改进的斜井和水平井 IPR 方程

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前　　言

油井的流入动态(IPR)曲线是描述油井产量和井底流压关系的曲线,它是预测油井产能的基础,亦是举升工艺设计的基础。Vogel[1]提出的垂直井 IPR 方程已得到广泛的应用,Wiggins[2]等在为 Vogel 提出的 IPR 方程的形式进行理论证明的同时,提出了两相流和三相流统计意义下的 IPR 方程。有些学者提出了斜井和水平井的 IPR 方程,例如,Cheng[3]在油藏模拟的基础上提出了不同井斜角下的一系列 IPR 方程,Bendaklia[4]提出了水平井的 IPR 方程。本文针对 Cheng 型斜井和水平井的 IPR 方程存在的问题,提出了改进的斜井和水平井 IPR 方程。

Cheng 型 IPR 方程存在问题

Cheng 型 IPR 曲线见图 1,其方程形式为:

$$q_D = a + bp_D + cp_D^2 \tag{1}$$

其中 $q_D = \dfrac{q_o}{q_{omax}}$　　$p_D = \dfrac{p_{wf}}{\bar{p}_r}$

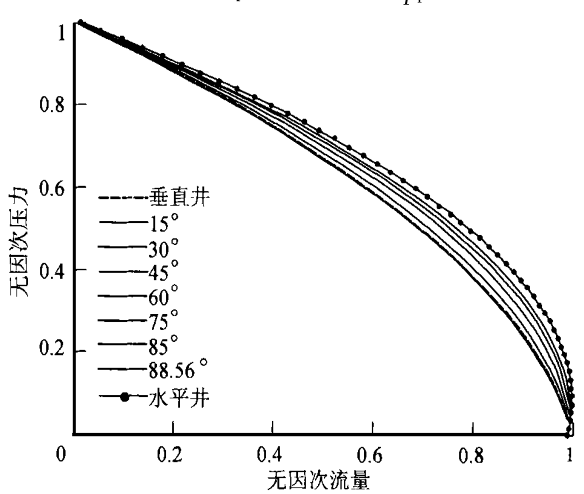

图 1　Cheng 型 IPR 曲线

由(1)式看出,当 $p_{wf}=0$ 时,$q_o \neq q_{omax}$。这是不合理的。主要原因是只有在水平井条件下,Cheng 型 IPR 方程中第一项系数系数 a 才为 1,其余情况下 a 值不为 1(见表 1)。

表 1　Cheng 型 IPR 方程系数表

井斜角(°)	a	b	c
0(垂直井)	0.9998	-0.2000	-0.8
15	0.9969	-0.2210	-0.7783
30	0.9946	-0.1254	-0.8682
45	0.9926	-0.0221	-0.9663
60	0.9915	0.0549	-1.0359
75	0.9915	0.1002	-1.0829
85	0.9914	0.1120	-1.0942
88.56	0.9885	0.1141	-1.0964
90(水平井)	1	0.2055	-1.1818

将(1)式两边对 p_{wf} 求导,可得到采油指数:

$$J = -\frac{\mathrm{d}q_o}{\mathrm{d}p_{wf}} = -q_{omax}\left(\frac{b}{\bar{p}_r} + \frac{2cp_{wf}}{\bar{p}_r^2}\right) \tag{2}$$

当井底压差为零($p_{wf}=\bar{p}_r$)时,J 应为零。但是从(2)式看出,此时,

$$J\Big|_{p_{wr}=\bar{p}_r} = -q_{omax}\left(\frac{b}{\bar{p}_r} + \frac{2c}{\bar{p}_r}\right) \neq 0$$

因此,Cheng 型 IPR 方程在 IPR 曲线的两端点处不合理,与油井的实际情况不符。

改进的斜井和水平井 IPR 方程

Fetkovich 型[5] IPR 方程的形式如下:

$$q_D = \left(1 - p_D^2\right)^n \tag{3}$$

其中的 n 为回归指数,主要与油藏流体、岩石性质及采出程度等有关。

图 2 为 Fetkovich 型斜井和水平井的 IPR 曲线。将 Cheng 型 IPR 曲线重新按 Fetkovich 型 IPR 方程

进行回归,可得到不同井斜角下的 n 值(见表 2),对于斜井和水平井来讲,n 值还包含了井斜角的影响(见图 3)。

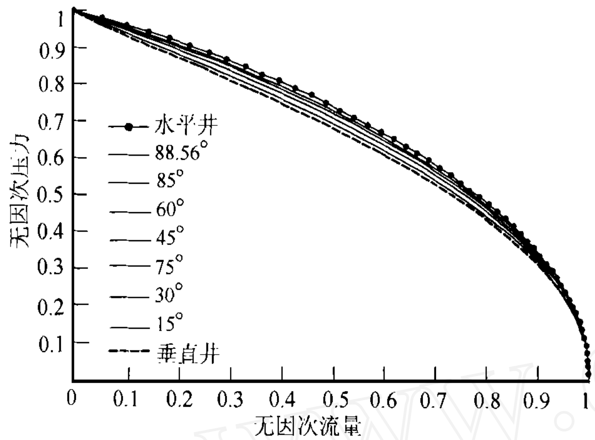

图 2　Fetkovich 型斜井和水平井的 IPR 曲线

表 2　不同井斜角下的 n 值

井斜角(°)	n	井斜角(°)	n
0 (垂直井)	1.132 75	75	0.937 74
15	1.147 11	85	0.936 48
30	1.080 55	88.56	0.936 07
45	1.011 78	90 (水平井)	0.892 42
60	0.964 42		

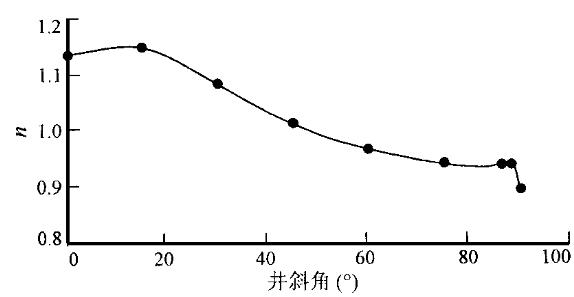

图 3　井斜角与 n 值的关系曲线

考察 Fetkovich 型 IPR 方程两端点处的情况。由(3)式看出,当 $p_{wf}=0$ 时,即

$$p_D = \frac{p_{wf}}{p_r} = 0$$

有

$$q_D = \frac{q_o}{q_{omax}} = 1$$

得到

$$q_o = q_{omax}$$

采油指数为:

$$J = -\frac{\mathrm{d}q_o}{\mathrm{d}p_{wf}} = -q_{omax}\,n\left[1-\left(\frac{p_{wf}}{p_r}\right)^2\right]^{n-1}\frac{2p_{wf}}{p_r} \qquad (4)$$

显然,当井底压差为零($p_{wf}=\bar{p}_r$)时,

$$J\Big|_{p_{wf}=\bar{p}_r} = 0$$

因此,Fetkovich 型 IPR 方程在两端点处符合油井的实际情况,能够弥补 Cheng 型 IPR 方程(或 Vogel 提出的 IPR 方程)的缺陷。

结　　论

针对 Cheng 提出的斜井和水平井 IPR 方程存在的问题,提出了 Fetkovich 型斜井和水平井 IPR 方程。改进后的斜井和水平井 IPR 方程在两端点处更合理,应用更可靠。

符 号 注 释

q_D ——无因次流量;p_D ——无因次压力;p_{wf} ——井底流压,MPa;q_o ——对应于井底压力 p_{wf} 的油井产量,m^3/d;q_{omax} ——油井最大产量,m^3/d;$\bar{p}_r$ ——油藏平均地层压力,MPa。

参 考 文 献

1　Vogel J V. Inflow performance relationships for solution-gas drive wells. JPT, Jan. 1986. 83～92.

2　Wiggins M L, Russell J E and Jennings J W. Analytical development of Vogel-type inflow performance relationships. In: Paper SPE 23580 Presented at the 1992 SPE Permion Basin Oil and Gas Recovery Conference, Midland TX, March 18-20, 1992.

3　Cheng A M. Inflow performance relationships for solution-gas drive slant/horizontal wells. In: Paper SPE 20720 Prensented at the 65th Annual Technical Conformance and Exhibition of the Society of Petroleum Engineers, New Orleans, LA, Sept. 23-26, 1990.

4　Bendakhlia H and Aziz K. Inflow performance relationships for solution-gas drive horizontal wells. In: Paper SPE 19823 Presented at the 1989 SPE Annual Technical Conference and Exhibition, San Antonio, TX, Oct. 8-11.

5　Fetkovich M J. The isochronal testing of oil wells. In: Paper SPE 4529, Presented at the 48th Annual Fall Meeting, Lasvegas, Nevada, Sept. 30-Oct. 3, 1973.

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Calculation , Method

The fractal characteristic of the permeability distribution in channel sandbodies and its application to predicting the heterogeneity of the permeability distribution. Huang , Shiyan ; et al. (Petroleum Exploration and Development Administration Department , SINOPEC , Beijing 100029 , P. R. China) . *Shiyou Kantan Yu Kaifa* 1999 , 26(4) , 60-63. The spatial change of the permeability in the channel sandbodies is strongly heterogeneous. In this paper , the permeability cross section prototype models of two types of channel sandbody are built through detailed study for the dense well spacing blocks and the fractal characteristics of the permeability distribution has been revealed by statistics analysis. Then the fractal parameters are calculated from the permeability prototype models through varigram analysis. Through taking some wells away from the prototype model to course it similar to the wide well spacing case , a series of equal-probable fractal stochastic realizations and a Kriging field are thus generated. After comparing the statistics indexes of these realizations with that of the prototype model and the Kriging field , it indicates that the Kriging field reduces the heterogeneity of the permeability distribution , whereas the fractal method can be used to predict the heterogeneous permeability distribution of the channel sandbodies in the wide well spacing cases when the depositional environments and the scale are same as the dense well spacing block. We can conclude that the fractal method can be used to characterize the heterogeneous permeability of the channel sandbodies under the control of some geological conditions. **Subject heading :** Channel sandbody , Reservoir , Heterogeneity , Fractal , Permeability , Distribution , Model

A simplified model of flow in horizontal wellbore. Wu , Shuhong ; et al. (Research Institute of Petroleum Exploration and Development , CNPC , Beijing 100083 , P. R. China) . *Shiyou Kantan Yu Kaifa* 1999 , 26(4) , 64-65 ,106. A "theory of micro-element "and equivalent seepage flow was raised to solve the various mass flow of single phase in the horizontal wellbore. Equivalent permeability of laminar flow , turbulent flow and transitional state was derived based on the theory of flow mechanics and seepage flow mechanics. For laminar flow pattern the equivalent permeability is the function of the wellbore radius , whereas for turbulent flow pattern it is related not only to the radius but also to the fluid property and wellbore pressure differential. A case study was make and it tested that the model can derive the continuous equivalent permeability in transitional state without any numerical mutation. In addition , the form of equivalent seepage flow equation derived is similar to that of Darcy flow equation , so the efficient techniques that have been developed for reservoir simulation can readily be used. As a result , the model can be easily applied in the coupling of wellbore flow and reservoir flow without using any complex fluid mechanics formula , which simplifies the solution of the coupling. **Subject heading :** Reservoir numerical simulation , Horizontal well , Well bore , Pipeline flow , Percolation , Coupling

Modified IPR equation for vertical and inclined wells. Yao , Jun ;et al. (University of Petroleum , Shandong 257062 , P. R. China) . *Shiyou Kantan Yu Kaifa* 1999 , 26(4) , 66-67. An IPR equation of a production well describes the relationship between production rate and the bottom hole pressure. Most popularly used inflow IPR equation for an inclined or a horizontal well is that one based on a numerical simulation and regressed from the form of Vogel IPR equation by Mr. Cheng. However in Cheng type equation the first item " *a* "is 1. 0 only when the well is a vertical one , thus the end points of the curve described this equation are irrational : the production rate calculated by this equation does not equal to its maximum production rate when the bottom-hole inflow pressure is "0 ", and the productivity index well not be "0 ", when inflow bottom-hole pressure differential is 0 ; these does not conform with the actual case. However Fetokovich type IPR equation can avoid these errors with the problems in Cheng type equation , Fetokovich type IPR equation for horizontal and inclined well are given. This type of IPR equation has a more reasonable result in the treatment of end points and is more reliable in application. Furthermore , the relation between the angle of inclination and the exponent " *n* " of Fetokovich IPR equation is given also. **Subject heading :** Inclined well , Horizontal well , Performance

The application of Newton-Rabinson algorithm to phase-equilibria calculation. He , Wei ; et al. (Research Institute of Petroleum Exploration and Development , CNPC , Beijing 100083 , P. R. China , *Shiyou Kantan Yu Kaifa* 1999 , 26(4) , 68-71. Phase behavior study is indispensable in gas-condensate system and it includes many methods. Phase-equilibria calculation is one of its important methods. In order to