Transient Pressure Analysis and Productivity Index Estimation in Horizontal Wells

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ABSTRACT

The Analysis of pressure build-up tests in horizontal wells are known as complicated due to changing of flow regimes, formation thickness, well horizontal length….etc. The main objective of study is presents an interpretation method for horizontal well pressure transient testing that is applied to a buildup test from a horizontal well The use of transient well testing for determining reservoir parameters and productivity of horizontal wells has become common because of the upsurge in horizontal drilling. Initially, horizontal well tests were analyzed with the conventional techniques. During the last decade, analytic solutions have been presented for the pressure behavior of horizontal wells. New flow regimes have been identified, and simple equations and flow regime existence criteria have been presented for them [1]. The flow regimes are now used frequently to estimate horizontal and vertical permeability of the reservoir, wellbore skin, and reservoir pressure. Where result of The Giger-Reiss-Jourdan and Joshi was considered more representative result as compared with actual the productivity index and flow rate for isotropic and anisotropy reservoir. One objective of this work is to recall the proper way to use these formulae and to recall the assumptions made that may limit their use.

Keywords: Productivity, horizontal wells, Pressure, test, flow

1. Introduction

The technology of drilling and production of horizontal wells has been recognized as one of the most important technical achievements in the oil and gas industry in the last twenty five years. The industry demand of horizontal drilling technology has produced a variety of new applications and techniques.

During the period of 1980 to1984, only one or two horizontal wells were drilled worldwide. In 1988 that number of horizontal wells jumped to over 200 wells[1]. Since, a gradual increase in wells has been noticed, with 1570 wells drilled in 1994. Industry projections in the year 2000 over 5000 wells were drilled horizontally.

A typical horizontal well project is different from a vertical well project because productivity of a well depends upon the well length. Moreover, well length depends upon the drilling technique that is used to drill the well. Therefore, it is essential that reservoir and drilling engineers work together to choose the appropriate drilling technique, which will give the desired horizontal well length.

The other important consideration is the well completion scheme. One can either have an open hole, insert a slotted liner, insert a liner with external casing packers, or case the hole and perforate the casing, depending upon local completion needs and experience. The type of completion affects horizontal well performance and certain types of completions are possible with certain types of drilling techniques and in certain formations [2].

Well length, the well's physical location in the reservoir, the tolerance in drilling location, and the type of completion that can be achieved strongly affects well performance[3]. Therefore, it is very important for reservoir engineers to understand different drilling and completion techniques and their advantages and disadvantages.

Due to this fact, we present an overview of horizontal well technology. This includes the advantages and disadvantages of horizontal wells, the suitable environment to drill horizontal wells (applications of horizontal wells), and the drilling and completion techniques.

2. Materials and Methods

This Pressure Transient Analysis in Horizontal Wells

The dramatic increase in horizontal drilling activity has made the use of transient well testing common practice in determining the productivity of horizontal wells. In the past, horizontal wells were analyzed using the techniques which had been developed for vertical wells. Over the last years however, new solutions have been presented for horizontal wells.Transient pressure analysis of horizontal wells is considerably more complicated than it is for vertical wells, due to new flow regimes identified in horizontal wells. Identification of the flow regimes is necessary for proper estimation of horizontal and vertical permeabilities of the reservoir, and of wellbore skin.

Horizontal wells pose two special problems for the reservoir engineer. The most obvious is the large wellbore storage effect associated with horizontal sections which may be thousands of feet in length. Wellbore storage effects are pressure effects related to the volume of fluids in the wellbore before the test begins. This potential problem can be overcome by downhole shut-in and downhole flow measurements. The second problem is the more complex nature of the transient and the existence of overlapping flow regimes.

Before discussing the analysis procedure, it is appropriate to state the goals of the well test analysis. In general, a well test analysis of a horizontal well is conducted to achieve the following objectives:

1. To obtain reservoir permeabilities, (kx, ky, kz),
2. To determine whether all the drilled length of a horizontal well is also a producing length,

3. To estimate mechanical skin factor (Sm) or damage related to drilling and completion of the horizontal well. Based upon magnitude of the damage a decision regarding well stimulation can be made.
4. Horizontal well performance (Productivity index).

Because of the 3D nature of flow geometry geometry complications of horizontal wells many authors presented analytical solutions for the pressure response in horizontal well test.
These methods resulted from solving the three dimensional Diffusivity Equation by different assumption at the wellbore condition or at the boundary. The following section describes the suggested equations which considering the physical model shown in Figure (1).
Theory and Calculation
A Theory section should extend, not repeat, the background to the article already dealt with in the Introduction and lay the foundation for further work. In contrast, a Calculation section represents a practical development from a theoretical basis.

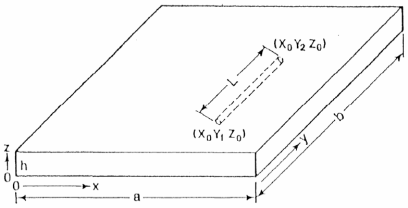


Figure 1: *Babu and Odeh physical model*

3. Theory and Calculation

Mathematical First Radial Flow Period:
Babu and Odeh(6) derived an equation Eq.(1) describes the flow behavior of a horizontal well producing at a constant rate during this period as the following:

$$P_i - P_{wf} = \left(\frac{162.6 q \mu B_o}{\sqrt{k_x k_z}\, L}\right)\left[\log\left(\frac{t\sqrt{k_x k_z}}{\phi \mu c_t r_w^2}\right) - 3.23 + 0.87 S_m\right] \qquad (1)$$

A plot of pwf vs. t for draw down test data and plot of pws vs. (tp+Δt)/ Δt for build up test data on semi-log paper gives a straight line with slope mr1, from this slope can be calculate the geometric average permeability $\sqrt{k_x k_z}$ and the mechanical skin Sm as the following:

$$\sqrt{k_x k_z} = \frac{162.6 q \mu B_o}{m_{1r} L} \qquad (2)$$

$$S_m = 1.151\left[\frac{\Delta P_{1hr}}{m_{1r}} - \log\left(\frac{\sqrt{k_x k_z}}{\phi \mu c_t r_w^2}\right) + 3.23\right] \qquad (3)$$

Where: Δp1hr = (pi - p1hr) for drawdown test, and Δp1hr = (pΔt=1 - pwfo) for buildup test.

First Linear Flow Period:

A requirement of L for this early linear flow period to occur is given by the following equation:

$$L > 3.33 D_z \sqrt{\frac{k_y}{k_z}} \text{; Where: } D_z = \max(z_o, h - z_o)$$

Babu and Odeh derived an equation Eq.(4) describes the flow behavior of a horizontal well producing at a constant rate during this period as the following:

$$P_i - P_{wf} = \left(\frac{8.13 q \mu B_o}{L h}\right)\left(\sqrt{\frac{t}{\phi \mu c_t k_x}} + \frac{17.37 h}{\sqrt{k_x k_v}}(S_z + S_m)\right) \tag{4}$$

A plot of pwf vs. t for drawdown test data and pws vs. $(\sqrt{t_p + \Delta t} - \sqrt{\Delta t})$ for buildup test data on linear paper should result in a straight line with a slope mL1, from this slope the horizontal permeability in x-direction kx can be calculated by using Eq.(5), and the mechanical skin from Eq.(6).

$$k_x = \left(\frac{8.13 q \mu B_o}{m_{1L} L h}\right)^2 \Big/ \phi \mu c_t \tag{5}$$

$$S_m = \left(\frac{L\sqrt{k_x k_z}}{141.2\, q \mu B_o}\right)\Delta P_{ohr} - S_z \tag{6}$$

Where: Δ_{p0hr} = (pi - p_{0hr}) for drawdown test, and Δp_{0hr} = ($p_{\Delta t=0}$ - p_{wfo}) for buildup test.

S_z is the pseudo skin may be visualized as the skin resulting from partial penetration in the vertical direction, given by:

$$S_z = \ln\left(\frac{h}{r_w}\right) + 0.25 \times \ln\left(\frac{k_x}{k_v}\right) - \ln\left(\text{Sin}\frac{180^\circ (d_z)}{h}\right) - 1.838 \tag{7}$$

Second Radial Flow Period:

For this period to occur, the penetration ratio should be L/b < 0.45. Babu and Odeh derived the following equation Eq.(8) to describe the flow in this period:

$$P_i - P_{wf} = \left(\frac{162.6 q \mu B_o}{h\sqrt{k_x k_y}}\right)\left[\log\left(\frac{k_y t}{\phi \mu c_t L^2}\right) - 1.76 + 0.87\sqrt{\frac{k_y}{k_v}}\frac{h}{L}(S_z + S_m)\right] \tag{8}$$

A plot of p_{wf} vs. t for the drawdown test data and p_{ws} vs. (tp+Δt)/ Δt for buildup test data on semi-log paper gives a straight line with slope mr2, from this slope can be calculate the geometric average permeability $\sqrt{k_x k_y}$ in horizontal plane and the mechanical skin Sm as the following:

$$\sqrt{k_x k_y} = \frac{162.6 q \mu B_o}{m_{2r} h} \tag{9}$$

$$S_m = \left(1.151\sqrt{\frac{k_z}{k_y}}\frac{L}{h}\right)\left[\frac{\Delta P_{1hr}}{m_{2r}} - \log\left(\frac{k_y}{\phi \mu c_t L^2}\right) + 1.76\right] - S_z \tag{10}$$

Where: Δp_{1hr} = (p_i - p_{1hr}) for drawdown test, and
Δp_{1hr} = ($p_{\Delta t=1}$ - p_{wfo}) for buildup test.

S_z as in Eq.(7).

Second Linear Flow Period:

Babu and Odeh derived the following equation Eq.(11) to describe the flow in this period:

$$P_i - P_{wf} = \left(\frac{8.13q\,\mu B_o}{b\,h}\right)\left(\sqrt{\frac{t}{\phi\,\mu\,c_t\,k_x}} + \frac{17.37\,h}{\sqrt{k_x k_z}}(S_z + S_t)\right) \tag{11}$$

A plot of pwf vs. t for drawdown test data and pws vs. ($\sqrt{t_p + \Delta t} - \sqrt{\Delta t}$) for buildup test data on linear paper should result in a straight line with a slope mL2, from which the horizontal permeability in x-direction kx can be calculated and also the total skin St as the following:

$$k_x = \left(\frac{8.13q\,\mu B_o}{m_{2L}\,b\,h}\right)^2 \Big/ \phi\,\mu\,c_t \tag{12}$$

$$S_t = \left(\frac{L\sqrt{k_x\,k_z}}{141.2\,q\,\mu\,B_o}\right)\Delta P_{ohr} - S_z \tag{13}$$

This is the only flow period that reflects the total skin, St Where:

$$S_t = S_m\left(\frac{b}{L}\right) + S_R \tag{14}$$

Where:

SR = Skin due to partial penetration in all directions.

Sz as in Eq.(9).

To calculate the Sm, we need calculate S_R as shown below, once S_R is calculated, then S_m = (L/b) (St – SR).

Calculation of S_R :

As known, $S_R = 0$ when L = b. If L < b, then the value of partial penetration skin factor S_R depends upon the following two conditions:

Case (a):

SR = PXYZ + P’XY (15)

The PXYZ Component is a result of the degree of penetration (L/b), and the P'XY component is a result of the location of the well in x-y plane. The skin component resulting from the z location is negligible.

$$P_{XYZ} = \left(\frac{b}{L} - 1\right)\left[\mathrm{Ln}\left(\frac{h}{r_w}\right) + 0.25\,\mathrm{Ln}\left(\frac{k_x}{k_z}\right) - \mathrm{Ln}\left(\sin\frac{180^\circ z_o}{h}\right) - 1.84\right] \tag{16}$$

$$P'_{XY} = \left(\frac{2b^2}{Lh}\sqrt{\frac{k_z}{k_y}}\right)\left[F\left(\frac{L}{2b}\right) + 0.5\left[F\left(\frac{4y_{mid} + L}{2b}\right) - F\left(\frac{4y_{mid} - L}{2b}\right)\right]\right] \tag{17}$$

Where pressure computations are made at ymid = (y1+y2)/2. (i.e. the midpoint along the well length).

$$F\left(\frac{L}{2b}\right)=-\left(\frac{L}{2b}\right)\left[0.145+\mathrm{Ln}\left(\frac{L}{2b}\right)-0.137\left(\frac{L}{2b}\right)^2\right] \tag{18}$$

The evaluation of F[(4y_{mid}+L)/2b] and F[(4y_{mid}–L)/2b] depends on their arguments; i.e. (4y_{mid}+L)/2b and (4y_{mid}–L)/2b. If the argument 1, Eq.(18) is used. In this case, (L/2b) is replaced by (4y_{mid}+L)/2b and/or (4y_{mid}–L)/2b. On the other hand, if the argument > 1, then the following equation is used:

$$F(x)=(2-x)\left[0.145+\mathrm{Ln}(2-x)-0.137\,(2-x)^2\right] \tag{19}$$

Where $F_{(x)}$ = Function used to describe effects of well location in horizontal plane, x = (4y_{mid}+L)/2b or (4y_{mid}–L)/2b, with x > 1.

Case (b):

$$SR = PXYZ + PY + PXY \tag{20}$$

The PXYZ Component is given by Eq.(16).

$$P_Y=\left(\frac{6.28b^2}{ah}\right)\left(\frac{\sqrt{k_x k_z}}{k_y}\right)\left[\left(\frac{1}{3}-\frac{y_{mid}}{b}+\frac{y_{mid}^2}{b^2}\right)+\frac{L}{24b}\left(\frac{L}{b}-3\right)\right] \tag{21}$$

$$P_{XY}=\left(\frac{b}{L}-1\right)\left(\frac{6.82a}{h}\sqrt{\frac{k_z}{k_x}}\right)\left(\frac{1}{3}-\frac{x_o}{a}+\frac{x_o^2}{a^2}\right) \tag{22}$$

3.1 Mathematical Expressions and Symbols

This section may each be divided by subheadings or may be combined. A combined Results Well x1 Test Analysis:

Pressure Build-up Test Analysis Calculations:

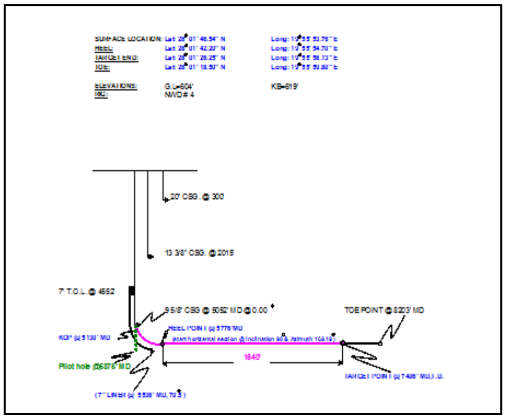


Figure 2: *A Schematic of a wellbore diagram for Well x1*

Step (1): General Data Required for the Test Analysis:

Table 1: *Well Information*

Well Orientation	Horizontal
Well Completion	Open Hole
Oil Production Rate, q	3792 STB/D
Producing Time, tP	24 hrs
Well Drilling Length, L	1640 ft
Well Radius, rw	0.250 ft
Vertical Well Location, zw	30 ft
Nearest Upper or Lower Boundary, dz	30 ft
Vertical Section Spacing, A	104 acres

Table 2: *Reservoir Rock and Fluid Data*:

Formation Thickness, h	60 ft
Formation Porosity, ф	26.9 %
Total Compressibility, ct	8.6×10-6 psi-1
Oil Formation Volume Factor, Bo	1.24 Bbl/STB
Oil Viscosity, μo	0.930 cp

Step (2): Calculate Pressure Drop and Pressure Derivative:

The pressure drop and derivative versus time data as shown in figure (3).

Step (3): Identification of Wellbore Storage Effect and Flow Periods:

1- Prepare a log-log plot of pressure drop [(P_{ws}-P_{wfo}) vs. Δt], as shown in figure (4)

2- From the log-log plot of [(P_{ws}-P_{wfo}) vs. Δt], unit slope line is not evident then there is no wellbore storage effect.

3- Prepare a pressure derivative [(d (P_{ws})/d (log Δt) vs. Δt] on a log-log graph. The plot is shown in figure (5).

4- From this plot, three flow periods can be clearly identified:

- The first radial flow appearing as horizontal line during the period (0.167 to 0.333) hours.
- The first linear flow period appearing as a ½ unit slope line approximately during the period (0.583 to 2.750) hours.

- The second radial flow appearing as horizontal line during the period (3.250 to 10) hours.

Step (4): Analysis of the First Radial Flow Period:

1) Plot pressure data versus Horner time function, [P_{ws} vs. (($t_{P+\Delta t}$)/ Δt))] on semi-log paper as shown in figure (6).
2) The semi-log plot of [Pws vs. (($t_{P\ +\Delta t}$)/ Δt))] and of its slope, shows clearly that the Horner time from (t_H= 145) to (t_H =73) can be fitted to a semi-log straight line as shown in figure (6). This could be interpreted as the effect of an early-time radial flow. (i.e., First radial flow period)
3) Read the slope directly from the plot, m_{1r} = 87.91 psi/cycle.

4) From this flow period the equivalent permeability in vertical plane (x-z directions), $\sqrt{k_x k_v}$, can be calculated:

$$\sqrt{k_x k_v} = 162.6\left(\frac{q\,\mu B_o}{m_{1r}\,L}\right) = 162.6\left(\frac{3792\times 0.930\times\ 1.24}{87.91\times 1640}\right) \qquad \sqrt{k_x k_v} = 4.93 \text{ md.}$$

Step (5): Analysis of the First Linear Flow Period:

1) Plot pressure data versus $(\sqrt{t_p+\Delta t}-\sqrt{\Delta t})$ on linear paper as shown in figure (7).

2) The linear plot of [Pws vs. $(\sqrt{t_p+\Delta t}-\sqrt{\Delta t})$], shows clearly that the square root time from [$(\sqrt{t_p+\Delta t}-\sqrt{\Delta t})$= 4.194] to [$(\sqrt{t_p+\Delta t}-\sqrt{\Delta t})$= 3.514] can be fitted to a linear straight line as shown in figure (7). This could be interpreted as the effect of an early-time linear flow. (i.e., First linear flow period)
3) Read the slope directly from the plot, mL1=141.67 psi/hr0.5.
4) From this flow period the horizontal permeability in x-directions (kx), can be calculated:

$$k_x = \left(\frac{8.13\,q\,\mu\,B_o}{m_{L1}\,L\,h}\right)^2\left(\frac{1}{\phi\,\mu\,c_t}\right) \quad k_x = \left(\frac{8.13\times 3792\times 0.930\times 1.24}{141.67\times 1640\times 60}\right)^2 \times\left(\frac{1}{0.269\times 0.930\times 8.6\times 10^{-6}}\right) = 3.02 \text{ md.}$$

5) Combining results of the analysis of the early-time radial flow and early-time linear flow,

k_x =3.02 md, and $\sqrt{k_x k_v}$ = 4.93 md. $\therefore$ k_v= 8.05 md
Step (6): Analysis of the Second Radial Flow Period:

1) The semi-log plot of (Pws vs. Horner time function) and its slope as shown in figure (6), shows clearly that the Horner time from (t_H= 8.385) to (t_H =3.400) can be fitted to a semi-log straight line. This could be interpreted as the effect of the late-time pseudo-radial flow. (i.e., Second radial flow period)
2) Read the slope directly from the plot, m2r = 273.30 psi/cycle.

3) From this flow period the average horizontal permeability in x, y directions $\sqrt{k_x k_y}$, can be calculated:

$$\sqrt{k_x k_y} = 162.6\left(\frac{q\,\mu B_o}{m_{2r} h}\right) \quad \sqrt{k_x k_y} = 43.36 \text{ md.}$$

4) Combining this result with the calculated value of k_x = 3.02 md (in step 4) we calculate the value of k_y =622.0 md.

The following table summarized the permeability estimation from each flow period.

Table 3: *summarized the permeability estimation from each flow period*

Flow Period	Permeability Estimation	Result	Unit
First Radial Flow	$\sqrt{k_x k_v}$	4.93	md
First Linear Flow	kx	3.02	md
	kv	8.05	md
Late-time Pseudo-Radial Flow	$\sqrt{k_x k_y}$	43.36	md
	ky	622.00	md

Step (7): Skin Factor Calculations:

1) Calculate the pseudo-skin caused by partial penetration in the vertical direction.

$$S_z = \ln\left(\frac{h}{r_w}\right) + 0.25 \times \ln\left(\frac{k_x}{k_v}\right) - \ln\left(\operatorname{Sin}\frac{180^\circ (d_z)}{h}\right) - 1.838 \qquad Sz = 3.51$$

2) Evaluate the mechanical skin using the early-time radial results:

$$S_m = 1.151\left[\frac{\Delta P_{1hr}}{m_{r1}} - \log\left(\frac{\sqrt{k_x k_v}}{\phi\,\mu\,c_t r_w^2}\right) + 3.23\right] \qquad Sm = -3.14$$

3) Evaluate the mechanical skin using the early-time linear results:

Extrapolate the straight line on figure (6) to $\sqrt{\Delta t}$ =0, (i.e., to $(\sqrt{tp+\Delta t} - \sqrt{\Delta t})$ =4.90) read Pws(Δt=0) , and read Pwfo from actual measured test values, and then calculate ΔPo.

$$S_m = \left(\frac{L\sqrt{k_x\,k_v}}{141.2\,q\,\mu\,B_o}\right) \times (P_{ws(\Delta t=0)} - P_{wfo}) - S_z \qquad Sm = -3.19$$

4) Evaluate the mechanical skin using the second radial flow results:

Extrapolate the straight line in figure (5) to Δt=1 hour, (i.e., ((tP+Δt)/Δt) =25), and read, Pws(1hr) , and then calculate ΔP1hr : Pws(1hr) =1623 psi, and Pwfo = 1519 psi ΔP1hr = Pws(1hr) - Pwfo = 1623 - 1519 = 104 psi

$$S_m = 1.151\frac{L}{h}\sqrt{\frac{k_v}{k_y}}\left[\frac{\Delta P_{1hr}}{m_{r2}} - \log\left(\frac{k_y}{\phi\,\mu\,c_t L^2}\right) + 1.76\right] - S_z \qquad Sm = -3.12$$

The following table summarizes the skin estimation from each flow period.

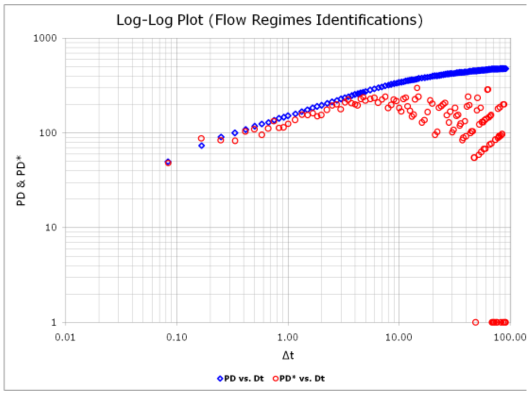
Table 4: *summarized the skin estimation from each flow period*

Flow Period	Reservoir Parameter	Value

First Radial Flow	Sm	-3.14
First Linear Flow	Sz	3.51
	Sm	-3.19
Second Radial Flow	Sm	-3.12

We note the high consistency in the evaluation of Sm from the three periods, the average Sm being (-3.15)

2- Productivity Index in Horizontal Well (x1) Calculations:



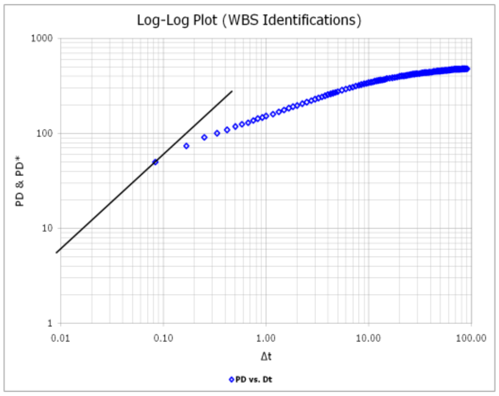


Figure 3: *Log-log plot, flow regimes identification*

Figure 4: *Log-log plot, wellbore storage effect identification*

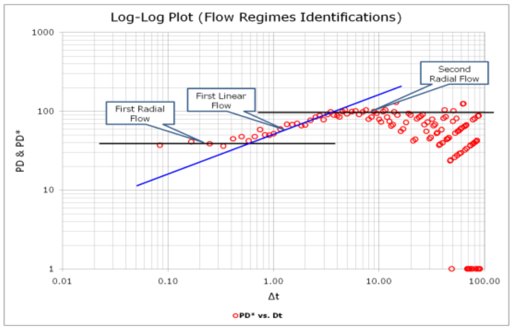


Figure 5: *Log-log plot of pressure derivative, flow regimes identification*

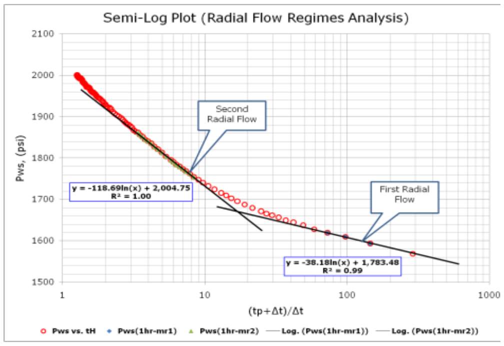


Figure 6: *Semi-log plot, radial flow analysis*

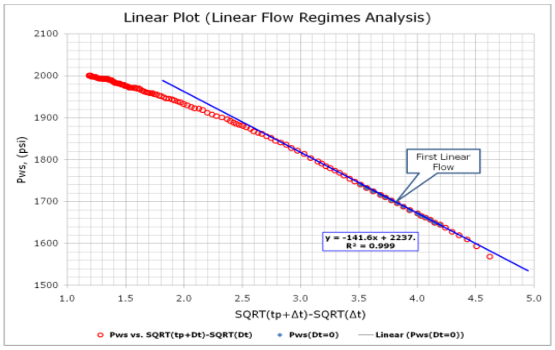


Figure 7: *Linear-log plot, linear flow analysis*

Calculation of drainage radius of the vertical well (rev) or (b):

$$r_{ev} = b = \sqrt{\frac{43560\,A}{\pi}} = \sqrt{\frac{43560 \times 104}{\pi}} = 1201\text{ft}$$

Calculation of the drainage area of the horizontal well (reh):

Method (1): $A_1 = \frac{L(2b) + \pi\, b^2}{43560} = 194\, acre$

Method (2): $A_2 = \frac{\pi\, a\, b}{43560} = 175$ acres

Drainage radius of the horizontal well (reh): $r_{eh} = \sqrt{\frac{43560\, A_{avg}}{\pi}} = 1600$ ft.

Productivity Index Calculation under Steady-State Condition:

The following table summarizes the productivity index and flow rate estimation for isotropic and anisotropy reservoir under steady state condition.

Table 5: *summarized the productivity index and flow rate estimation for isotropic and anisotropy reservoir under steady state condition*

Method	Steady State Condition			
	Isotropic reservoir		Anisotropic reservoir	
	Jh STB/day/Psi	qoh STB/day	Jh STB/day/Psi	qoh STB/day
Actual	7.88	3792	7.88	3792
Borisov	10.68	5137	#	#
The Giger-Reiss-Jourdan[4]	10.00	4810	6.75	3247
Joshi[8]	10.37	4988	6.92	3328
The Renard-Dupuy[5]	10.67	5132	9.39	4517
---	Pseudo Steady State Condition			
Mutalik et al.[7]	#	#	25.53	12280
Babu and Odeh[9]	#	#	1.56	750
Kuchuk et al.[10]	#	#	6.72	3232

4. Conclusions

Transient pressure analysis of horizontal wells is considerably more complicated than it is for vertical wells because of The existence of three and more flow regimes, in contrast to just one radial flow regime in normal vertical wells and The presence of at least three different types of skins and the non-uniformity of the mechanical skin, the skin value in a homogeneous formation would be minimum at the farthest end of the horizontal section and increasing as we approach the slanted and vertical section. The pressure test provides only an average value of the mechanical skin along the horizontal section. To obtain a clear semi-log straight line of the late-time radial flow, there should be enough time kept for the production before shutting-in the well for build-up test. It is better and preferable to use Horner time function instead of using shut-in time for calculating the pressure derivative, especially in case of a long time test. In the fortunate case where most of the flow regimes are evident, it would be possible to calculate more than one value for the permeability perpendicular to the horizontal section (kx) and for the mechanical skin (Sm), and checked against each other. This advantage is not available in case of vertical wells. The Giger-Reiss-Jourdan and Joshi was considered more representative result as compared with actual the productivity index and flow rate for isotropic and anisotropy reservoir In horizontal wells the vertical permeability plays an important role, since it is a main factor in the duration of early radial flow period. The flow rate value obtained by using anisotropy Renard-Dupuy method was confirmed by the actual flow rate that means the reservoir is anisotropic reservoir under steady-state condition

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