CARD International Journal of Engineering and Emerging Scientific Discovery
ISSN: 2536-7250 (Print): 2536-7269 (Online)
Volume 2, Number 4, December 2017
http://www.casirmediapublishing.com

Selection of Candidate Wells for Polymer Water Shut-off

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ABSTRACT
Water production challenges arise when water produced from an oil well is in excess, resulting to productivity decline and uneconomical oil production. This research focuses on the development of a pseudo-steady state model that will improve the selection of candidate wells with high water – oil ratio (WOR) for polymer water shut off treatment. This model is tested using production history data from five (5) wells (Well 1, Well 2, Well 3, Well 4 and Well 5) producing with a very high WOR and validated by comparing our results with conventional WOR and its derivative diagnostic plots. From the results obtained, Well 1 showed bottom water coning with late time channelling up to 1200 days after the first production started. Well 2 water problem was due to bottom water coning up to its 1000 days of production. Well 3 was significant with bottom water coning with late time channelling from the 900th day to 1530th day of its first production. Well 4 showed a water problem that is due to channelling. The excessive water production problem for Well 5 was as a result of bottom water coning which started from the 700th day to the1400th day after the first production. However, Well 1, Well 3 and Well 4 is candidate wells for polymer water shut off, as their channelling problems can be resolved by the selective use of coiled tubing to apply flowing gel (polymer) that can offer a relative permeability that is favourable to oil than water at the point of water entry. While Well 2, Well 5 are not candidate wells for polymer water shut off because their excess water production is due to producing too close to the water – oil contact (WOC) or above the critical rate. However, this study aimed at ranking wells with high water production problems and evaluating which well(s) are suitable for the application of polymer to mitigate the excessive water production problems.
Keywords: Coning, Channelling, Production, Pseudo-steady, Polymer

INTRODUCTION
During hydrocarbon production, water from the formation is brought alongside to the surface. This is normal but problem occurs when this water from the formation is in much higher percentage when compared to the hydrocarbon produced. In excess, water from the formation often

brings along complicated issues; these issues include economical, technical, and environmental challenges[1]. Determining the reasons for water encroachment/production is very important in reaching optimum solution for dealing, controlling and management of unwanted water. The production of water can occur at the early stage after completion or later-on in active phase of the well[2] but challenges arises when the water produced is uneconomical to operations. Usually, reservoir water produced alongside with hydrocarbon which cannot be shut-off and cause a stop in production is termed "good water", whereas "bad water" causes reservoir and productivity decline. The latter is a fear to producing companies especially when in excess. Separation cost, lifting and discarding, environmental issues, high corrosion degree of occurrence, formation of scales, emulsion are just the various several challenges that can result from high water production, thus the economic life of the wells begin to drop and diminish. There are three basic classifications of water problems, most noticeable among others, they are namely: water coning, multilayer channelling and near wellbore problems[3]. Produced water source can come from formation water, injected water or even from an underlying aquifer. Each problem has a control method that is unique to their occurrence; thus the identification of where the water is coming from a particular well is essential[4]. Weakening of these problems caused by water can be achieved either by mechanical or chemical means which is dependent on the location where the water is coming from. Many near wellbore glitches can be controlled by the use mechanical means. This involves mainly the fitting of mechanical barriers to help isolate the point of entry for water. The barriers can be straddle (packers), bridge plugs, patches (tubing type), cement plugs and wellbore sand plugs[5]. Chemical solutions can either be sealing or non-sealing. The sealing system will completely prevent flow of fluids, passing through the porous medium while the non-sealing system restricts but does not prevent the overall fluid flow through the medium. The chemical solution encompasses the practice of applying cement, resins or polymer[6]. Polymer systems developed for control of water are classified from their functions as: sealants, flow diverting chemicals (mobility control), weak sealant (relative permeability modifiers).

Although polymer systems are efficient, their success is hinged on proper candidate selection, treatment design and placement technique. Also, there are various technologies that can be put in work to drastically diminish these problems caused by the water such as separation in the down hole, injection, mechanical and applying chemical shut-offs. All of these operations from using different tools for logging (density and temperature logs) to modelling of the reservoir to pinpoint these problems are exorbitant for oil companies. Therefore, using a method that has low cost in identifying problems caused by water is of interest to all. Studies involving numerical, laboratory, field applications and theoretical analysis to minimize the production of water from hydrocarbon wells has identified that often, water flow paths in the reservoir; especially all over the region of the wellbore are irregular, by-passing large hydrocarbon zones that are saturated, thus inducing undesirable high water cut levels[7].If a well has begun producing an excess water cut compared with neighbouring wells, the increased water rate could come from premature breakthrough around a zone of elevated permeability or water coning, channelling from alternative zone behind pipe. By running a suite of production logs that can locate channelling and measure the profile and the point of entry of water in the well, the engineer may use this to distinguish among these causes and more importantly, properly plan a corrective workover. However, information from production logging should be used as a supplement to the information derived from the well flow rate, pressure history and other well tests[8].

Various categories of drilling and completion techniques can affect the quantity (amount) of water produced during different stages of the wells life span. However, the instant the well is been completed and stimulated, remedial actions may be limited. Consequently, at the outset, operators should consider all their options[9]. During water production, most fines, clay and sand are transported more efficiently than oil and gas, however creating mobile clay and fine problems. Lifting produced fluid, separation of water from oil, treatment and disposal, re-injection of the water, power and personnel required to operate these facilities can accelerate operating cost[10]. A high production rate is extremely an important factor of appearance on coning and fast water fingering due to unfavourable mobility ratio, which lowers the recovery effectiveness of oil caused by water displacement. Also, caution ought to be utilized while an artificial lifting pump is set at a high rate, especially after well shut off period. The optimum pump rate should be technically designed for the individual wells below the critical value of forming water coning, to avoid early stage water breakthrough, and thus enables maximization of the oil-reserves[11]. There are different causes of water production: tubing-leaks, parker-leaks or casing-leaks, channel flow outside the pipe, moving oil water contact, cross flow layer that are not watered out, fractures or faults around the injector and producer, fracture or faults nearby a water layer (Figure 1), coning or cusping, poor area sweep, gravity segregated layer, cross flow layer that are watered out[12]. There are listed according to the order of increasing treatment difficulty. Each problem type has treatment choices that vary from simple and somewhat inexpensive mechanical and chemical solutions, down to the more multiplex and expensive reworked completion type of solution. Produced water inflow source may be channelling or from coning in the lower zones. Distinguishing between coning and flow from a much inflow layer will be difficult with production logs alone. The most conclusive test for coning would be to subject the well into production the well at rates that are dissimilar or drawdowns as coning is inherently a rate sensitive phenomenon[13].

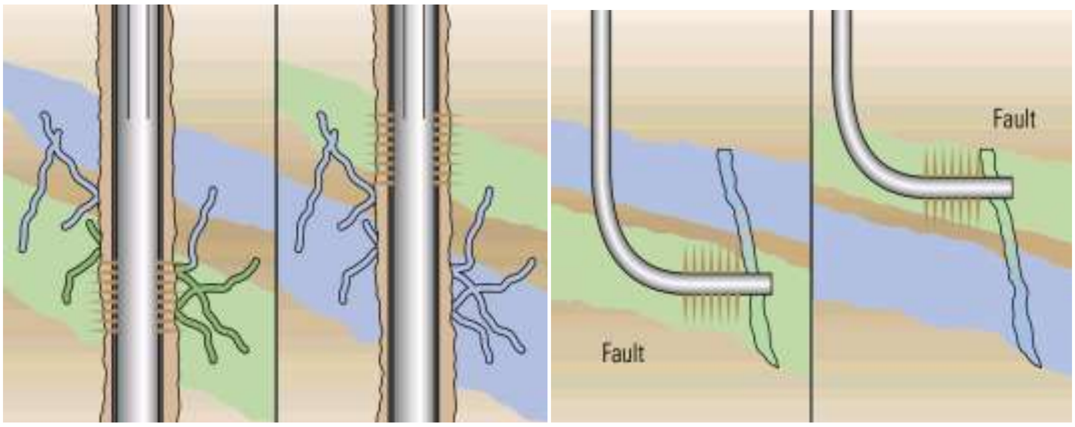

Figure 1: Water flow into well due to fractures or faults from a waterlayer[12]

Candidate Well Selection Technique

This technique is beneficial in the diagnosis of the well's specific water problem. Well diagnostics are used in three ways:

i. To screen wells that is an appropriate candidate for water control.
ii. To define the water problem, so that a suitable water control techniques can be selected.
iii. To locate the water entry point inside the well so that a treatment can be correctly implemented.

METHODOLOGY

For the proper excessive water control, it is a prerequisite to first understand the water production nature. This will help in the plan of an effective treatment. This can happen at any point either at an early or later period of the well active life. Once the cause is understood, an effective plan or strategy can be formulated to monitor, control and manage this problem.

For this research work, the methodology adopted in this research work is the development of a systematic model that will improve the diagnosis of wells with high water production using c# and excel interface. This study will provide the production engineers with the information needed to effectively respond to problems of this category that occurs in the reservoir.

Model Development

Over time, a collection of several empirical methods have been offered for the evaluation of water-oil production ratios, these methods follows a particular steady state assumption. However, the necessity for the development of a model that represents the performance of a reservoir (oil-water phase) in a flow system that is pseudo is often needed. We begin by using the single phase variable, pseudo-steady state equation [14].

$$\Delta P = 70.6\frac{q\beta\mu}{kh}\ln\frac{4A}{e^{\gamma}C_A r_w^2} + 0.2339\frac{q\beta}{\emptyset h C_t A}t_{mb} \quad (1)$$

Eq. 1 will be subjected to the following assumptions:

i. The flow condition is characterized by pseudo-steady state.
ii. Homogeneous and isotropic reservoir.
iii. Constant porosity, permeability and viscosity.
iv. Small or constant fluid compressibility.
v. Small (negligible) pressure change.
vi. Non slippage amidst the oil – water system.
vii. The reservoir is circular.

$$\Delta P = q\left[\left(70.6\frac{\beta\mu}{kh}\ln\frac{4A}{e^{\gamma}C_A r_w^2}\right) + \left(0.2339\frac{\beta}{\emptyset h C_t A}t_{mb}\right)\right] \quad (2)$$

$$\frac{\Delta P}{q} = 70.6\frac{\beta\mu}{Kh}\ln\frac{4A}{e^{\gamma}C_A r_w^2} + 0.2339\frac{\beta}{\emptyset h c_t A}t_{mb} \quad (3)$$

For simplicity, we can make q the subject of the formula and linearize to simple terms. Eq. 3 becomes:

$$q = \frac{\Delta P}{70.6\frac{\beta\mu}{Kh}\ln\frac{4A}{e^{\gamma}C_A r_w^2} + 0.2339\frac{\beta}{\emptyset h c_t A}t_{mb}} \quad (4)$$

Let;

$\alpha = 0.2339\frac{\beta}{\emptyset h C_t A}$, $d = 70.6\frac{\beta\mu}{Kh}\ln\frac{4A}{e^{\gamma}C_a r_w^2}$ and $t_{mb} = \frac{1}{q}\int_0^t q dt$

Thus;

$$q = \frac{\Delta P}{\alpha t_{mb} + d} \quad (5)$$

Re-casting eq. 5 to give water and oil phase flow

$q_w = \frac{\Delta P}{\alpha_w t_w + d_w}$ (water form)

(6)

$q_o = \frac{\Delta P}{\alpha_o t_o + d_o}$ (oil form)

(7)

Recalling the definition of water – oil ratio, WOR

$WOR = \frac{q_w}{q_o}$

(8)

$$WOR = \frac{\Delta P}{\alpha_w t_w + d_w} \times \frac{\alpha_o t_o + d_o}{\Delta P}$$

$WOR = \frac{\alpha_o t_o + d_o}{\alpha_w t_w + d_w}$

(9)

Eq. 9 can be re-written in fractional flow terms of oil and water

$f_w = \frac{1}{1+\frac{\alpha_w t_w + d_w}{\alpha_o t_o + d_o}}$ and $f_o = \frac{1}{1+\frac{\alpha_o t_o + d_o}{\alpha_w t_o + d_w}}$

Assuming non slippage among the oil – water system, then

$f_o = \frac{1}{1+\frac{\alpha_o t_o + d_o}{\alpha_w t_o + d_w}} = \frac{1}{\left[1+WOR\left(\frac{B_w}{B_o}\right)\right]}$

(10)

let $A_o = \frac{f_o}{f_w}$

Applying Taylor Series to A_o using a phase increase of $n+1$ in time

$$(A_o)_{n+1} = (A_o)_n + (A_o)^I(t_{n+1} - t_n)$$

$$(A_o)^I = \frac{(A_o)_{n+1} - (A_o)_n}{t_{n+1} - t_n} \tag{11}$$

A good application of the derivation above is that points with zero (0%) water production cases can be plotted and not neglected as previously presented in the past.

Model Testing and Model Validation

The model developed will be tested using the production history data from five wells (Well 1, Well 2, Well 3, Well 4 and Well 5) producing at a very high water – oil ratio (WOR). The data from the wells will be applied and using the developed computer model and generate results and plots of $A_o, (A_o)^I$ against time will be made. This will be validated through the comparison of our results with a conventional model[3]. This will enable us carry out the classification of wells with water problems according to their coning, channelling or near wellbore problems to enhance the candidate selection of wells in which polymer (shut – off) can be applied to resolve this water problems.

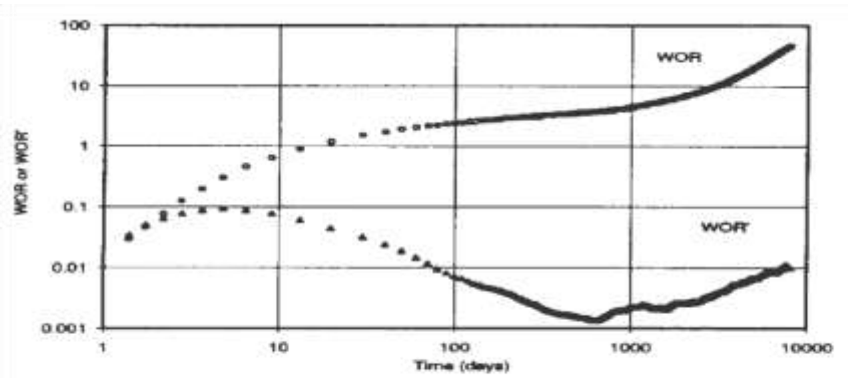

Figure 2: Bottom water coning with late time channelling[3]

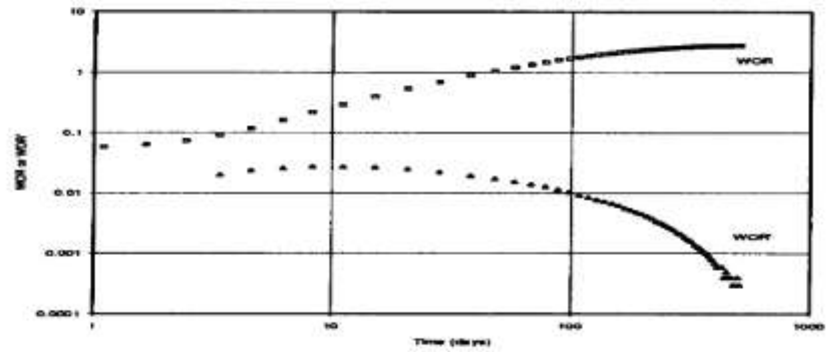

Figure 3: Bottom water coning[3]

RESULTS AND DISCUSSION

WELL 1:

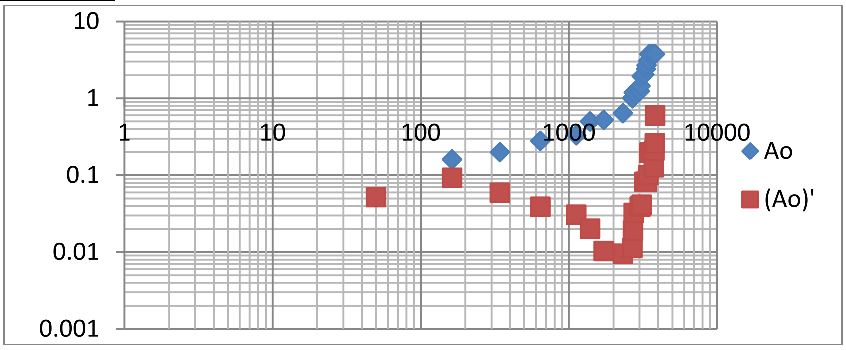

Figure 4: Plot of A_o, $(A_o)^I$ against Time for Well 1

Results from figure 4 and Appendix A-1 shows that, until 120 days, the production of water was low, this signifies that the fraction of the fluid produced were mainly oil. After 300 days, the degree of increase production (water) was gradual until 1300 days. For this period $(A_o)^I$ displayed a slope that is negative, water cone was formed until 1200 days and then showed a positive slope which is revealing of channelling. However, comparing with Figure 3, it shows bottom water coning with late time channelling. For the channelling problem, polymer application at the point of water entry will resolve this problem up to 60%. Therefore, well 1 can be said to be a candidate for applying polymer gel to help shut off produced water coming through a water source during production.

WELL 2:

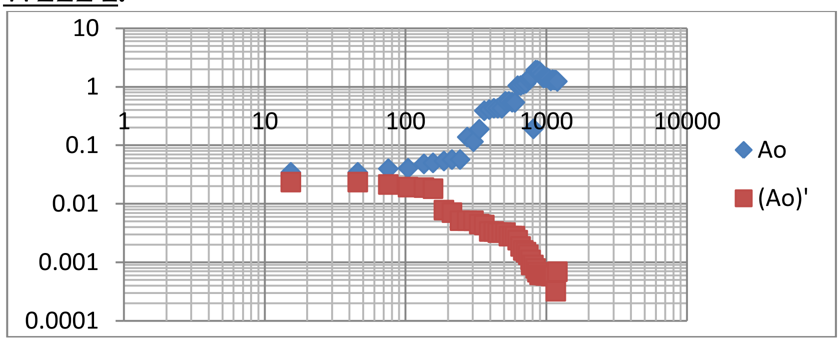

Figure 5: Plot of A_o, $(A_o)^I$ against Time for Well 2

Water production started after 300 days, with a continuous rise up to 1000 days as seen in figure 5 and Appendix A-2. During this time $(A_o)^I$ show a negative slope which is indicative of coning problems.

Figure 5 can be compared with Figure 3 with shows a bottom water coning. Coning problem can show up from producing above the critical rate (value) forming water coning. Therefore, polymer gel cannot be applied in the control of high water-to-oil ratio. Well 2 cannot be said to be a candidate well for polymer water shut-off.

WELL 3:

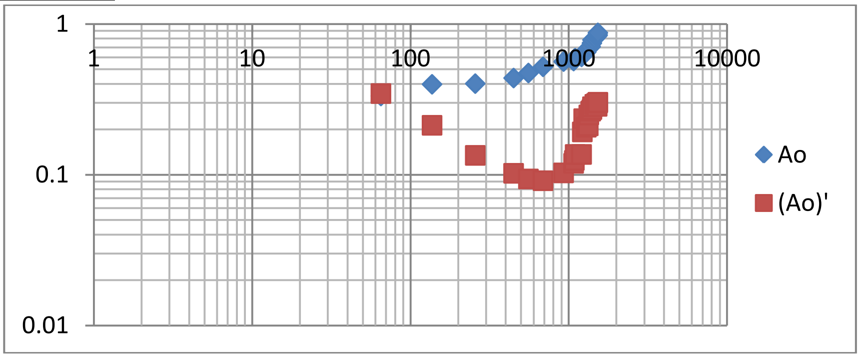

Figure 6: Plot of A_o, $(A_o)^I$ against Time for Well 3

Results from Appendix A-3 and figure 6, indicates that the water problem was due to bottom water coning which later showed a late time channelling as expressed and confirmed from figure 4. The negative slope of $(A_o)^I$ is an indication of the pseudo-steady state cone formed from the 60th day up to 900 days. The positive slope till 1530 days showed the initiation of water channelling. Channelling problems can come from fracture from a watered layer, tubing-leak or even casing, etc. Thus, polymer gel cannot be applied to control this problem is will be an excellent choice. Thus, well 3 is a candidate well.

WELL 4

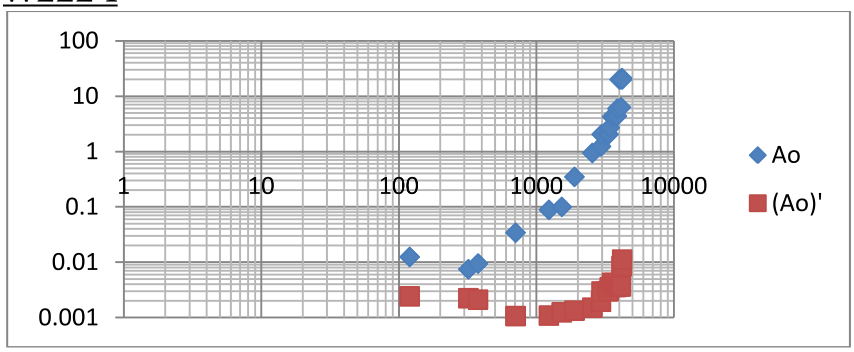

Figure 7: Plot of A_o, $(A_o)^I$ against Time for Well 4

From Figure 7, the water problem for well 4 was due to channelling. The positive slope of $(A_o)^I$ is indicative of water channelling into the production zone. This can come from tubing or packer or casing leak, fracture from a watered layer or from water flooding. To put an end to this problem, coiled-tubing can be used to inject flowing gel can help reduce the water-to-oil ratio to favour oil production without harmfully affecting the production of hydrocarbon in the reservoir. Application of polymer (gel) is ideal to mitigate this problem. However, Well 4 is a candidate well.

WELL 5

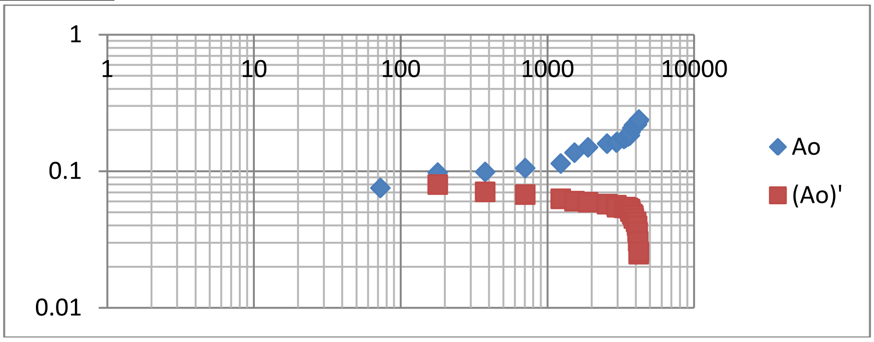

Figure 8: Plot of A_o, $(A_o)^I$ against Time for Well 5

The high WOR of Well 5 was due to coning of the formation water at around 700 days to 1400 days as displayed in Figure 8. During this period, $(A_o)^I$ started to show a decline and a further negative slope and progressively advanced to an unvarying value indicating the visibility of water coning. A_o showed a positive slope, indicating that the bulk of the fluid produced is water. This can be confirmed from Figure 4.4. Such a problem can arise when producing above the critical rate or too close to the WOC. Using polymer gel to control this problem will not yield any good result. Therefore, Well 5 cannot be ranked as a candidate well.

Table 1: Candidate Well Classification

WELL	PROBLEM	SHUT-OFF CANDIDATE
1	Bottom water coning with later time channelling	YES
2	Coning	NO
3	Bottom water coning with late	YES

	time channelling	
4	Bottom water coning with late time channelling	YES
5	Coning	NO

CONCLUSION

In an attempt to accomplish this work's objectives, discussions have been centred on the development of a pseudo-steady state model with defined assumptions, testing the model by analysing the data from five wells and validating the model using a conventional WOR and WOR[I] plots with a view of determining which of the five (5) wells is a candidate for polymer water shut-off. From the results obtained, the subsequent conclusions were made from this study:

1. The proposed pseudo-steady state model can help improve the diagnosis of unnecessary problems of water associated with a particular well as successfully confirmed in this study.
2. The model derived does not provide a tool(s) for the forecasting of future productions.
3. Each water production problem is unique and as such has a distinct solution as presented in this research work. That is, from a less expensive simple solution (channeling) to a complex and expensive solution (coning and near wellbore problems).

NOMENCLATURE

φ = Porosity
μ_o = Oil viscosity, cp
μ_w = Water viscosity, cp
$\Delta \varrho$ = Change in density, ibs/ft^3
ΔP = Drawdown, psi
e^{γ} = Eulier's constant, 1.7811
A = Reservoir drainage area, acres
B_o = Oil formation volume factor, rb/stb
B_w = Water formation volume factor, rb/stb
C_A = Reservoir shape factor, 31.62
C_t = Total compressibility, psi -1, $20 \times 10^{-6} psi^{-1}$
D = Well depth, ft
f_w = Fractional Water cut, %
H = Formation height, ft
K_{abs} = Absolute permeability, mD
K_{eo} = Effective permeability to oil, mD
K_{ew} = Effective permeability to water, mD
K_{ro} = Relative permeability to oil, mD
K_{rw} = Relative permeability to water, mD
K_t = Permeability of the treated region, mD
K_{avg} = Average water permeability, mD

K'_{avg} = Desired average permeability, mD
Q_o = Oil rate, bbl/day
Q_w = Water rate, bbl/day
Q_{Gross} = Total production from oil and water, bpd
R_e = External radius, ft
R_w = Wellbore radius, ft
S_w = Water saturation, fraction
S_{wc} = Connate water saturation, fraction
$t_o = N_p/q_o$
$t_w = N_p/q_w$
WOR = Water oil ratio, dimensionless
WOR′ = Water oil ratio derivative, day^{-1}

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APPENDIX

Appendix A-1: Presentation of Results for Well 1

Gross Prod. (b/d)	t_o	t_w	f_o	f_w	A_o	$(A_o)'$
5643	1	0	0.060365	1.162993	0.051905	0.051905
2453	1	0	0.060365	0.376809	0.1602	0.092393
3425	1	0	0.060365	0.302839	0.19933	0.059
3546	1.19047619	6.25	0.112309	0.402407	0.279094	0.0388
3456	1.17647059	6.66666667	0.115592	0.349961	0.3303	0.03059
1200	1.19047619	6.25	0.112309	0.224847	0.499494	0.0201
3429	1.19047619	6.25	0.112309	0.214556	0.52345	0.010318
2657	1.20481928	5.88235294	0.109391	0.171059	0.639494	0.0095
2739	1.20481928	5.88235294	0.109391	0.109404	0.99988	0.0113
2618	1.42857143	3.33333333	0.088534	0.086011	1.02933	0.019025
2495	1.38888889	3.57142857	0.090536	0.075868	1.19333	0.032271
2325	4.25531915	1.30718954	0.069416	0.056253	1.234	0.038919
2510	4.90196078	1.25628141	0.068543	0.04729	1.4494	0.0392
2339	5.10204082	1.24378109	0.068302	0.035148	1.94323	0.041244
2248	5.10204082	1.24378109	0.068302	0.033408	2.04444	0.081823
1758	7.51879699	1.15340254	0.065953	0.027431	2.404334	0.081823
1833	7.87401575	1.14547537	0.06566	0.024368	2.694494	0.081823
1700	8.40336134	1.13507378	0.065239	0.021083	3.0944	0.100304

1908	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.196164
1742	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.196164
1709	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.196164
1500	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.126864
100	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.208594
10	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.259866
2	4.76190476	1.26582278	0.068719	0.018267	3.761905	0.59696

Appendix A-2: Presentation of Results for Well 2

Gross Prod. b/d)	t_o	t_w	f_o	A_o	$(A_o)'$
56761.05	1.034475	30.00658	0.280712	0.034474934	0.0234942
83019.51	1.001001	999.9941	0.911168	0.034474934	0.0234942
85824.62	1.001001	1000.054	0.911173	0.039724345	0.02136464
84949.52	1.001001	999.9943	0.911168	0.040498492	0.019283
88731.66	1.001001	1000.019	0.91117	0.048	0.018893776
96192.13	1.002506	400.0005	0.805974	0.05	0.018094006
114231.22	1.020408	50.0001	0.372512	0.05374	0.00779275
78892.82	1.028807	35.71427	0.309549	0.0569	0.007061169
101914.37	1.052632	19.99999	0.223877	0.057	0.005143386
125679.88	1.138025	8.245045	0.144419	0.138025368	0.005132233
89791.78	1.115172	9.682673	0.155008	0.115171912	0.005121298
60179.72	1.187787	6.325186	0.129843	0.187786857	0.004495759
58735.6	1.388889	3.571428	0.107944	0.388888955	0.004327792
57791.27	1.40768	3.452907	0.106969	0.40767954	0.003361209
54569.43	1.428571	3.333333	0.105981	0.428571466	0.003361209
48540.13	1.428571	3.333333	0.105981	0.428571471	0.00321399
53216.38	1.428571	3.333334	0.105981	0.428571275	0.00321399
56844.67	1.5625	2.777778	0.101334	0.562499948	0.00321399
57122.71	1.5625	2.777777	0.101334	0.562500188	0.002801633
37073.89	1.543672	2.839345	0.101855	0.543671921	0.002801633
50697.45	1.539452	2.853733	0.101976	0.539452037	0.002801633
19486.71	2.043551	1.958267	0.094162	1.043551031	0.00238865
20702.95	2.050077	1.952311	0.094107	1.050077139	0.001868363
15550.27	2.024677	1.975917	0.094325	1.10293	0.001594989
18706.41	2.143409	1.874578	0.093383	1.143409098	0.001489789
12336.7	2.347746	1.74198	0.092109	1.347745828	0.001341805
18266.75	2.403792	1.712356	0.091815	1.403791745	0.001096498
4747.8	2.472555	1.679092	0.091481	1.472554942	0.000899596
22613.69	1.191078	6.233462	0.129134	0.191078116	0.000899596
48100.5	2.924114	1.51972	0.089779	1.924113656	0.000784233
56499.68	2.905525	1.52479	0.089837	1.905525157	0.000676552
59708.98	2.822745	1.548623	0.090103	1.82274459	0.00060949
42784.74	2.623258	1.616045	0.09083	1.623258329	0.00060949

31882.73	2.410895	1.70877	0.091779	1.410894526	0.00060949
32685.31	2.41665	1.705891	0.091751	1.416649846	0.00059333
33994	2.429661	1.699466	0.091686	1.429661396	0.000599247
39029.41	2.361246	1.734621	0.092036	1.361245823	0.000599247
35169.09	2.26187	1.792475	0.092601	1.261869818	0.000582553
34589.52	2.321444	1.756748	0.092253	1.321444295	0.000582553
28847.39	2.484182	1.673772	0.091427	1.30394	0.000582553
34765.25	2.557107	1.642217	0.091103	1.29844	0.000319698
24205.071	2.492549	1.669995	0.091388	1.235474	6.91E-04

Appendix A-3: Presentation of Results for Well 3

Gross Prod. (b/d)	t_o	t_w	f_o	A_o	$(A_o)'$
2257.2	1	0	0.060711	0	0
981.2	1.333333	4	0.090223	0.333333	0.34595
1370	1.333333	4	0.090223	0.398544	2.13E-01
1418.4	1.587302	2.702703	0.080618	0.40284	0.13456
1382.4	1.568627	2.758621	0.081041	0.43849	1.02E-01
480	1.587302	2.702703	0.080618	0.473629	0.09384
1371.6	1.587302	2.702703	0.080618	0.52044	9.13E-02
1062.8	1.606426	2.649007	0.080211	0.56383	1.03E-01
1095.6	1.606426	2.649007	0.080211	0.568627	1.19E-01
1047.2	14.99492	1.071455	0.061154	0.587302	1.25E-01
998	7.550196	1.152667	0.065615	0.594568	1.36E-01
930	13.2584	1.081577	0.062086	0.606426	1.36E-01
1004	6.535948	1.180638	0.066388	0.62934	0.19252854
935.6	15.41605	1.069367	0.060935	0.63659	0.2358069
899.2	5.485854	1.222923	0.067299	0.65284	0.20688
703.2	1.279057	4.583496	0.094444	0.68474	0.211309
733.2	1.360499	3.773935	0.088574	0.69272	0.24956
680	11.20448	1.097996	0.063254	0.70834	0.264623
763.2	6.349206	1.186944	0.06654	0.74754	0.27103
696.8	6.349206	1.186944	0.06654	0.78474	2.83E-01
683.6	6.349206	1.186944	0.06654	0.80287	0.29342923
600	6.349206	1.186944	0.06654	0.82844	0.29739484
40	6.349206	1.186944	0.06654	0.83585	2.85E-01
4	6.349206	1.186944	0.06654	0.84533	0.299374
0.8	6.349206	1.186944	0.06654	0.875035	0.30292

Appendix A-4: Presentation of Results for Well 4

Gross Prod. (b/d)	to	t_w	f_o	A_o	$(A_o)'$
6207.3	68.28037	1.014863	0.052818	0.0124	0.002409
6207.3	12.8073	1.084693	0.07388	0.00744	0.002229
3900.6	7.73486	1.148481	0.076969	0.00943	0.002098
3801.6	6.749473	1.173929	0.077667	0.03405	0.00106
3771.9	3.76689	1.361417	0.080451	0.08789	0.001084
3767.5	3.397817	1.417046	0.080984	0.09934	0.00124
3012.9	2.209461	1.826815	0.084	0.3467	0.001327
2922.7	1.935999	2.068377	0.085518	0.935999	0.001504
2879.8	1.818473	2.221787	0.086446	1.23055	0.001928
2761	1.727587	2.374406	0.087352	2.034	0.00295
2744.5	1.646999	2.545597	0.088354	2.034	0.00296
2698.3	1.365509	3.735912	0.095092	2.034	0.003011
2698.3	1.209263	5.778687	0.106239	2.6788	0.003523
2572.9	0.802201	4.055643	0.097249	4.2304	4.20E-03
2557.5	0.807191	4.186474	0.097959	4.2304	4.25E-03
2472.8	0.916429	10.96585	0.133369	4.2304	0.00355
2016.3	1.000218	4582.5	0.968498	4.2304	0.00355
1933.8	1.244693	5.086752	0.102505	4.34554	0.003643
1916.2	6.930099	1.168631	0.077535	5.930099	0.003643
1879.9	20.8667	1.050335	0.069732	19.8667	0.003643
1650	2.900334	1.526223	0.081895	20.0222	0.003643
1320	7.259999	1.159744	0.077299	6.259999	0.003643
110	2.169796	1.85485	0.084181	20.39455	0.008433
11	1.016824	60.43956	0.326495	21.13939	0.008433
2.2	1.21	5.761908	0.106149	19.86677	0.0111

Appendix A-5: Presentation of results for well 5

Gross Prod. (b/d)	t_o	t_w	f_o	A_o	$(A_o)'$
6207.3	6.274012	1.189609	0.066425	0.0753	0
2698.3	1.370455	3.699387	0.086909	0.09755	0.0798
3767.5	11.3796	1.096343	0.062889	0.09865	0.070539
3801.6	1.105184	10.50713	0.131308	0.105184	0.0674
3900.6	1.11377	9.789658	0.126844	0.11377	6.27E-02
1320	2.986259	1.503459	0.07064	0.136584	0.0603
3771.9	1.45848	3.18112	0.083301	0.149387	0.0593
2922.7	1.04377	23.84657	0.206659	0.159012	0.057321
3012.9	1.636558	2.570948	0.078968	0.162038	0.056329
2879.8	17.14623	1.061934	0.059689	0.16321	0.05443
2744.5	3.454016	1.407495	0.069671	0.172294	0.054031
2557.5	1.154871	7.456981	0.112002	0.173229	0.05394
2761	1.124927	9.004652	0.121906	0.175229	0.054567
2572.9	1.826043	2.21059	0.076338	0.179242	0.053732
2472.8	1.28803	4.471859	0.092206	0.18246	0.052732
1933.8	2.491953	1.670262	0.072127	0.192577	0.0506
2016.3	1.176631	6.661523	0.10682	0.206763	0.048573
1870	1.064318	16.5478	0.167137	0.20705	0.047321
2098.8	1.469925	3.128	0.082928	0.21707	0.04502
1916.2	11.66823	1.093736	0.062715	0.218704	0.042569
1879.9	1.110526	10.04761	0.128454	0.219704	0.03982
1650	2.000176	1.999824	0.074753	0.231287	0.035756
110	1.615682	2.624214	0.079352	0.232629	0.030586
11	1.008855	113.9352	0.499655	0.233287	0.024674
2.2	1.110526	10.04762	0.128454	0.238704	0.025732