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A Review of Drainage Area Effect on Horizontal Well Productivity Models

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Abstract:- World energy demand is so increasing and driving the oil and gas industry to produce more efficiently. Horizontal wells are expected to fulfill the energy needs through its advantages over conventional vertical wells. In this paper Joshi model and Furui et al. model for horizontal well productivity are analyzed by calculating with variables such as horizontal drainage area and vertical permeability. Vertical to horizontal permeability anisotropy is the primary important factor for the productivity of a horizontal well to reveal interesting results. Hence, the effect of changing vertical permeability and drainage area on inflow performance is primarily take into account in this paper.

Keywords:- *Horizontal Drainage Area, Vertical Permeability.*

I. INTRODUCTION

Drilling horizontal wells is growing and acquiring the most proportion of hydrocarbon production. Many advantages of horizontal wells over conventional vertical wells are (1) reducing water/gas coning, (2) changing radial flow pattern to combination flow pattern, and (3) more exposure to reservoir pay section. The horizontal well productivity estimations were initiated by comparing with vertical well productivity calculation, by converting equivalent form of vertical well and/or by assuming to be approximately equal to the fracture conductivity in the foregoing investigation of horizontal well performance. These theories did not give enough consideration to the influence of fluid flowing characteristics, reservoir heterogeneity and pressure drop caused by horizontal wellbore flow on productivity. The effect of formation fluid characteristics, reservoir heterogeneity, and production associated wellbore pressure drop should be reflected in more detail to be an accurate horizontal well productivity model.

II. LITERATURE REVIEW

➢ *The Joshi Model*

One of the early horizontal well inflow model was developed by Joshi in 1988 for steady-state flow. An equation to predict the flow rate to a horizontal well having length of L was developed by considering a solution for the flow resistance in both horizontal and vertical plane and also permeability anisotropy.

The horizontal well inflow was assumed as a combination of the flow in the *x-y* plane and the flow in the *y-z* plane for a horizontal well protruding in a reservoir having thickness h as depicted in Figure 1.

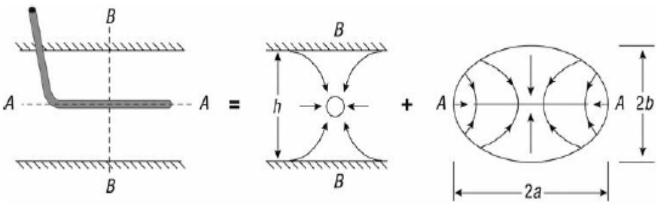

Fig 1:- A schematic of the Joshi Horizontal Well Productivity Model.

In the *x-y* horizontal, two-dimensional flow to an embedment of length L will have elliptical isobars at steady state (the right-hand picture in Figure 1), so viewing as a drainage ellipse having a major axis length of $2a$ and a constant pressure at the drainage boundary provides the following equation

$$q = \frac{2\pi k \Delta p}{\mu B_0 \left(ln \left(\frac{a + \sqrt{a^2 - (L/2)^2}}{L/2} \right) \right)} \quad (1)$$

To estimate the production from a two-dimensional plane of embedment, the preceding equation was multiplied by reservoir thickness. Reservoir fluid flow in the perpendicular plane, *y-z* plane (the center picture in Figure 1) was estimated to be radial flow from the vertical boundary found at a distance $h/2$ from the well trajectory, and the pressure was assumed to be the same as at the elliptical horizontal boundary in this approximation.

The recently aforementioned statement gives

$$q_v = \frac{2\pi k \Delta p}{\mu B_o \ln\left(\frac{h}{2r_w}\right)} \quad (2)$$

Equation (2) was multiplied by the total well length, L, to quantity the *y-z* flow contributions of the entire well. Then, the flow resistances$\Delta p/q$ for the *x-y* and *y-z* surfaces were sum up and correlated to $\Delta p/q$ for the well to calculate the inflow for an isotropic formation as:

$$q = \frac{2\pi k_H h \Delta p}{\mu B_o \left(\ln\left(\frac{a + \sqrt{a^2 - (L/2)^2}}{L/2} \right) + \frac{h}{L} \ln\left(\frac{h}{2r_w} \right) \right)} \quad (3)$$

For an anisotropic reservoir, Equation (2) becomes (Economides, Deimbacher, Brand, and Heinemann, 1991):

$$q = \frac{k_H h\, (p_e - p_{wf})}{141.2 \mu B_0 \left(ln\left(\frac{a + \sqrt{a^2 - (L/2)^2}}{L/2} \right) + \frac{I_{ani}\, h}{L}\, ln\left(\frac{I_{ani}\, h}{r_w (I_{ani} + 1)} \right) \right)} \quad (4)$$

Where the anisotropy ratio, *Iani*, is defined as

$$I_{ani} = \sqrt{\frac{k_H}{k_V}} \quad (5)$$

With k_H as horizontal permeability and k_V as vertical permeability. Equation (3) is stated in oilfield units of STB/d for oil rate, permeability is in md, thickness in ft, pressure in psi, and viscosity in cp. In Equation (3), the half length of the drainage ellipse in the horizontal plane, *a*, is the vital reservoir dimension. In Figure 1(b), the minor axis of the ellipse is limited by the description of well length and the major axis length, *2a*, because the terminations of the well are the foci of the ellipse. The dimension *a* was correlated to an equivalent cylindrical drainage radius by equating the areas of the ellipse to areas of a cylinder having radius r_e, giving

$$a = \frac{L}{2} \left\{ 0.5 + \left[0.25 + \left(\frac{r_{eH}}{L/2} \right)^4 \right]^{0.5} \right\}^{0.5} \quad (6)$$

For a well situating at the center of the drainage volume with respect to both x-y and y-z planes, Equation (4) was developed. Choosing the suitable value of the parameter, *a*, is an imperative portion in using this equation. It should be designated in accordance with the finest data accessible concerning with the drainage area extent either in the direction of the well (*x*-direction) or in the horizontal direction normal to the well (*y*-direction).

➢ *The Furui Model*

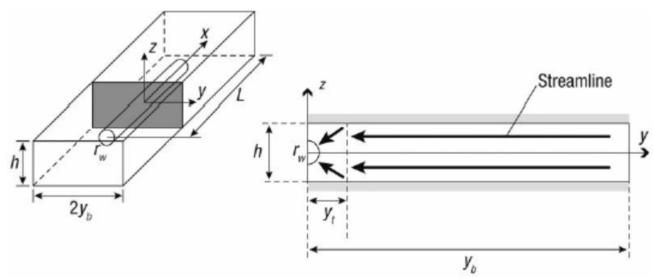

Fig 2:- A schematic of Furui et al. Horizontal Well Productivity Model (2003).

An equation for the fluid flow in the cross-sectional area normal to the horizontal wellbore was derived by Furui et al. (2003) revealing by a schematic of Figure 2. The assumption for this model are (1) the flow near the well is radial and (2) the flow becomes linear farther from the well. Hence, by adding the overall pressure drop, it becomes:

$$\Delta p = \Delta p_r + \Delta p_l \quad (7)$$

Where *Δpr* and *Δpl* are the pressure drops for the corresponding radial and linear flow areas. By Darcy's law in radial coordinates, the pressure drop is given by the following equation,

$$\Delta p_r = \frac{q\mu}{2\pi k L} \ln\left(\frac{r_t}{r_w} \frac{2I_{ani}}{(I_{ani} + 1)} \right) \quad (8)$$

Where r_t is the outer extent of the radial flow area or the location of the transition to linear flow, and k is the geometric mean permeability,

$$k = \sqrt{k_H k_V} \quad (9)$$

And the ratio $2I_{ani}/(I_{ani} + 1)$ represents the Peaceman transform for radial flow in an anisotropic medium. In the same way, the pressure drop across the linear flow area is

$$\Delta p_l = \frac{(q/2)\mu(y_b - y_t)}{k I_{ani} h L} \quad (10)$$

Where y_t is the location of the start of the linear flow area and y_b is the distance to the drainage boundary in the *y*-axis. Substitution of k_H with kI_{ani} for the anisotropic case in Equation (10) should be recognized. An appropriate empirical geometric relationship for r_t and y_t is taken from finite element modelling as follow

$$r_t = y_t \sqrt{2} = \frac{\sqrt{2} I_{ani}}{2} h. \quad (11)$$

Substituting the above equations into Equations (8) and (10) yields

$$\Delta p_r = \frac{q\mu}{2\pi k L} \ln\left(\frac{\sqrt{2}h}{r_w} \frac{I_{ani}}{(I_{ani} + 1)} \right) \quad (12)$$

And

$$\Delta p_l = \frac{q\mu(y_b/h - I_{ani}/2)}{2k I_{ani} L} \quad (13)$$

Thus, the total pressure drop for the *y-z* dimensional flow to the wellbore is the summation of Equations (12) and (13)

$$\Delta p = \frac{q\mu}{2\pi kL}\left[\ln\left(\frac{\sqrt{2}hI_{ani}}{r_w(I_{ani}+1)}\right) + \frac{\pi}{I_{ani}}(y_b/h - I_{ani}/2)\right]. \quad (14)$$

Recalling the customary skin factor in the radial flow area as

$$\Delta p_{skin} = \frac{q\mu}{2\pi kL}s, \quad (15)$$

The total pressure drop can be described by

$$\Delta p = \frac{q\mu}{2\pi kL}\left[\ln\left(\frac{\sqrt{2}hI_{ani}}{r_w(I_{ani}+1)}\right) + \frac{\pi}{I_{ani}}(y_b/h - I_{ani}/2) + s\right] \quad (16)$$

Solving for *q*, and combining the conversions for oilfield units, the equation will be

$$q = \frac{kL(p_e - p_{wf})}{141.2\,\mu B_o\left(\ln\left[\frac{hI_{ani}}{r_w(I_{ani}+1)}\right] + \frac{\pi y_L}{hI_{ani}} - 1.224 + s\right)} \quad (17)$$

The constant 1.224 in the above equation is from $\ln(2^{0.5}) - \pi/2$. For explanation of the drainage area beyond the horizontal well length, a partial penetration skin, s_R should be accounted for a non-fully penetrating wellbore. For a partially-penetrating well, Equation (17) becomes

$$q = \frac{kb(p_e - p_{wf})}{141.2\,\mu B_o\left(\ln\left[\frac{hI_{ani}}{r_w(I_{ani}+1)}\right] + \frac{\pi y_b}{hI_{ani}} - 1.224 + s + s_R\right)} \quad (18)$$

Where *k* is the geometry mean permeability.

III. METHODOLOGY

In this paper, simple method to analyse the effect of drainage area and vertical permeability upon productivity is used through Microsoft Excel spreadsheet. In calculating by Furui equation, skin factor is assumed to be zero in order to identify the clear effect of two varying factors.

- **Step 1**: Some reservoir rock and fluid data are chosen for calculation.
- **Step 2**: Horizontal drainage area is assumed to be 1000 ft long, and calculate the production rate with varying horizontal permeability order of 10 through decreasing bottom hole flowing pressure.
- **Step 3**: Again horizontal area is assumed to be 4000 ft long, and calculate as the proceeding step.
- **Step 4**: Compare the resulted IPR for two drainage areas with Furui and Joshi models.

IV. PVT PROPERTIES OF THE RESERVOIR FLUIDS

A summary of the reservoir and well properties is shown in Table 1:

No.	Parameters	Value
1.	Horizontal lateral	4000 - 1000 ft
2.	Reservoir thickness	100 ft
3.	Lateral diameter	6 in.
4.	Oil viscosity	5 cp
5.	Reservoir thickness	100 ft
6.	Formation volume factor	1.1
7.	Actual reservoir area	200 acres
8.	Initial oil saturation	0.8
9.	Initial water saturation	0.2
10.	Well depth	10, 000 ft
11.	Initial reservoir pressure	4000 psi
12.	Avg. reservoir temperature	284° F
13.	Production skin	0
14.	Partial penetration skin	14

Table 1:- Input Data Sheet

V. RESULT AND DISCUSSION

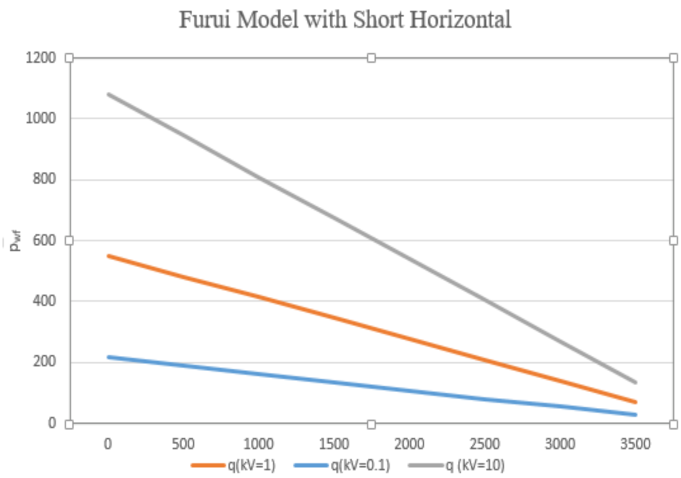

Fig 3:- Inflow Performance of a Horizontal Well by Furui's Equation (Short Horizontal Drainage Area).

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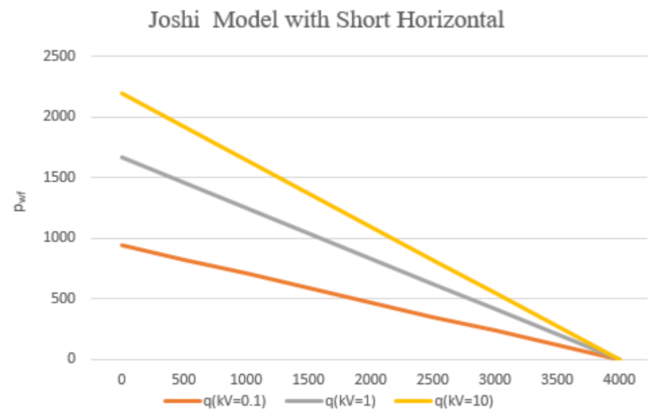

Fig 4:- Inflow Performance of a Horizontal Well by Joshi's Equation (Short Horizontal Drainage Area).

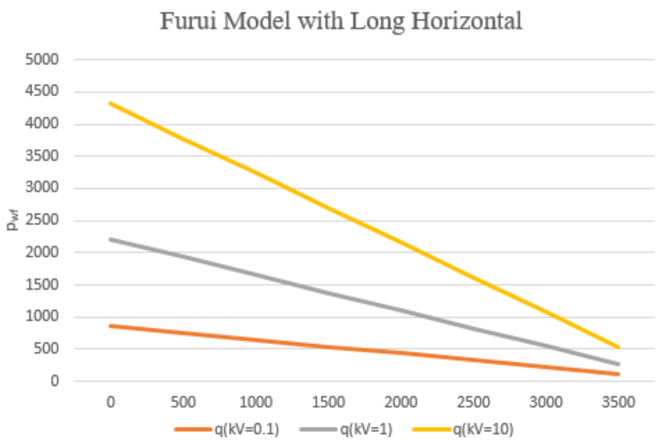

Fig 5:- Inflow Performance of a Horizontal Well by Furui's Equation (Long Horizontal Drainage Area).

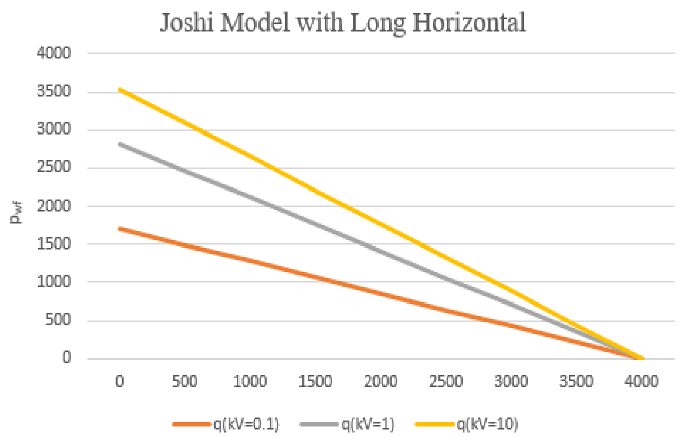

Fig 6:- Inflow Performance of a Horizontal Well by Joshi's Equation (Long Horizontal Drainage Area).

As a recommendation for future work, the most governing factor for a horizontal well's productivity should be determined systematically considering reservoir rock and fluid data, gravity drainage, and the distance to flow boundary variation in order to accurately estimate the horizontal wells' performance.

VI. CONCLUSION

As the above figures showed, production rate from a horizontal well presuming short horizontal drainage area by Furui's equation is relatively lower than the ones obtained by Joshi's equation. Influence of vertical permeability is more pronounced in higher rates with Furui's equation in both calculation of areas with long and short horizontal length. Another character it could be noticed is in lower production rates, effect of vertical permeability is almost diminished in calculating by Joshi' equation. In Furui' model, the primary governing factor would be the distance to boundary in y- direction and in Joshi's one, the half of the drainage ellipse in the horizontal plane as mentioned above.

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