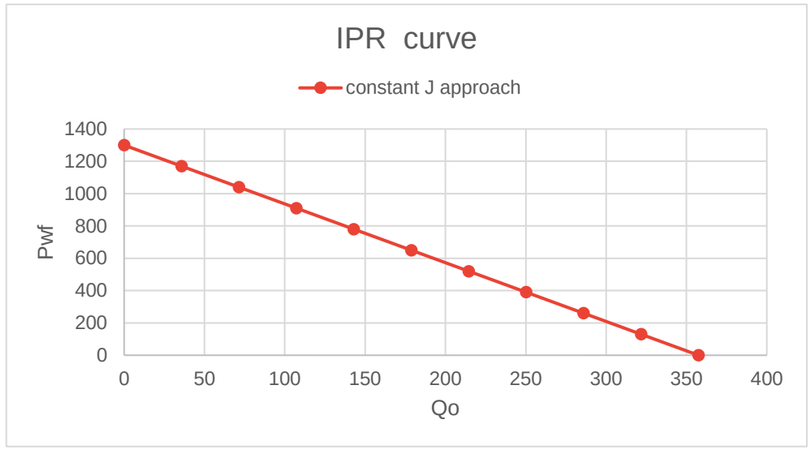
SIMPLE IPR CURVE FOR UNDERSATURATED RESERVOIR

Avg. Pr	1300	psi
(Pwf)stablized	900	psi
(Qo)stablized	110	STB/day

Productivity index	0.275	STB/day-psi
AOF	357.5	STB/day

data values for plotting IPR curve

Pwf	Qo
1300	0
1170	35.75
1040	71.5
910	107.25
780	143
650	178.75
520	214.5
390	250.25
260	286
130	321.75
0	357.5



Vogel's Method

Saturated oil reservoirs (pr ≤ pb)

Avg. Pr	2500	psi
$(Pwf)_{stablized}$	2000	psi
$(Qo)_{stablized}$	350	STB/day

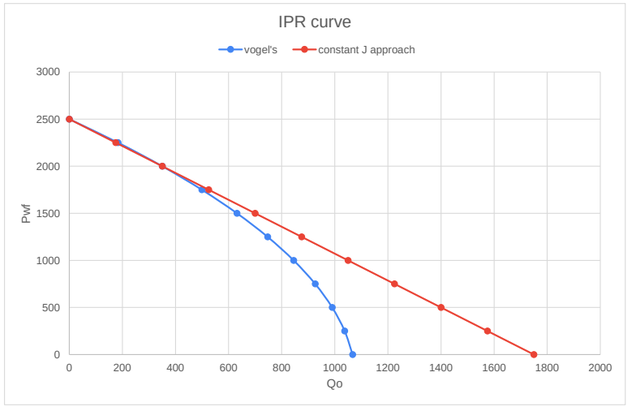
data for plotting IPR curve

	vogel's	*constant J approach*
Pwf	**Qo**	**Qo**
2500	0	0
2250	183.5365854	175
2000	350	350
1750	499.3902439	525
1500	631.7073171	700
1250	746.9512195	875
1000	845.1219512	1050
750	926.2195122	1225
500	990.2439024	1400
250	1037.195122	1575
0	1067.073171	1750

$$(Q_o)_{max} = Q_o / \left[1 - 0.2\left(\frac{P_{wf}}{P_r}\right) - 0.8\left(\frac{P_{wf}}{P_r}\right)^2\right]$$

J	0.7 STB/day-psi
(Qo)max	1067.073171 STB/day

$$Q_o = (Q_o)_{max}\left[1 - 0.2\left(\frac{P_{wf}}{P_r}\right) - 0.8\left(\frac{P_{wf}}{P_r}\right)^2\right]$$



Undersaturated oil reservoirs (pr > pb)

Avg. Pr	3000	psi
$(Pwf)_{stablized}$	2500	psi
$(Qo)_{stablized}$	250	STB/day
Pb	2130	psi

CASE 1:

The recorded stabilized bottom-hole flowing pressure is greater than or equal to the bubble-point pressure, i.e. pwf ≥ pb

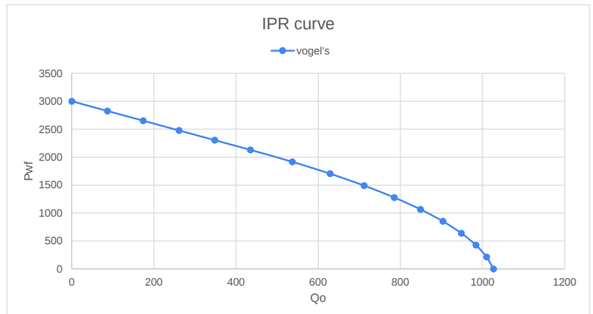
J	0.5	STB/day-psi
Qob	435	STB/day
(Qmax)vogel	591.6666667	STB/day

$$J = \frac{Q_o}{P_r - P_{wf}} \qquad Q_{ob} = J\,(\bar{p}_r - p_b)$$

Pwf	Qo
3000	0
2826	87
2652	174
2478	261
2304	348
2130	435
1917	536.7666667
1704	629.0666667
1491	711.9
1278	785.2666667
1065	849.1666667
852	903.6
639	948.5666667
426	984.0666667
213	1010.1
0	1026.666667

$$Q_o = J\,(\bar{p}_r - p_{wf}).$$

$$Q_o = Q_{ob} + \frac{Jp_b}{1.8}\left[1 - 0.2\left(\frac{P_{wf}}{P_b}\right) - 0.8\left(\frac{P_{wf}}{P_b}\right)^2\right]$$



Undersaturated oil reservoirs (pr > pb)

Avg. Pr	3000	psi
$(Pwf)_{stablized}$	1700	psi
$(Qo)_{stablized}$	630.7	STB/day
Pb	2130	psi

CASE 2:

The recorded stabilized bottom-hole flowing pressure is less than the bubble-point pressure pwf < pb

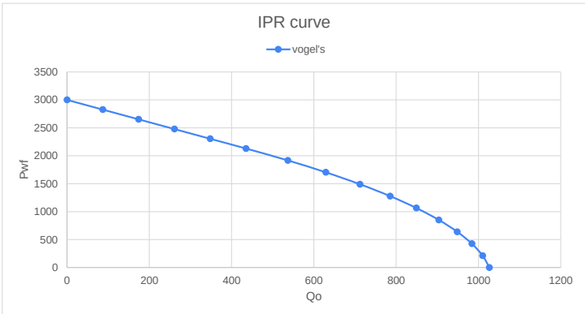
J	0.499992515	STB/day-psi
Qob	434.993488	STB/day
(Qmax)vogel	591.6578093	STB/day

$$J = \frac{Q_o}{(\bar{p}_r - p_b) + \frac{p_b}{1.8}\left[1 - 0.2\left(\frac{P_{wf}}{P_b}\right) - 0.8\left(\frac{P_{wf}}{P_b}\right)^2\right]} \qquad Q_{ob} = J\,(\bar{p}_r - p_b)$$

Pwf	Qo
3000	0
2826	86.99869759
2652	173.9973952
2478	260.9960928
2304	347.9947904
2130	434.993488
1917	536.7586312
1704	629.0572494
1491	711.8893427
1278	785.2549111
1065	849.1539545
852	903.5864729
639	948.5524664
426	984.051935
213	1010.084879
0	1026.651297

$$Q_o = J\,(\bar{p}_r - p_{wf}).$$

$$Q_o = Q_{ob} + \frac{Jp_b}{1.8}\left[1 - 0.2\left(\frac{P_{wf}}{P_b}\right) - 0.8\left(\frac{P_{wf}}{P_b}\right)^2\right]$$



VOGEL'S FUTURE IPR PREDICTION

Saturated oil reservoirs (pr ≤ pb)

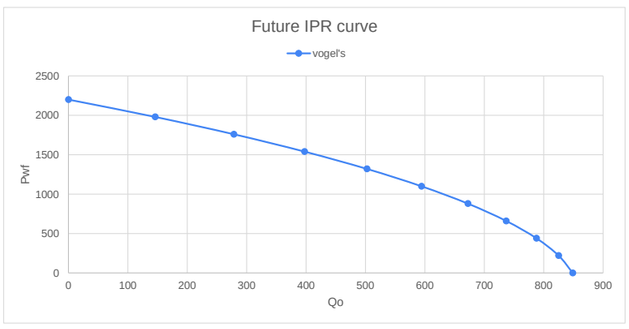
Avg. Pr	2500	psi
$(Pwf)_{stablized}$	2000	psi
$(Qo)_{stablized}$	350	STB/day
Future Avg. Pr	2200	psi

(Qomax)f	848.8780488	STB/day

$$(Q_{o\,max})_f = (Q_{o\,max})_p \left[\frac{(\bar{p}_r)_f}{(\bar{p}_r)_p}\right]\left[0.2 + 0.8\left[\frac{(\bar{p}_r)_f}{(\bar{p}_r)_p}\right]\right]$$

Pwf	(Qo)f
2200	0
1980	146.0070244
1760	278.432
1540	397.2749268
1320	502.5358049
1100	594.2146341
880	672.3114146
660	736.8261463
440	787.7588293
220	825.1094634
0	848.8780488

$$Q_o = (Q_o)_{max}\left[1 - 0.2\left(\frac{P_{wf}}{P_r}\right) - 0.8\left(\frac{P_{wf}}{P_r}\right)^2\right]$$



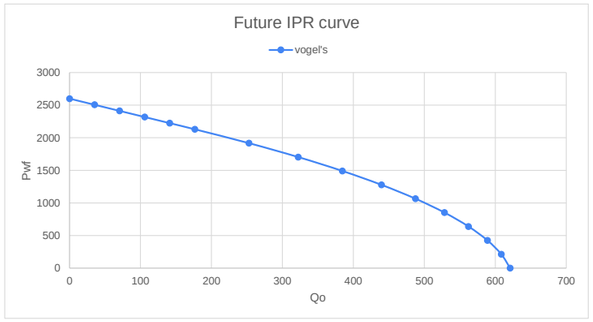
Undersaturated oil reservoirs (pr > pb)

Avg. Pr	3000	psi
$(Pwf)_{stablized}$	2500	psi
$(Qo)_{stablized}$	250	STB/day
Pb	2130	psi
Future Avg. Pr	2600	psi

(J)p	0.5	STB/day-psi
(J)f	0.375555556	STB/day-psi

$$J_f^* = J_p^*\left[(\bar{p}_r)_f / (\bar{p}_r)_p\right]^2$$

Pwf	(Qo)f
2600	0
2506	35.30222222
2412	70.60444444
2318	105.9066667
2224	141.2088889
2130	176.5111111
1917	252.9491852
1704	322.2767407
1491	384.4937778
1278	439.6002963
1065	487.5962963
852	528.4817778
639	562.2567407
426	588.9211852
213	608.4751111
0	620.9185185

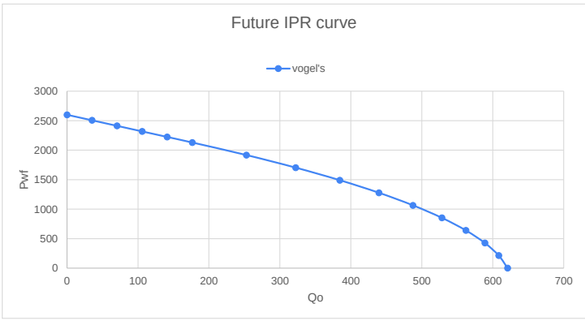


Undersaturated oil reservoirs (pr > pb)

Avg. Pr	3000	psi
$(Pwf)_{stablized}$	1700	psi
$(Qo)_{stablized}$	630.7	STB/day
Pb	2130	psi
Future Avg. Pr	2600	psi

(J)p	0.499992515	STB/day-psi
(J)f	0.375549933	STB/day-psi

Pwf	(Qo)f
2600	0
2506	35.30169374
2412	70.60338748
2318	105.9050812
2224	141.206775
2130	176.5084687
1917	252.9453985
1704	322.2719162
1491	384.4880218
1278	439.5937154
1065	487.5889969
852	528.4738663
639	562.2483237
426	588.9123689
213	608.4660021
0	620.9092233



IPR CURVE USING FETKOVITCH MODEL

$$Q_o = \frac{0.00708kh}{\left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s\right]} \int_{pwf}^{\bar{p}_r} f(p)\,dp \qquad f(p) = \left(\frac{k_{ro}}{\mu_o B_o}\right)_p$$

Saturated oil reservoirs (pr ≤ pb)

Avg. Pr	3600	psi

Qo, STB/day	pwf, psi	(Pr^2 - Pwf^2)
263	3170	2911100
383	2890	4607900
497	2440	7006400
640	2150	8337500

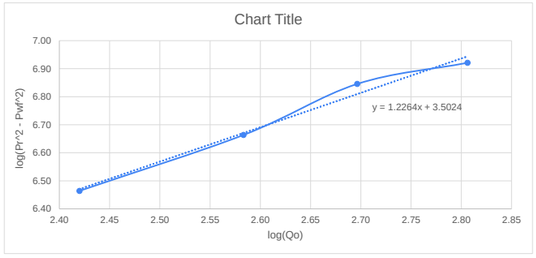
$$f(p) = \left(\frac{1}{\mu_o B_o}\right)_{pb}\left(\frac{P}{pb}\right)$$

$$Q_o = \left[\frac{0.00708kh}{\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s}\right] \int_{Pwf}^{\bar{p}_r} \frac{1}{(\mu_o B_o)_{pb}}\left(\frac{p}{p_b}\right)dp \qquad Q_o = J\left(\frac{1}{2p_b}\right)\left(\bar{p}_r^{\,2} - p_{wf}^2\right) \qquad Q_o = C\left(\bar{p}_r^{\,2} - p_{wf}^2\right)^n$$

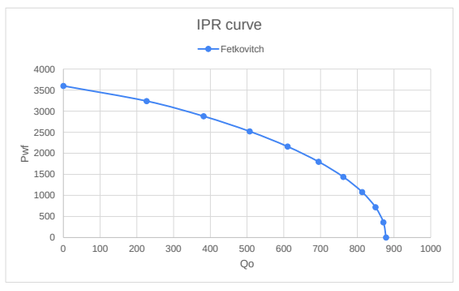
log(Qo)	log(Pr^2 - Pwf^2)
2.42	6.46
2.58	6.66
2.70	6.85
2.81	6.92

$$\log\left(\bar{p}_r^{\,2} - p_{wf}^2\right) = \frac{1}{n}\log Q_o - \frac{1}{n}\log C$$

slope	1.2264304
intercept	3.5023980
n	0.8153744
C	0.0013939



Pwf	Qo
3600	0
3240	226.7695
2880	381.8483
2520	507.2600
2160	610.4282
1800	694.7021
1440	761.9557
1080	813.3432
720	849.6007
360	871.1872
0	878.3557



Undersaturated oil reservoirs (pr > pb)

Avg. Pr	3000	psi
(Pwf)stablized	2200	psi
(Qo)stablized	280	STB/day
Pb	1500	psi

h	20	in
rw	0.3	in
re	660	in
uo at 2600psi	2.4	cp
Bo at 2600psi	1.4	bbl/STB
S	-0.5	---
K	65	md

$$f(p) = \left(\frac{k_{ro}}{\mu_o B_o}\right)_p$$

value of uo and Bo is measured at (Pr+Pwf)/2

CASE 1:

The recorded stabilized bottom-hole flowing pressure is greater than or equal to the bubble-point pressure, i.e. pwf ≥ pb

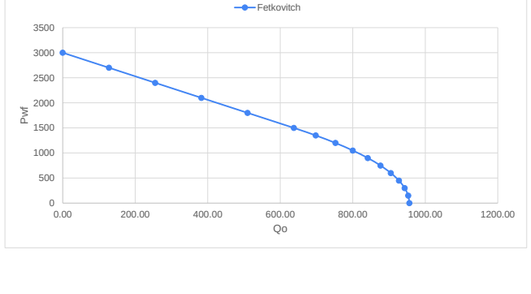
$$Q_o = \frac{0.00708kh}{\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s} \int_{pwf}^{\bar{p}_r} \left(\frac{1}{\mu_o B_o}\right) dp \qquad Q_o = \frac{0.00708kh}{\mu_o B_o\left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + S\right]}\left(\bar{p}_r - p_{wf}\right)$$

J	0.424944982	STB/day-psi

Pwf	Qo
3000	0.00
2700	127.48
2400	254.97
2100	382.45
1800	509.93
1500	637.42
1350	697.97
1200	752.15
1050	799.96
900	841.39
750	876.45
600	905.13
450	927.44
300	943.38
150	952.94
0	956.13

$$Q_o = J\left(\bar{p}_r - p_{wf}\right)$$

$$Q_o = J\left[\frac{1}{2p_b}\left(p_b^2 - p_{wf}^2\right) + \left(\bar{p}_r - p_b\right)\right]$$



Undersaturated oil reservoirs (pr > pb)

Avg. Pr	4000	psi
(Pwf)stablized	3000	psi
(Qo)stablized	700	STB/day
Pb	3200	psi

$$f(p) = \left(\frac{1}{\mu_o B_o}\right)_{pb}\left(\frac{P}{pb}\right) \qquad f(p) = \left(\frac{k_{ro}}{\mu_o B_o}\right)_p$$

CASE 2:

The recorded stabilized bottom-hole flowing pressure is less than the bubble-point pressure pwf < pb

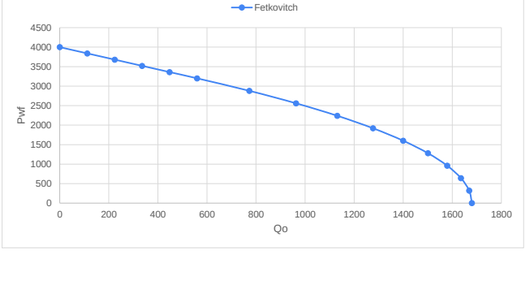
$$Q_o = \frac{0.00708kh}{\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s}\left[\int_{Pwf}^{pb} f(p)\,dp + pb\int_{pb}^{\bar{p}_r} f(p)\,dp\right]$$

J	0.7	STB/day-psi

Pwf	Qo
4000	0
3840	112
3680	224
3520	336
3360	448
3200	560
2880	772.8
2560	963.2
2240	1131.2
1920	1276.8
1600	1400
1280	1500.8
960	1579.2
640	1635.2
320	1668.8
0	1680

$$Q_o = J\left(\bar{p}_r - p_{wf}\right)$$

$$Q_o = J\left[\frac{1}{2p_b}\left(p_b^2 - p_{wf}^2\right) + \left(\bar{p}_r - p_b\right)\right]$$



FETKOVITCH'S FUTURE IPR CURVE PREDICTION

Saturated oil reservoirs (pr ≤ pb)

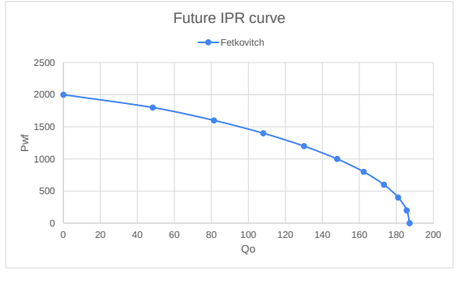
Avg. Pr	3600	psi
Future Avg. Pr	2000	psi

(n)p	0.8153744
(C)p	0.0013939
(C)f	0.0007744

$$(C)_f = (C)_p\left[(\bar{p}_r)_p/(\bar{p}_r)_f\right]^n$$

Fetkovich assumes that the value of the exponent n would not change as the reservoir pressure declines.

Pwf	Qo
2000	0
1800	48.3088543
1600	81.34540218
1400	108.0619508
1200	130.0399249
1000	147.992856
800	162.319938
600	173.2670576
400	180.9910161
200	185.5896063
0	187.1167222



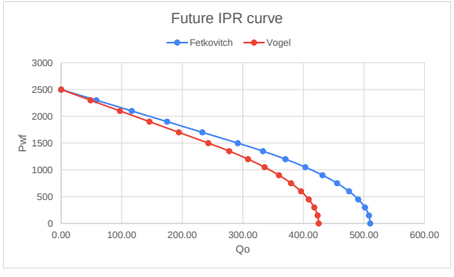
Undersaturated oil reservoirs (pr > pb)

Avg. Pr	3000	psi
(Pwf)stablized	2200	psi
(Qo)stablized	280	STB/day
Pb	1500	psi
Future Avg. Pr	2500	psi

(C)p	0.000116667	
(C)f	9.72222E-05	
(J)p	0.35	
(J)f	0.243055556	(vogels method)
(J)f	0.291666667	(fetkovitch method)

Pwf	fetkovitch Qo	vogel Qo
2500	0.00	0.00
2300	58.33	48.61
2100	116.67	97.22
1900	175.00	145.83
1700	233.33	194.44
1500	291.67	243.06
1350	333.23	277.69
1200	370.42	308.68
1050	403.23	336.02
900	431.67	359.72
750	455.73	379.77
600	475.42	396.18
450	490.73	408.94
300	501.67	418.06
150	508.23	423.52
0	510.42	425.35

$$Q_o = J\left[\frac{1}{2p_b}\left(p_b^2 - p_{wf}^2\right) + \left(\bar{p}_r - p_b\right)\right]$$



Field case 3: Well B, Keokuk Pool, Seminole County, Oklahoma, August 1935

Saturated reservoir

Pr	1714	psi
Pb	3420	psi
C1	0.41	

Multi-rate test data

Pwf (psi)	Oil Rate (bbl/day)	
1714	0	
1583	280	
1443	508	***test point (for two point correlation's)***
1272	780	
1196	1125	***test point (for single point correlation's)***
982	1335	

IPR curve by using New correlation

C1	0.41	
(Qo)max	2636.899892	STB/day

$$\frac{q_o}{q_{o\,max}} = 1 - C_1\left[\frac{P_{wf}}{P_r}\right] - (1 - C_1)\left[\frac{P_{wf}}{P_r}\right]^2$$

Pwf	Qo
1714	0
1583	311.3553721
1443	624.0096558
1272	977.7314268
1196	1125
982	1506.812135
800	1793.363642
600	2067.796199
400	2299.863093
200	2489.564324
0	2636.899892

IPR curve by using Vogel's method

(Qo)max	2388.927833	STB/day

Pwf	Qo
1714	0
1583	317.4879492
1443	632.106709
1272	981.7948926
1196	1125
982	1487.863165
800	1749.580982
600	1987.482024
400	2173.340179
200	2307.155449
0	2388.927833

IPR curve by using Fetkovitch's method

Multi-rate test data

	Pwf (psi)	Oil Rate (bbl/day)	(Pr^2-Pwf^2)	log(Qo)	log(Pr^2-Pwf^2)
	1714	0	0	*null*	*null*
	1583	280	431907	2.447158031	5.635390243
test point	1443	508	855547	2.705863712	5.932243873
	1272	780	1319812	2.892094603	6.120512073
test point	1196	1125	1507380	3.051152522	6.178222749
	982	1335	1973472	3.125481266	6.295230969

using test points to calculate C and n

Pwf	log(Qo)	log(Pr^2-Pwf^2)	
1443	2.705863712	5.932243873	***test point***
1196	3.051152522	6.178222749	***test point***

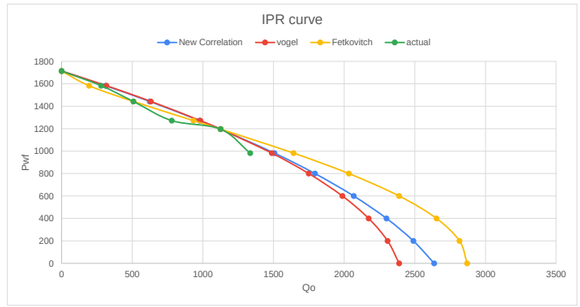
intercept	4.004624747	C	2.39097E-06
slope	0.712385889	n	1.403733588

Pwf	Qo
1714	0
1583	194.607826
1443	508
1272	933.5597266
1196	1125
982	1642.104878
800	2033.107343
600	2389.233856
400	2653.458781
200	2815.75826
0	2870.469609

		New correlation	***Vogel's***	***Fetkovitch's***
Pwf (psi)	Oil Rate (bbl/day)	Qo	Qo	Qo
1714	0	0	0	0
1583	280	311.3553721	317.4879492	194.607826
1443	508	624.0096558	632.106709	508
1272	780	977.7314268	981.7948926	933.5597266
1196	1125	1125	1125	1125
982	1335	1506.812135	1487.863165	1642.104878

Percentage Error

New correlation	***Vogel's***	***Fetkovitch's***
11.19834719	13.38855328	30.49720499
22.83654641	24.43045453	2.57362E-13
25.35018292	25.87114008	19.68714444
0	0	2.62743E-13
12.86982287	11.45042437	23.00411072
Average absolute errors	14.45097988	15.02811445	14.63769203



Field case 3: Well B, Keokuk Pool, Seminole County, Oklahoma, August 1935.

The multi rate test has been repeated for this well from Field Case 2 after 8 months of production with a drop in reservoir pressure from 1714 psi to 1605 psi.

Saturated reservoir

(Pr)f	1605	psi
(Pr)p	1714	psi
Pb	3420	psi
C1	0.49	

Multi-rate test data

Pwf (psi)	Oil Rate (bbl/day)	
1605	0	
1381	420	***test point (for two point correlation's)***
1231	720	***test point (for single point correlation's)***
1120	850	

Future IPR curve by using New correlation

C1	0.49	
(Qomax)p	2636.899892	STB/day
(Qomax)f	2165.141578	STB/day

$$q_{o,max2} = q_{o,max1}\left(\frac{P_{r2}}{P_{r1}}\right)^2$$

Pwf	Qo
1605	0
1381	434.7769194
1231	701.8747149
1120	887.1085623
982	1102.669899
800	1361.996156
600	1614.220934
400	1832.153431
200	2015.793646
0	2165.141578

$$\frac{q_o}{q_{o\,max}} = 1 - C_1\left[\frac{P_{wf}}{P_r}\right] - (1 - C_1)\left[\frac{P_{wf}}{P_r}\right]^2$$

Future IPR curve by using Vogel's method

(Qomax)p	2388.927833	STB/day
(Qomax)f	1961.533311	STB/day
(Qomax)f	2123.198485	STB/day

(by using Eickmeier equation)

$$q_{o,max2} = q_{o,max1}\left(\frac{P_{r2}}{P_{r1}}\right)^2$$

(by using vogel's equation)

$$\left(Q_{o\,max}\right)_f = \left(Q_{o\,max}\right)_p\left[0.2 + 0.8\left(\frac{\left(P_r\right)_f}{\left(P_r\right)_p}\right)\right]\left(\frac{\left(P_r\right)_f}{\left(P_r\right)_p}\right)$$

Pwf	Qo
1605	0
1381	462.2009897
1231	737.5363727
1120	923.6364101
982	1134.071865
800	1376.124858
600	1595.576882
400	1766.295632
200	1888.281109
0	1961.533311

$$Q_o = (Q_o)_{max}\left[1 - 0.2\left(\frac{P_{wf}}{P_r}\right) - 0.8\left(\frac{P_{wf}}{P_r}\right)^2\right]$$

IPR curve by using Fetkovitch's method

n	1.403733588	
(C)p	0.000002391	
(C)f	0.000002239	

$$(C)_f = (C)_p\left[(\bar{p}_r)_f/(\bar{p}_r)_p\right]$$

Pwf	Qo
1605	0
1381	336.7133354
1231	643.1968966
1120	875.8771461
982	1157.208629
800	1496.876726
600	1809.398535
400	2042.734009
200	2186.569916
0	2235.135746

		New correlation	***Vogel's***	***Fetkovitch's***
Pwf (psi)	Oil Rate (bbl/day)	Qo	Qo	Qo
1605	0	0	0	0
1381	420	434.7769194	462.2009897	336.7133354
1231	720	701.8747149	737.5363727	643.1968966
1120	850	887.1085623	923.6364101	875.8771461

Percentage Error

New correlation	***Vogel's***	***Fetkovitch's***
3.518314133	10.04785469	19.83015823
2.517400704	2.435607313	10.66709769
4.365713211	8.663107068	3.044370135
Average absolute errors	3.467142683	7.048856355	11.18054202