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EVALUATION OF PRODUCTIVITY PERFORMANCE OF HORIZONTAL WELLS

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Abstract

Horizontal well performance functionality depends on the relative level of the injury caused to the wellbore. Well bore impairment is commonly accounted for by an apparent skin factor in the productivity function. Examination of productivity performance ratio of horizontal well gives an appreciation of how well or otherwise a completed well performs. Productivity performance ratio is the actual productivity of the well relative to the ideal situation. A comparison between the productivity performance ratio of horizontal well and that of the vertical well shows that permeability reduction around the wellbore is less harmful to horizontal wells. Increasing the well length minimizes the effect of the damage caused to the horizontal well. It is also established that at large permeability ratio values, the effect of damage to the neighborhood of the well is relatively smaller in horizontal well than vertical well. The increase in the performance of the horizontal well productivity is limited to the length to thickness ratio as well as the decrease in vertical permeability. The decline in productivity performance of the horizontal well reduces at higher drainage radius. The effects of the following parameters were also investigated: parallel permeability, vertical permeability, perpendicular permeability and horizontal permeability. The productivity performance ratio is significantly affected by horizontal permeability and perpendicular permeability.

Keywords: Productivity performance ratio; Skin effect; Well length; Drainage radius; Reservoir anisotropy ratio.

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1. Introduction

Significant portion of the research related to horizontal wells concerns pressure productivity index estimation. Little has been done on the quantitative effect of formation damage on well performances. Among the parameters that play an important role in the determination of horizontal well performances, formation damage in the well bore is the most important. Literature is replete with performance ratios of horizontal wells compared with the conventional wells regarding their productivity index, Joshi [1]. Recent research has expressed different viewpoints on the role of formation damage in the performance of horizontal wells. De Monteigny [2], Mauduit [3] suggest that, as horizontal-well length, L, increases, the influence of formation damage on total pressure drop can become negligible, resulting in an additional advantage over vertical wells. Sparlin [4] indicate that the damaged zone may affect productivity more in horizontal wells than in vertical wells, and that skin damage sometimes can prevent horizontal-well projects from succeeding. These two suggestions of the influence of formation damage on horizontal-well productivity come from a lack of well-defined reservoir and well characteristics to quantify the effect of formation damage on the flow efficiency of horizontal wells. Merkulov [5] and later Borisov [6] presented analytical expressions for horizontal wells producing under ideal conditions of isotropic reservoirs with no formation damage and no friction. Joshi [7] studied the same problem extended to three dimensional steady state flow with relatively short horizontal wells compared to the drainage area which is assumed to be elliptical. Giger [8] generalized the results to a rectangular area to account for longer horizontal wells using the potential flow theory. Other investigators like Economides [9-10] and Renard and Dupuy [11] did more work to take into account the anisotropy ratio and contributed in developing the theoretical expression for the productivity index as it is now accepted as reported by Economides [10].

Goode and Wilkinson [12] studied the inflow performance of a partially completed well based on the consideration that the different sections open to flow can be assimilated to a series of vertical fractures.

The expressions of formation damage on inflow performance ratios, the effect of formation damage on productivity index is assumed as constant along the whole length of the horizontal section of the well. As a result a constant skin S is added to the productivity index theory identical to the vertical wells. Recent literature shows that this is not accurate. Many investigators [13, 18] demonstrated that formation damage varies in fact from the heel to the toe in a horizontal well, especially if it is a long well as it is often the case now.

Economides [14], Yan *et al.* [15], Engler *et al.* [16], Toulekima [17] and others, all showed that the skin decreases along the horizontal section of the well from heel to toe. The reason is that formation damage is proportional to the exposure time of the reservoir during drilling and completion operations. Economides [10] for example, using a numerical model showed that the distribution of damage along the horizontal well and around it is not uniform. Particularly, because of permeability anisotropy, the invasion zone has the shape of an elliptical cone with the larger base near the vertical section of the well.

Consequently, the skin profile decreases from heel to toe and therefore the constant skin assumption used in vertical wells is not valid.

The challenge in assuming the constant skin is in the fact that it can lead to significant deviation from the real well performance. The objective of this paper is to provide a basis for comparing the flow performance ratios of vertical and horizontal wells. The comparison considers an altered zone of the same radius and reduced permeability around the vertical and horizontal wellbores. The effects of reservoir anisotropy, well length, drainage radius and length to thickness ratio on the productivity performance ratios have also been considered.

2. Mathematical model

2.1 Vertical wells performance

Horner [19] and van Everdingen [20] have estimated the effect of pressure drop within the wellbore due to long term production at constant rate, *q* for time t. In the estimation the effect of further reduction in permeability near the wellbore due to drilling, completion and production practices. The summary of the above effects were accounted for with a dimensionless product to account for the above as in the Eq. 1.

$$\Delta p_t = \frac{q\mu}{4\pi k_e h}\left[ln\left(\frac{k_e t}{\mu c\emptyset r^2{}_w}\right) + 0.809 + 2S\right] \qquad (1)$$

A zone of altered permeability k_a greater than the general (unaltered) permeability k_e out to a radius r_a exits about the well. The pressure drop due to variation in the permeability in the altered and unaltered zone was estimated as in Eq. 2.

$$\Delta p_s = \frac{q\mu\, ln\left({}^{r_a}/_{r_w}\right)}{2\pi k_a h} - \frac{q\mu\, ln\left({}^{r_a}/_{r_w}\right)}{2\pi k_e h} \qquad (2)$$

Rearranging Eq. 2,

$$\Delta p_s = \frac{q\mu}{2\pi k_a}\left[\frac{k_e - k_a}{k_e k_a} ln\left({}^{r_a}/_{r_w}\right)\right] \qquad (3)$$

Adding Eq. 3 to Eq. 1 gives the total pressure drop as:

$$\Delta p_t = \frac{q\mu}{4\pi k_e h}\left[ln\left(\frac{k_e t}{\mu c\emptyset r^2{}_w}\right) + 0.809 + 2\frac{q\mu}{2\pi k_a}\left[\frac{k_e - k_a}{k_e k_a} ln\left({}^{r_a}/_{r_w}\right)\right]\right] \qquad (4)$$

$$\Delta p_t = \frac{q\mu}{4\pi k_e h}\left[ln\left(\frac{k_e t}{\mu c\emptyset r^2{}_w}\right) + 0.809 + 2\left(\frac{k_e}{k_a} - 1\right) ln\left({}^{r_a}/{}_{r_w}\right)\right] \tag{5}$$

Comparing Eq. 1 and Eq. 5, it is observed that the skin effect may be defined as

$$S_v = \left[\left(\frac{k_e}{k_a} - 1\right) ln\left({}^{r_a}/{}_{r_w}\right)\right] \tag{6}$$

The productivity ratio or flow efficiency of vertical well (P.R.V.) is the ratio of actual well performance index to the ideal well performance index (PI). The ideal performance index is when the permeability is considered as unaltered up to the face of the wellbore.

$$\text{P.R.V.} = \frac{PI_{actual}}{PI_{ideal}} = \frac{ln\left({}^{r_e}/{}_{r_w}\right)}{ln\left({}^{r_e}/{}_{r_w}\right) + S} = \frac{\Sigma_1}{\Sigma_1 + S} \tag{7}$$

2.2 Horizontal wells performance

Model on ideal productivity performance index of horizontal well in an isotropic reservoir was first reported by Merkulov [5]. Joshi [1] and Giger [8] advanced the idea by analyzing pressure profile in a 3D steady state flow of horizontal well located inside an ellipsoidal drainage area. The limitation on their model is the fact that it is constrained to small well lengths when compared to the drainage radius. Giger [8] therefore considered the case of rectangular drainage area and the case of large well lengths. Their model is summarized as Eq. 8

$$PI_{ideal} = \frac{2\pi k_H h}{\mu B}\left\{\frac{1}{\left[cosh^{-1}(X) + \beta\left(\frac{h}{L}\right)\ln\left(\frac{h}{2\pi r'_w}\right)\right]}\right\} \tag{8}$$

$$r'_w = \left[\frac{(1+\beta)}{2\beta}\right] r_w \tag{9}$$

The effect of the skin damage in the neighborhood of the well gives the actual productivity performance of the horizontal well as Eq. 9

$$PI_{actual} = \frac{2\pi k_H h}{\mu B}\left\{\frac{1}{\left[cosh^{-1}(X) + \beta\left(\frac{h}{L}\right)\ln\left(\frac{h}{2\pi r'_w}\right)\right] + S_h}\right\} \tag{10}$$

Where $S_h = (h/L)\beta S_v$

The productivity performance ratio or flow efficiency of horizontal well (P.R.H.) is given as in Eq. 7

$$\text{P.R.H.} = \frac{PI_{actual}}{PI_{ideal}} = \frac{\left[cosh^{-1}(X) + \beta\left(\frac{h}{L}\right)\ln\left(\frac{h}{2\pi r'_w}\right)\right]}{\left[cosh^{-1}(X) + \beta\left(\frac{h}{L}\right)\ln\left(\frac{h}{2\pi r'_w}\right)\right] + (h/L)\beta S_v} = \frac{\Sigma}{\Sigma + S} \tag{11}$$

Eq. 7 is simplified further as

$$\text{P.R.H.} = \frac{PI_{actual}}{PI_{ideal}} = \frac{\left[\left(\frac{L}{h\beta}\right) cosh^{-1}(X) + \ln\left(\frac{h}{2\pi r'_w}\right)\right]}{\left[\left(\frac{L}{h\beta}\right) cosh^{-1}(X) + \ln\left(\frac{h}{2\pi r'_w}\right)\right] + S_v} = \frac{\Sigma_2}{\Sigma_2 + S} \tag{12}$$

2.3 Comparison of horizontal and vertical wells productivity performance ratios

From Eq. 7 and Eq. 12, the productivity performance ratio for both horizontal and vertical wells are seen as indistinguishable irrespective the value of the skin factor. Hence equating $\Sigma_1 and\ \Sigma_2$, gives

$$\left[\left(\frac{L}{h\beta}\right) cosh^{-1}(X) + \ln\left(\frac{h}{2\pi r'_w}\right)\right] = ln\left({}^{r_e}/{}_{r_w}\right) \tag{13}$$

Traditionally, $X = \frac{2r_{eH}}{L}$ where r_{eH} is the horizontal drainage radius inside a circular drainage area. Assuming the horizontal drainage radius is identical to the vertical drainage radius. Eq. 13 can be simplified as

$$\left[\left(\frac{L}{h\beta}\right) ln\left(X+\sqrt{X^2-1}\right)+\ln(\frac{h}{2\pi r'_w})\right] = ln(r_{ev}/r_w) \tag{14}$$

$$\left[\left(\frac{L}{h\beta}\right) ln\frac{(4r_{eH})}{L}+\ln\left(\frac{h}{2\pi r'_w}\right)\right] = ln(r_{ev}/r_w) \tag{15}$$

$$2\frac{r_{eH}}{L} = 1/2exp\left[\frac{ln\left(\frac{L}{h}\frac{\pi}{4\alpha}\frac{1+\beta}{\beta}\right)}{\frac{L}{h\beta}-1}\right] \tag{16}$$

where $r_{eH} = \alpha r_{ev},\ \beta = \sqrt{\frac{k_h}{k_v}},\ and\ k_h = \sqrt{k_x \times k_y}$.

3. Results and discussion

The productivity ratio of horizontal well is identical to the vertical well as both are expressed as function of the skin factor. Fig. 1 shows the representation of productivity performance ratio for both horizontal and vertical wells. As the formation damage increases, productivity ratio of both horizontal and vertical wells decreases as compared to undamaged wells. Fig. 1 depicts the influence of formation damage on both horizontal and vertical wells.

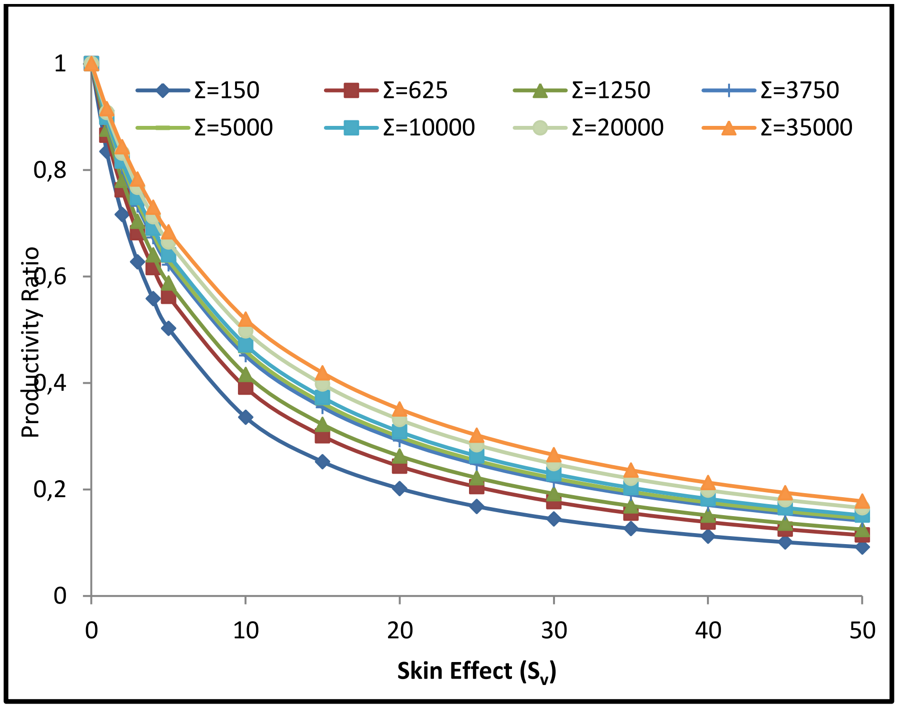

Figure 1 Productivity ratio as a function of skin for both vertical and horizontal wells

3.1 Comparison of horizontal and vertical wells productivity performance ratios

Figs. 2, 3 and 4 show the relationship between the horizontal and vertical well for reservoir anisotropy ratio (β) varying from 3.16 to 10 under different conditions of α between 0.5 and 2. It can be seen from Fig. 2 that the formation damage disrupts the productivity performance ratio of horizontal well less than that of vertical well for the same drainage radius and for all values of the skin factors up to a limiting β value of 4.472 and 3.162 with $\frac{L}{h}$ of 20 and $\frac{2r_{eH}}{L}$ $equal\ to\ 1.2$ and $\frac{L}{h}$ of 12.5 and $\frac{2r_{eH}}{L}$ $equal\ to\ 1.2$ respectively.

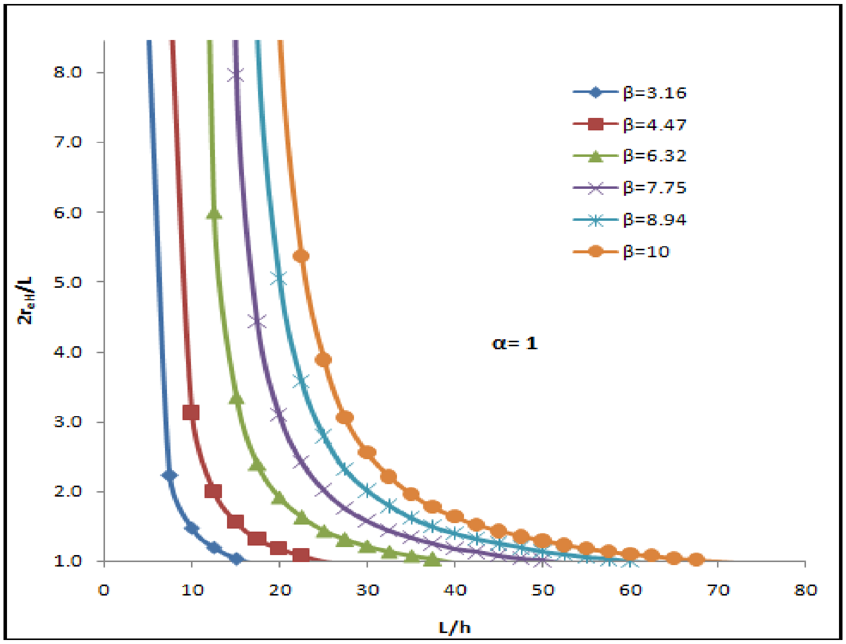

Figure 2 Horizontal well drainage to length ratio versus length to thickness ratio, $\alpha = 1$

From Fig. 3, when r_{eH} =2r_{ev} the formation damage disrupts the productivity performance ratio of horizontal well less than that of vertical well for all values of the skin factors up to a limiting β value of 10 and 4.472 with $\frac{L}{h}$ of 32.5 and $\frac{2r_{eH}}{L}$ $equal\ to\ 1.6$ and $\frac{L}{h}$ of 15 and $\frac{2r_{eH}}{L}$ $equal\ to\ 1.2$ respectively. Fig. 4, shows the effect of the formation damage when $r_{eH} = 0.5r_{ev}$. Under this condition the formation damage influences the productivity performance ratio of horizontal well less than that of vertical well for reservoir vertical permeability ratio $\left(\frac{kv}{kh}\right)$ value of 0.01. Beyond this the effect of the forma-tion damage on productivity performance ratio of horizontal well less than the vertical well for all the reservoir anisotropy considered up to a limiting value of Sv of 5. The analysis of the well comparison shows that the formation damage is more consequential on the vertical well than the horizontal well where the vertical permeability of the reservoir is high and this means that the horizontal will drain more volume than the vertical well, the limiting value of β increases as $\frac{L}{h}$ increases. However, when the reservoir drainage radius for the horizontal well is half the vertical well the formation damage affect the horizontal well for small well damage. The productivity performance ratio of both well is identical only under ideal conditions.

Detail comparison of the productivity performance ratio of both horizontal and vertical wells is presented in Tables 2 to 5 for α value of 0.5 to 3, for different skin factors and different reservoir anisotropy ratios. The results are based on the reservoir properties showed in Table 1. It is observed from the comparison that the formation damaged on productivity performance ratio of the horizontal well is less detrimental than in the vertical well for lower reservoir aniso-tropy ratios. The productivity performance ratio of the horizontal well to the vertical well decreases as the reservoir anisotropy increases. The productivity performance ratio of the horizontal well approximates that of the vertical well for reservoir anisotropy ratio β=7.2 or kH/kV=51 and β=4.5 or kH/kV=20 for α=1 and α=0.5 respectively. For α>1, the formation damage always affect the productivity performance of the vertical well than horizontal well.

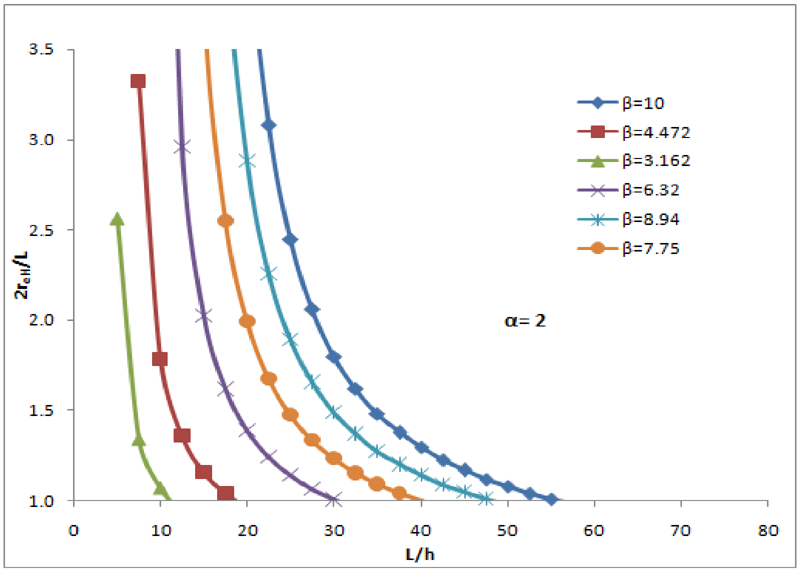

Figure 3 Horizontal well drainage to length ratio versus length to thickness ratio, $\alpha = 2$

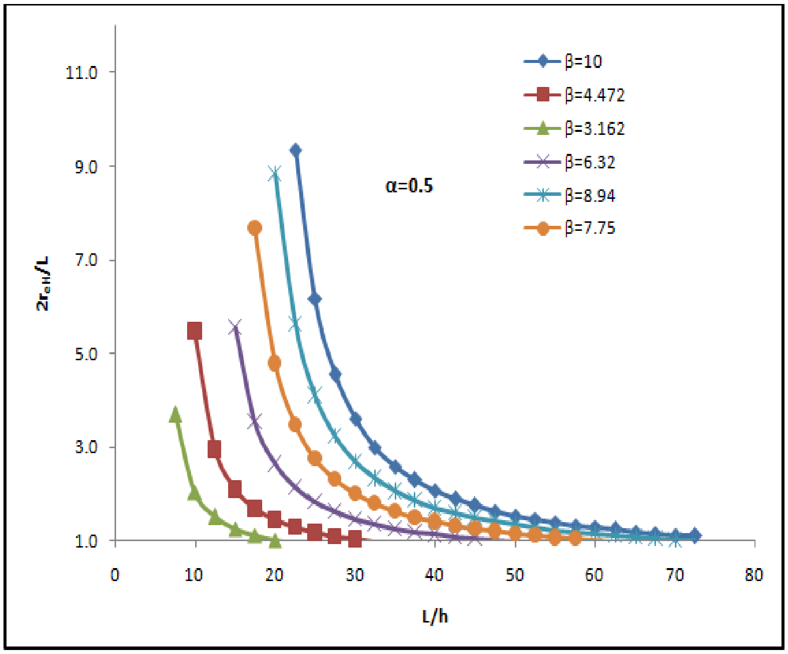

Figure 4 Horizontal well drainage to length ratio versus length to thickness ratio, $\alpha = 0.5$

Table 1 Reservoir and fluid properties

L ft	Area acres	r_w, ft	Viscosity, μ	B_o	Porosity, ø	Height, ft	β
700	180	0.32	0.68	1.23	3.8	40	1
1200							1.41
1800							3.16
2200							4.47
2800							10

Table 2 Evaluation of productivity performance ratios for horizontal and vertical wells α=1

		E_h, α=1				
		β=10,	β=4.4721,	β=3.162,	β=1.4142,	β=1,
Sv	Ev	Kv/Kh = 0.01	Kv/Kh = 0.05	Kv/Kh = 0.1	Kv/Kh = 0.5	Kv/Kh = 1.0
1	0.89	0.88	0.93	0.94	0.97	0.98
2	0.81	0.79	0.87	0.94	0.97	0.98
3	0.74	0.71	0.81	0.91	0.96	0.97
4	0.68	0.65	0.76	0.89	0.95	0.97
5	0.63	0.60	0.72	0.86	0.94	0.96
10	0.46	0.43	0.56	0.76	0.88	0.92
15	0.36	0.33	0.46	0.68	0.83	0.88
20	0.30	0.27	0.39	0.61	0.78	0.85
25	0.25	0.23	0.34	0.56	0.74	0.82
30	0.22	0.20	0.30	0.51	0.71	0.79
35	0.20	0.18	0.27	0.48	0.67	0.76
40	0.18	0.16	0.24	0.44	0.64	0.74
45	0.16	0.14	0.22	0.41	0.62	0.71
50	0.15	0.13	0.21	0.39	0.59	0.69
$(J_h/J_v)_{)ideal}$		2.86	3.67	3.94	4.35	4.44

Table 3 Evaluation of productivity performance ratios for horizontal and vertical wells α=0.5

		E_h, α=0.5				
		β=10,	β=4.4721,	β=3.162,	β=1.4142,	β=1,
Sv	Ev	Kv/Kh = 0.01	Kv/Kh = 0.05	Kv/Kh = 0.1	Kv/Kh = 0.5	Kv/Kh = 1.0
1	0.89	0.85	0.90	0.92	0.95	0.97
2	0.81	0.73	0.81	0.96	0.98	0.99
3	0.74	0.65	0.74	0.94	0.97	0.98
4	0.68	0.58	0.68	0.92	0.97	0.98
5	0.63	0.52	0.63	0.90	0.96	0.97
10	0.46	0.35	0.46	0.82	0.92	0.95
15	0.36	0.27	0.36	0.76	0.88	0.92
20	0.3	0.21	0.30	0.70	0.85	0.90
25	0.25	0.18	0.25	0.65	0.82	0.88
30	0.22	0.15	0.22	0.61	0.79	0.86
35	0.2	0.14	0.20	0.57	0.76	0.84
40	0.18	0.12	0.18	0.54	0.74	0.82
45	0.16	0.11	0.16	0.51	0.71	0.80
50	0.15	0.10	0.15	0.48	0.69	0.79
$(J_h/J_v)_{)ideal}$		3.89	5.56	6.19	7.27	7.53

Table 4 Evaluation of productivity performance ratios for horizontal and vertical wells, α=2

		E_h, α=2				
Sv	Ev	β=10, Kv/Kh = 0.01	β=4.4721, Kv/Kh = 0.05	β=3.162, Kv/Kh = 0.1	β=1.4142, Kv/Kh = 0.5	β=1, Kv/Kh = 1.0
1	0.89	0.90	0.94	0.96	0.98	0.99
2	0.81	0.82	0.89	0.93	0.96	0.98
3	0.74	0.75	0.85	0.89	0.95	0.96
4	0.68	0.70	0.81	0.86	0.93	0.95
5	0.63	0.65	0.77	0.83	0.92	0.94
10	0.46	0.48	0.63	0.71	0.85	0.89
15	0.36	0.38	0.53	0.62	0.78	0.85
20	0.3	0.32	0.46	0.55	0.73	0.80
25	0.25	0.27	0.40	0.50	0.69	0.77
30	0.22	0.24	0.36	0.45	0.65	0.73
35	0.2	0.21	0.33	0.42	0.61	0.70
40	0.18	0.19	0.30	0.38	0.58	0.67
45	0.16	0.17	0.27	0.36	0.55	0.65
50	0.15	0.16	0.25	0.33	0.52	0.62
$(J_h/J_v)_{ideal}$		2.31	2.81	2.96	3.19	3.24

Table 5 Evaluation of productivity performance ratios for horizontal and vertical wells, α=3

		E_h, α=3				
Sv	Ev	β=10, Kv/Kh = 0.01	β=4.4721, Kv/Kh = 0.05	β=3.162, Kv/Kh = 0.1	β=1.4142, Kv/Kh = 0.5	β=1, Kv/Kh = 1.0
1	0.89	0.91	0.95	0.96	0.98	0.99
2	0.81	0.84	0.91	0.92	0.96	0.97
3	0.74	0.77	0.86	0.88	0.94	0.96
4	0.68	0.72	0.83	0.85	0.92	0.95
5	0.63	0.67	0.79	0.82	0.91	0.93
10	0.46	0.51	0.66	0.69	0.83	0.88
15	0.36	0.41	0.56	0.60	0.76	0.83
20	0.3	0.34	0.49	0.53	0.71	0.78
25	0.25	0.29	0.43	0.47	0.66	0.74
30	0.22	0.25	0.39	0.43	0.62	0.70
35	0.2	0.23	0.35	0.39	0.58	0.67
40	0.18	0.20	0.32	0.36	0.55	0.64
45	0.16	0.19	0.30	0.33	0.52	0.61
50	0.15	0.17	0.28	0.31	0.49	0.59
$(J_h/J_v))_{ideal}$		2.08	2.47	2.59	2.76	2.80

3.2 Effect of well length on productivity performance ratio

From the discussions above Eq. 16, it can be established that for a reservoir with a given anisotropy ratio β, the effect of the reservoir anisotropy reduces with increasing horizontal well length. Therefore, increasing the length of the horizontal well must reduce the undesirable influence of the anisotropy ratio. The effect of the horizontal well length on the productivity performance ratio is presented in Tables 6 to 12. The effect of the horizontal well length on productivity performance ratio though marginal however increases with increasing well length for a given reservoir anisotropy ratio. Generally, the effect of the well length is observed as the reservoir anisotropy decreases.

Significant effect of the well length is established in the ratio of the productivity performance of horizontal well to that of vertical well.

Table 6 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 0.01				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.881	0.894	0.898	0.895	0.877
2	0.788	0.809	0.815	0.811	0.780
3	0.712	0.738	0.746	0.740	0.703
4	0.650	0.679	0.688	0.681	0.640
5	0.597	0.628	0.638	0.631	0.587
10	0.426	0.458	0.469	0.461	0.415
15	0.331	0.361	0.370	0.363	0.321
20	0.271	0.297	0.306	0.300	0.262
25	0.229	0.253	0.261	0.255	0.221
$(J_h/J_v)_{ideal}$	2.007	3.017	4.339	5.4672	8.384

Table 7 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 0.0167				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.895	0.908	0.9116	0.909	0.89
2	0.810	0.831	0.8376	0.833	0.802
3	0.739	0.766	0.7747	0.769	0.73
4	0.680	0.7111	0.7205	0.714	0.669
5	0.630	0.6632	0.6735	0.666	0.618
10	0.460	0.49611	0.5077	0.499	0.447
15	0.362	0.39627	0.4074	0.399	0.35
20	0.298	0.32988	0.3402	0.333	0.288
25	0.254	0.28255	0.292	0.285	0.245
$(J_h/J_v)_{ideal}$	2.259	3.34	4.7883	6.053	9.490

Table 8 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 0.0125				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.887	0.900	0.904	0.901	0.882
2	0.797	0.819	0.825	0.820	0.790
3	0.724	0.750	0.759	0.753	0.714
4	0.663	0.693	0.702	0.695	0.652
5	0.611	0.643	0.653	0.646	0.600
10	0.440	0.474	0.485	0.477	0.429
15	0.344	0.376	0.386	0.378	0.333
20	0.282	0.311	0.320	0.313	0.273
25	0.239	0.265	0.274	0.268	0.231
$(J_h/J_v)_{ideal}$	2.118	3.162	4.539	5.727	8.869

Table 9 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 0.025				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.906	0.918	0.922	0.919	0.901
2	0.827	0.849	0.855	0.851	0.820
3	0.762	0.789	0.797	0.792	0.752
4	0.706	0.737	0.747	0.740	0.694
5	0.657	0.692	0.703	0.695	0.645
10	0.490	0.529	0.541	0.533	0.476
15	0.390	0.428	0.440	0.432	0.377
20	0.324	0.360	0.371	0.363	0.312
25	0.277	0.310	0.321	0.313	0.267
$(J_h/J_v)_{ideal}$	2.45	3.59	5.12	6.49	10.35

Table 10 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 0.05				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.923	0.935	0.938	0.936	0.919
2	0.858	0.878	0.884	0.879	0.850
3	0.801	0.827	0.835	0.829	0.791
4	0.751	0.782	0.791	0.785	0.739
5	0.707	0.742	0.752	0.745	0.694
10	0.546	0.590	0.603	0.593	0.531
15	0.445	0.489	0.503	0.493	0.430
20	0.376	0.418	0.432	0.422	0.362
25	0.325	0.365	0.378	0.369	0.312
$(J_h/J_v)_{ideal}$	2.763	3.97	5.637	7.169	11.74

Table 11 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 0.1				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.939	0.950	0.952	0.950	0.936
2	0.886	0.904	0.909	0.905	0.879
3	0.838	0.862	0.869	0.864	0.829
4	0.795	0.825	0.833	0.827	0.784
5	0.756	0.790	0.800	0.793	0.744
10	0.608	0.653	0.666	0.657	0.592
15	0.508	0.556	0.571	0.560	0.492
20	0.437	0.485	0.499	0.489	0.421
25	0.383	0.429	0.444	0.433	0.367
$(J_h/J_v)_{ideal}$	3.033	4.2898	6.065	7.737	12.97

Table 12 Effect of horizontal length and anisotropy on flow P.R.H

	E_h, Kv/Kh = 1				
Sv	L=700ft	L=1200ft	L=1800ft	L=2200ft	L=2800ft
0	1	1	1	1	1
1	0.977	0.981	0.982	0.982	0.975
2	0.954	0.963	0.965	0.964	0.951
3	0.933	0.946	0.949	0.947	0.928
4	0.913	0.929	0.933	0.930	0.906
5	0.893	0.913	0.918	0.914	0.886
10	0.807	0.839	0.848	0.842	0.795
15	0.736	0.777	0.788	0.780	0.721
20	0.677	0.723	0.736	0.727	0.659
25	0.626	0.676	0.691	0.680	0.607
$(J_h/J_v)_{ideal}$	3.56	4.882	6.848	8.786	15.39

3.3 Effect of payzone thickness on P.R.H

Figure 5 shows the effect of the payzone thickness on PI with the following constants: L = 500ft, Kx = Ky = Kh = 150mD, Kz =Kv = 30mD. When the payzone thickness h is shallower (h < 70ft), PI increases rapidly with the increasing h, but when h >70ft, PI increases slowly with increasing h. For h between 10 and 70ft, PI increases about 3 times; beyond this PI increases about 1.3 times. This suggests that horizontal wells perform much better in thin reservoirs.

3.4 Effect of horizontal permeability on P.R.H

Figure 6 presents the effect of horizontal permeability on P.R.H. It is observed that P.R.H. significantly depends on the horizontal permeability. From the analysis, horizontal permeability increases 11 times, at the same time β only increases about 3.3 even as P.R.H increases about 5.8 times.

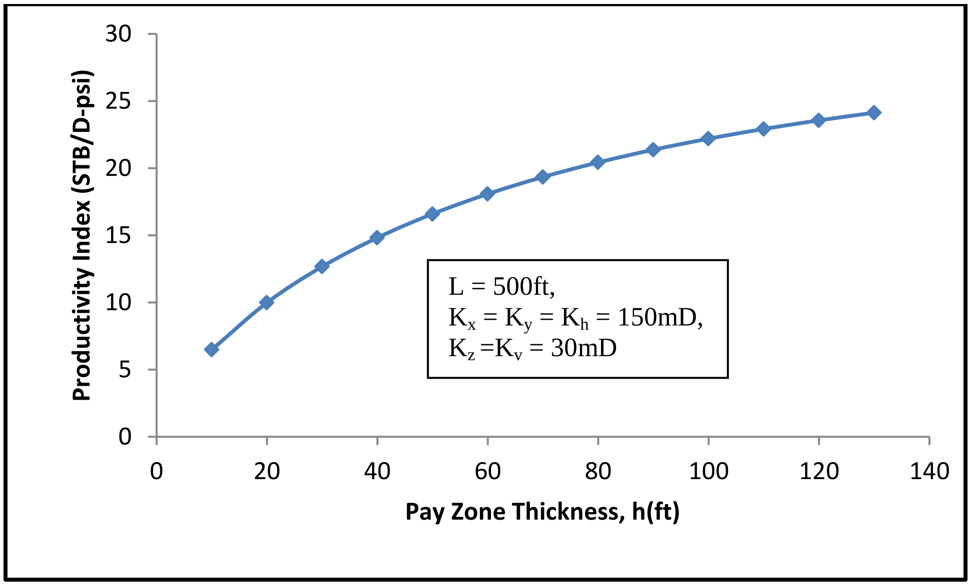

Figure 5 Effect of payzone thickness on P.R.H.

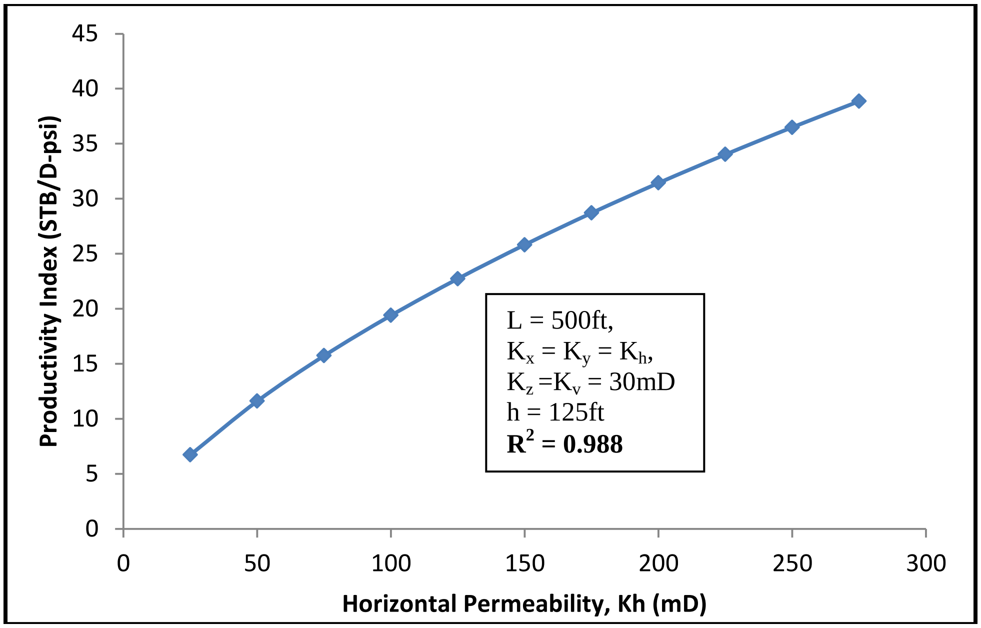

Figure 6 Effect of horizontal permeability on P.R.H. ($K_x = K_y = K_h$)

3.5 Effect of vertical permeability on P.R.H.

Figure7 presents the effect of vertical permeability on P.R.H. It is observed that P.R.H. is not significantly affected by vertical permeability. From the analysis, vertical permeability increases 10 times, at the same time β decreases about 3.2 even as P.R.H increases about 1.7 times.

3.6 Effect of permeability perpendicular to horizontal well on P.R.H.

Figure 8 presents the effect of permeability perpendicular to horizontal well on P.R.H. It is observed that P.R.H. is significantly affected by perpendicular permeability K_y. When K_y < 25mD (from 2mD to 25mD) K_y increases 12.5 times even as P.R.H increases 3.4 times. When K_y > 25mD (25mD to 225mD), P.R.H is not significantly affected by as K_y increases 9 P.R.H increases just about 3.14 times.

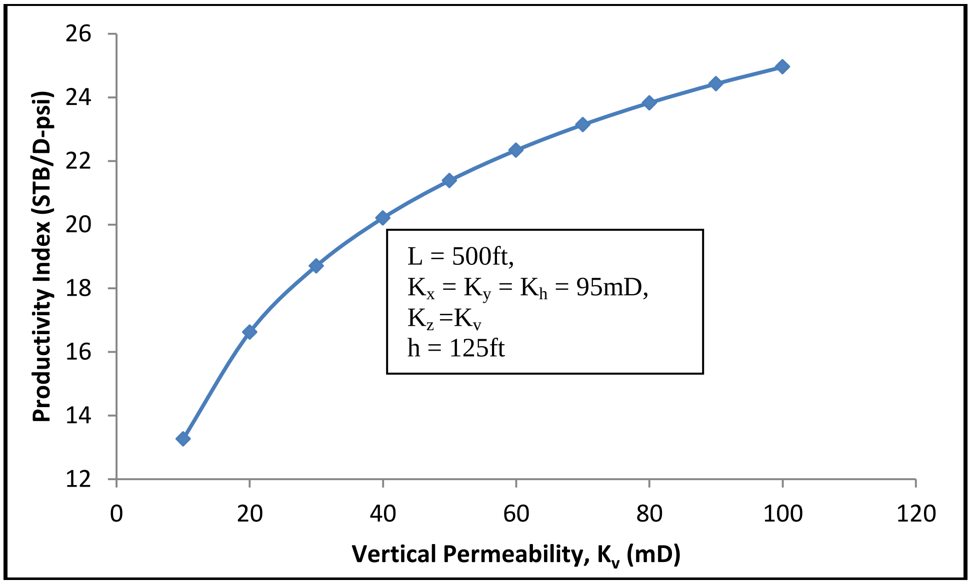

Figure 7 Effect of vertical permeability Kv on P.R.H.

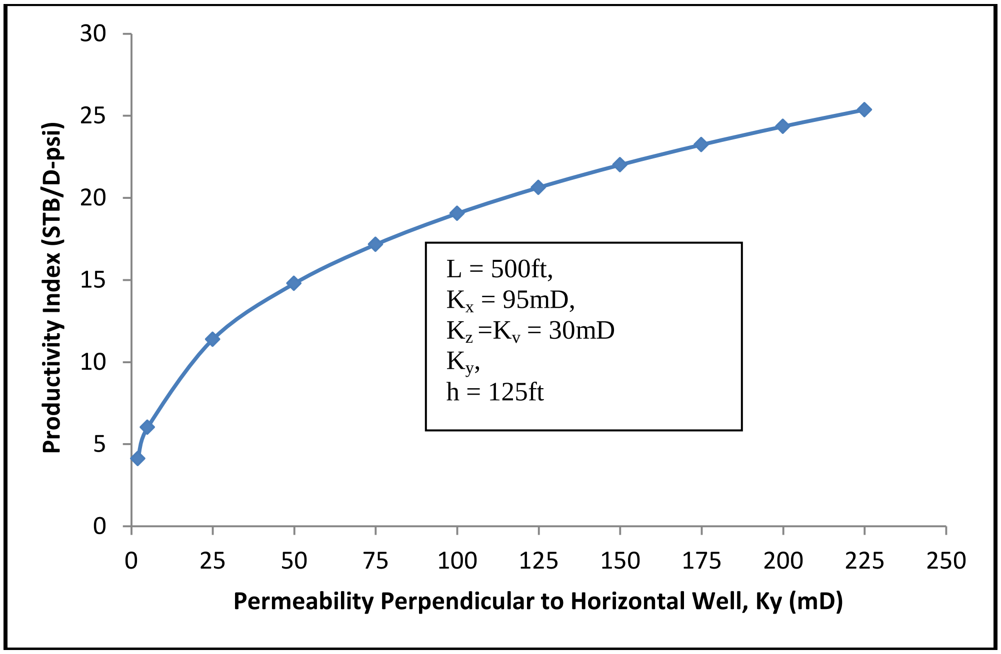

Figure 8 Effect of perpendicular permeability K_y on P.R.H.

3.7 Effect of parallel permeability to horizontal well on P.R.H.

Figure 9 presents the effect of permeability parallel to horizontal well on P.R.H. It is observed that P.R.H. is a weak function of parallel permeability to the horizontal well in that as Kx increases 55times even as β increases 2.2 times P.R.H. increases about 4.6times.

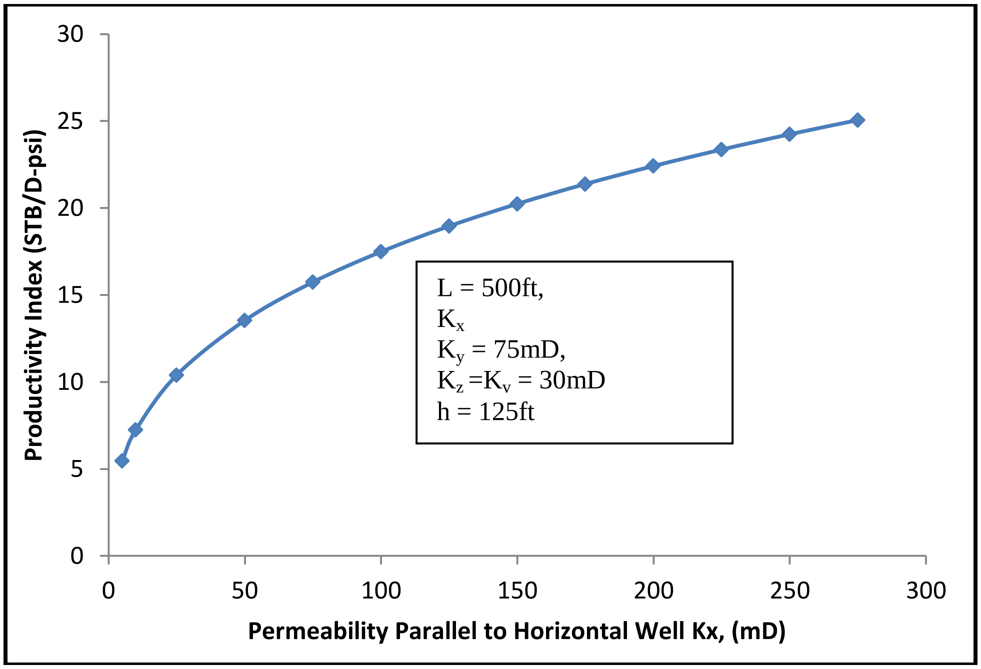

Figure 9 Effect of K_x on P.R.H.

3.8 Effect of reservoir drainage area on P.R.H.

Figure 10 presents the effect of reservoir drainage area on P.R.H. It is observed that P.R.H. is a weak function of reservoir drainage area of the horizontal well in that as the horizontal drainage radius increases 13times the P.R.H decreases by about 1.3times.

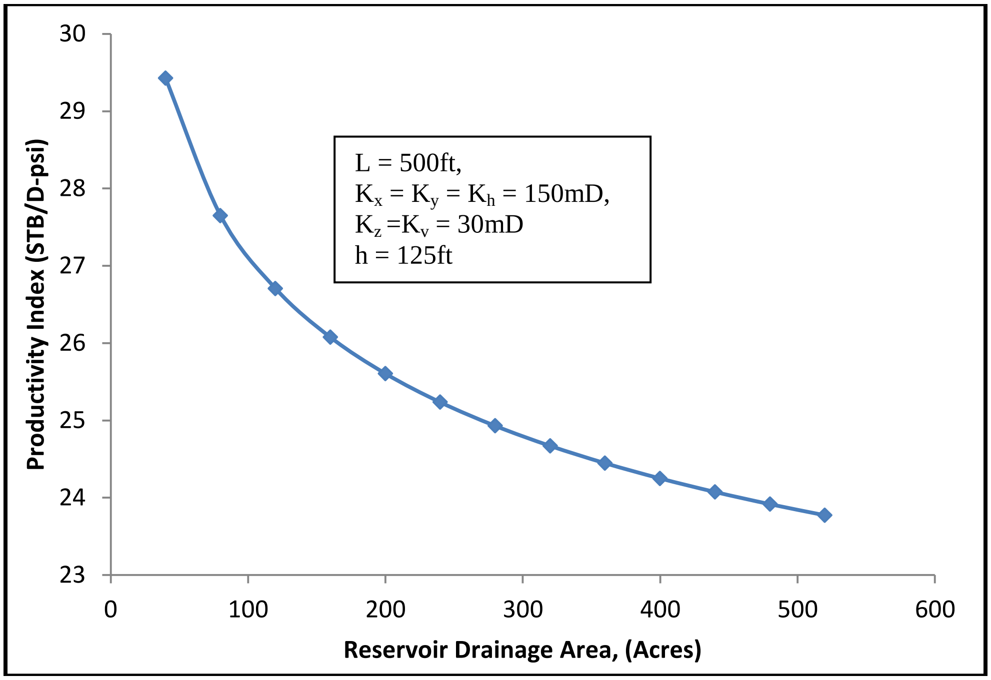

Figure 10 Effect of Reservoir Drainage Area on P.R.H.

4. Conclusion

Considering the investigation of the productivity performance ratio of horizontal and vertical wells, it is observed, that both productivity performance ratio of horizontal and vertical wells are affected by the formation damage. The formation damage influences horizontal well less than vertical well for the same drainage radius and for all values of skin factors. For reservoir with a given anisotropy, β, the effect of the reservoir anisotropy reduces with increasing horizontal well length. The effect of the well length on productivity graduates marginally at lower vertical permeability to significant values as the vertical permeability increases. A meaningful effect of the well length on productivity performance is found in the ratio of the productivity performance ratio of the horizontal well to the vertical well. The gain in growth in the performance of the horizontal well is limited to the length to thickness ratio as well as the decrease in reservoir vertical permeability. Increasing the well drainage radius decreases the performance of the productivity of the horizontal well.

The productivity performance ratio is a weak function of permeability parallel, vertical permeability, and reservoir drainage radius. The horizontal well productivity performance ratio is a strong function of permeability perpendicular to the well and horizontal permeability. For maximum productivity performance ratio, horizontal well should be located in thin reservoir.

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Nomenclature

P.R.H= productivity performance ratio of horizontal well
P.R.V= productivity performance ratio of vertical well
PI actual = actual productivity performance ratio with skin *s,* STB/(D-psi)
PI ideal = ideal productivity performance ratio with skin *s (s=O),* STB/(D-psi)
μ_o= fluid viscosity, cp
B_o= oil formation factor
r_e= drainage radius, ft
r_w= wellbore radius, ft
k_h= horizontal permeability, mD
S= skin factor
L= horizontal well length, ft
S_h= skin factor in horizontal well
S_v= skin factor in vertical well
$\alpha= r_{eH}/r_{ev}$
$\beta = \sqrt{k_h/k_v}$, permeability
$r'_w= [(1 + \beta)/ 2\beta]r$, ft
r_{eh}= drainage radius, ft
Δp= change in pressure, psia
q= flow rate, STB/D
$\emptyset$= porosity, %
c = Compressibility of the reservoir fluid
X = parameter depending on shape and dimensions of area drained by well
ke =permeability unaltered zone
ka = zone of altered permeability near the wellbore
ra= radius of altered zone
t = time
kx=permeability in the x-direction, mD
ky= permeability in the y-direction, mD
kz= permeability in the z-direction, mD

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