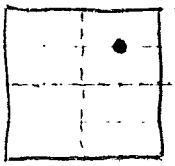
Example Problem - Single Phase Liquid

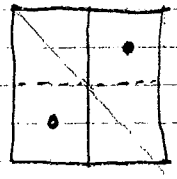
40 acres

1 Well 

- 1 Oil Well on Forty Acres - use liquid solution, $b = 0$
- Assume original well completed and acidized open hole. 0 skin low K layer - 2 or 0 skin high perm. layer.
- Use K ratio of 10
- 2 layer volume ratio 1/5. $b \cong 0.6$
- Shape Factor Skin $S = +0.973$

Infill Drill Phase I

20 acre Spacing

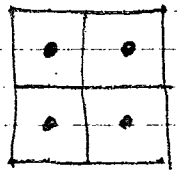
2 Wells 

- 2 Wells 20 acre Spacing.
- Original Well 0 skin low Perm Layer.
- Infill Well - 4 skin both layers.
- Shape Factor skin $S = +0.973$ (Surprisingly
- * Completion in high K layer not necessary.

Δ I wish how used this

Infill Drill Phase II

10 acre Spacing

4 Wells 

- 4 Wells 10 acre Spacing
- Original Well 0 skin low Perm. Layer.
- Shape Factor Skin Now = 0.

43,560 ft^2/acre ; 40 acre $r_o = 745$ ft ; 20 ac $r_e = 527$ ft ; 10 ac $r_e = 3$

$$r_e' = \sqrt{\frac{A}{\pi}} \quad ; \quad q_o = \frac{7.08 k h (P_R - P_{wf})}{\mu_o B_o \left[\ln\left(\frac{r_e'}{r_w}\right) - \frac{3}{4} + S\right]}$$

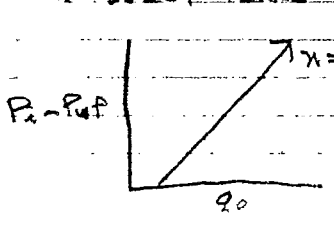
$K_1 = 20$ MD ; $h_1 = 62$ ft
$K_2 = 2$ MD ; $h_2 = 312$ ft
$h_T = 374$ ft

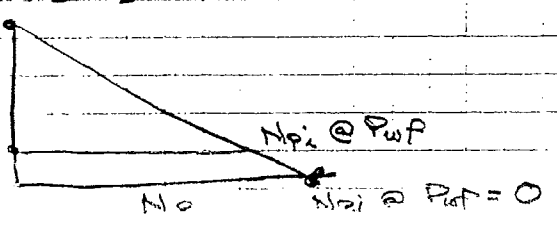
$P_i = 1000$ psia ; $P_{wf} = 100$ psia
$\phi_{AC} = 20\%$ and $C_t = 27 \times 10^{-6}$

$$; N_{pi} = \frac{\pi r_e^2 \phi_{AC} C_t P_i}{5.615 B_{oi}}$$

$\mu_o = 5$ cps
$B_o = 1.30$ bbl/bbl

* West Texas Carbonate Variables





Basic Ratio - Time Equations

$$q(t) = \frac{q_i}{e^{\left[\frac{q_{i(max)}}{N_{pi}}\right] t_{days}}} \quad \text{or} \quad \frac{q_i}{e^{\left[\frac{q_{i(max)} \times 365}{N_{pi}}\right] t_{yrs}}} \quad \text{or} \quad \frac{q_i}{e^{\left[\frac{q_i \times 365}{\left(1 - \frac{P_{wf}}{P_i}\right) N_{pi}}\right] t}}$$

Where $q_{i(max)} = \frac{q_i}{\left[1 - \frac{P_{wf}}{P_i}\right]}$ or $q_{i(max)}$ @ $P_{wf} = 0$

Recall that N_{pi} is to $P_{wf} = 0$ also.

$$\frac{N_p(t)}{N_{pi}} = \left(1 - \frac{P_{wf}}{P_i}\right)\left\{1 - e^{-\frac{q_i}{\left[\frac{q_{i max} \times 365}{N_{pi}}\right] t}}\right\}$$

And for $\bar{P}$ vs $N_p(t)$

$$\bar{P}(t) = P_i - \left(\frac{N_{pt}}{N_{pi}}\right) P_i = P_i \left[1 - \frac{N_p(t)}{N_{pi}}\right]$$

Layer 1 40 Acre Case

$$q_{i1} = \frac{7.08 \times 0.020 \times 62 \ (1000 - 100)}{5 \times 1.30 \left[\ln\left(\frac{745}{0.25}\right) - 0.75 + 0.933 + S\right]} = \begin{array}{l} q_{i1} = 197 \text{ BOPD}, S = -2 \\ q_{i1} = 149 \text{ BOPD}, S = 0 \end{array}$$

$$N_{pi\,1} = \frac{3.1416 \times 745^2 \times 0.20 \times 62 \times 27 \times 10^{-6} \times 1000_{PSI}}{5.615 \times 1.30} = \boxed{79,975 \text{ STK BBL}}$$

Layer 2 40 Acre Case

$$q_{i2} = \frac{7.08 \times 0.002 \times 312 \ (1000 - 100)}{5 \times 1.30 \left[\ln\left(\frac{745}{0.25}\right) - 0.75 + 0.933 + 0\right]} = \begin{array}{l} q_{i2} = 75 \text{ BOPD}, S = 0 \\ q_{i2} = 146 \text{ BOPD}, S = - \end{array}$$

$$N_{pi\,2} = \frac{3.1416 \times 745^2 \times 0.20 \times 312 \times 27 \times 10^{-6} \times 1000_{PSI}}{5.615 \times 1.30} = \boxed{399,876 \text{ STK BBL}}$$

40 ACRE CALCULATIONS

$$q(t) = \frac{q_i}{\left[\frac{q_{i\,max}\ 365\ days}{N_{pi_o}}\right]t} \qquad \text{AND} \qquad q_{i\,max} = \frac{q_i}{\left[1 - \frac{P_{wf}}{P_i}\right]}$$

e

LAYER 1

$S = -2$; $q_i = 197$ BOPD; $q_{i\,max} = 219$ BOPD; $\left[\frac{219 \times 365}{79,975\ BBL}\right] = 0.9995$

$S = 0$; $q_i = 149$ BOPD; $q_{i\,max} = 166$ BOPD; $\left[\frac{166 \times 365}{79,975\ BBL}\right] = 0.7576$

LAYER 2

$S = 0$; $q_i = 75$ BOPD; $q_{i\,max} = 83$ BOPD; $\left[\frac{83 \times 365}{399,876\ BBL}\right] = 0.07576$

CROSSFLOW ($S = 0$ BOTH LAYERS)

$q_i = 149 + 75 = 224$ BOPD; $q_{i\,max} = 166 + 83 = 249$ BOPD

$$\left[\frac{249 \times 365}{79,975 + 399,876}\right] = \left[\frac{249 \times 365}{479,851}\right] = 0.1894\ yr^{-1}$$

	LAYER 1		LAYER 2	COMMINGLED		CROSSFLOW
	$q_i = 197$ BOPD	$q_i = 149$ BOPD	$q_i = 75$ BOPD		$b = 0.6$	$q_i = 224$
	$e^{[.9995]t}$	$e^{[.7576]t}$	$e^{[.07576]t}$			$e^{[.1894}$
	$S = -2$	$S = 0$	$S = 0$	$S = -2.0$	$S = 0.0$	$S = 0$
YR	$q(t)$	$q(t)$	$q(t)$	BT	BT	$q(t)$
0	197	149	75	272	224	224
1	73	70	70	143	140	185
2	27	33	64	91	97	153
3	9.8	15	60	70	75	127
4	3.6	7.2	55	59	62	105
→ 5	1.3	3.4	51	52	54	87
10	0.01	0.1	35	35	35	34
15			24	24	24	13
20			16	16	16	5
25			11	11	11	2
30			8	8	8	0.
40			4	4	4	
50			2	2	2	

INFILL DRILL AFTER 5 YEARS BUT COMPLETE ONLY IN LAYER 2 SINCE LAYER 1 IS ALL DEPLETED.

LAYER 2 @ END OF 5 YEARS

$$\frac{N_p(t)}{N_{pi}} = \left[1 - \frac{100}{1000}\right]\left[1 - e^{-0.07576 \times 5}\right] = 0.28377$$

$$\Delta P = 1000\left[0.28377\right] = 284 \text{ psi} \quad \text{OR} \quad \bar{P}_{5YR} = 1000 - 284 = \boxed{716 \text{ psi}}$$

DRILL & STIMULATE INFILL WELL IN LAYER 2 WITH -4 SKIN
Ye 20 ACRES = 527 FT.

$$q_{2_{s=-4}} = \frac{7.08 \times .002 \times 312 \,(716 - 100)}{5 \times 1.29\left[\ln\left(\frac{527}{.25}\right) - 0.75 + 0.933 - 4\right]} = 110 \text{ BOPD}$$

ORIGINAL WELL LAYER 2 WITH 0 SKIN AND NOW "20 ACRES"

$$q_{2_{s=0}} = \frac{7.08 \times .002 \times 312 \,(716 - 100)}{5 \times 1.29\left[\ln\left(\frac{527}{.25}\right) - 0.75 + 0.933 + 0\right]} = 54 \text{ BOPD}$$

"BUT NOW WITH DRAIN VOLUME IN PROPORTION TO RATE"!!!

(IF ORIGINAL WELL WERE NOW RESTIMULATED TO -4 SKIN LIKE THE INFILL WELL PRODUCTION FROM BOTH WELLS WOULD BE 110 BOPD + 110 BOPD = 220 BOPD AS COMPARED TO 110 BOPD + 54 BOPD = 164 BOPD BUT THIS WOULD BE ADJUSTED "VERY SLIGHTLY" FOR SHAPE FACTOR SKIN.)

NEW WELL	110 BOPD	OR 67% OF 40 ACRES	=	26.8 ACRES
OLD WELL	54 BOPD	33% OF 40 ACRES	=	13.2 ACRES
	164 BOPD			40 ACRES

THIS REDUCTION OF ORIGINAL WELL FROM 40 ACRES TO 13.2 ACRES VOLUME WILL SHOW UP IN FORECAST AS AN "INTERFERENCE EFFECT".

LAYER 1 @ END OF 5 YEARS

$$\frac{N_p(t)}{N_{pi}} = \left[1 - \frac{100}{1000}\right]\left[1 - e^{-0.7576 \times 5}\right] = 0.8796$$

$$\Delta P = 1000\left[0.8796\right] = 880 \text{ psi} \quad \text{OR} \quad \bar{P}_{5YR} = 1000 - 880 = \boxed{120 \text{ psi}}$$

END OF 5YR IS $t=0$ FOR THESE FORECASTS

FORECAST WITH INFILL WELL TO 20 ACRE SPACING LAYER 2 ONLY. ORIGINAL WELL COMPLETED IN LAYER 1 AND LAYER 2 WITH 0 SKIN. INFILL WELL −4 SKIN.

OLD WELL 13.2 ACRE DRAINAGE; $r_e' = \sqrt{\frac{43560 \times 13.2}{3.1416}} = 428$ FT

INFILL WELL 26.8 ACRE DRAINAGE; $r_e' = \sqrt{\frac{43560 \times 26.8}{3.1416}} = 610$ FT

$$q_{OLD, S=0} = \frac{7.08 \times .002 \times 312 (716 - 100)}{5 \times 1.29 \left[\ln\left(\frac{428}{.25}\right) - 0.75 + 0.933 + 0\right]} = 55 \text{ BOPD} = @ t=0$$

$$q_{NEW, S=-4} = \frac{7.08 \times .002 \times 312 (716 - 100)}{5 \times 1.29 \left[\ln\left(\frac{610}{.25}\right) - 0.75 + 0.933 - 4\right]} = 106 \text{ BOPD} = @ t=0$$

$$q_{i\ max\ OLD} = \frac{55}{\left[1 - \frac{100}{716}\right]} = 64 \text{ BOPD} \qquad \left[\frac{64 \times 365}{97,377}\right] = 0.2399$$

$$q_{i\ max\ NEW} = \frac{106}{\left[1 - \frac{100}{716}\right]} = 123 \text{ BOPD} \qquad \left[\frac{123 \times 365}{189,026}\right] = 0.2375$$

LAYER 2 N_p @ 5YR = $0.28377 \times 399,876$ BBL = 113,473 BBL

$N_{pi\ 2} = 399,876 - 113,473 = 286,403$ BBL

$N_{pi\ OLD\ WELL}$ @ 34% PROD = 97,377 BBL

$N_{pi\ INFILL}$ @ 66% PROD = $\frac{189,026}{286,403}$ BBL

		ORIGINAL WELL $q_i = 55$ BOPD $e^{[0.2399]t}$	NEW WELL $q_i = 106$ BOPD $e^{[0.2375]t}$	LAYER 2 2 WELL INFILL −4	LAYER 2 WELL INFILL S=(*
YR	t	$q(t)$	$q(t)$	q_{TOTAL}	q_{TOTAL}
5	0	55	106	161	108
6	1	43	84	127	92
8	3	27	52	79	67
10	5	17	32	49	48
15	10	5.0	9.9	15	22
20	15	1.5	3.0	4.5	7
25	20	0.5	0.9	1.4	4
30	25	0.1	0.3	0.4	2

* SEE WORKSHEET

DRILL 2 MORE INFILL WELLS @ YEAR 10 TO GET 10 ACRE SPACING FOR TOTAL OF 4 COMPLETIONS IN LOW PERM. LAYER 2 AND 1 COMPLETION IN HIGH PERM LAYER. ASSUME OLD WELL WILL BE RESTIMULATED TO −4 IN LOW K LAYER TO HAVE ALL WELLS EQUAL.

1.) CALCULATE N_p TO YEAR 10 FOR ORIGINAL AND FIRST INFILL WELL TO GET $\bar{P}_R$.

@ 5 YRS

$N_{pi_T} = 399,876$ BBL ; $N_{p_{6W}} = 113,473$ BBL ; $N_{pi_W} = 286,403$ BBL.

ORIGINAL WELL @ $\frac{N_p(t)}{N_{pi}} = \left[1 - \frac{100}{716}\right]\left[1 - e^{\left[\frac{0.2399}{64\times365}{97,377}\right]5}\right] = 0.60106$

$\Delta P = 716\left[0.60106\right] = 430$ psi ; $\bar{P}_R = 716 - 430 = 286$ psia

$N_p(t) = 97377 \times 0.60106 = 58529$ BBL

INFILL WELL $\frac{N_p(t)}{N_{pi}} = \left[1 - \frac{100}{716}\right]\left[1 - e^{\left[\frac{128\times365}{189,026}\right]5}\right] = 0.59793$

$\Delta P = 716\left[0.59793\right] = 428$ psi ; $\bar{P}_R = 716 - 428 = 288$ psia

USE 287 psia $= \bar{P}_{R_i}$ FOR NEXT INFILL WELLS

$N_p(t) = 189,026 \times 0.59793 = 113,024$ BBL

$N_{p(TOTAL)} = 58,529 + 113,024$ BBL $= 171,553$ BBL

$N_{REMAINING} = {}^{ORIGINAL}399,876 - {}^{1^{ST}5\,YR}113,473 - {}^{NEXT\,5\,YR}171,553 = 114,850$ BBL CHECKS w/ $\bar{P}_R = 287$ psia

CALCULATE RATES FOR ORIGINAL WELL AND THE 3 INFILL WELLS

ASSUME OLD WELL ACIDIZED ∴ $S = -4$ ALL WELLS, SHAPE FACTOR SKIN $S = 0$. 10 ACRE $r_e = 372$ FT.

INFILL WELL $q_i = \dfrac{7.08 \times .002 \times 312\,(287-100)}{5 \times 1.2\left[\ln\left(\frac{372}{.25}\right) - 0.75 + 0 - 4\right]} = q_i = 54$ BOPD

($\ln\left(\frac{372}{.25}\right) = 2.55$)

$q_{i\,max} = \dfrac{54}{\left[1 - \frac{100}{287}\right]} = 83$ BOPD ; $N_{pi} = 114,850$ BBL

OLD WELL IF $S = 0$ $q_i = \dfrac{7.08 \times .002 \times 312\,(287-100)}{5 \times 1.2\left[\ln\left(\frac{372}{.25}\right) - 0.75\right]} = q_i = 21$ BOPD

$q_{i\,max} = 32$ BOPD

$$q(t) = \frac{q_i}{e^{\left[\frac{q_{i\,max}\,365}{N_{pi}}\right]t}} = \frac{54}{e^{\left[\frac{4\times83\times365}{114,850}\right]t}} = \frac{54}{e^{1.05222\,t}}$$