两夹角不渗透断层对油井压力及压力导数的影响研究

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摘　要　利用镜像映射和叠加原理推导了理想油藏中油井位于两夹角 (θ)不渗透断层间定产量生产时的井底压力及压力导数表达式,分析了夹角不渗透断层对油井压力及压力导数的影响,并得出结论:油井无论位于夹角断层间哪一位置,其压力半对数曲线上均出现斜率为径向流第一直线段斜率 360 °/θ倍的第二直线段,压力导数曲线上出现值为 360 °/θ ×0.5的第二水平线。

关键词　夹角断层　镜像映射　压力响应

引言

断块油藏是油田开发中后期增储上产的主要阵地之一。准确认识断块油藏的断层对布井、提高动用储量和原油采收率具有重要意义。目前,断块油藏中规则边界对油井压力及压力导数的影响已研究的比较清楚[1~5],而对夹角断层的情况则研究较少。然而实际上,断块油藏中夹角断层的分布更加广泛,可见,对该问题加以研究将有助于断块油藏的合理开发,因而具有重要意义。

1　油井压力及其导数曲线特征

已知理想无限大油藏中一口井定产量生产时的油井无因次压力表达式如下

$$P_D = -\frac{1}{2}E_i\left(-\frac{1}{4t_D}\right) \tag{1}$$

其中:

$$P_D = \frac{Kh}{1.842\times10^{-3}q\mu B}\Delta P$$

$$t_D = \frac{3.6Kt}{\phi\mu C_t r_w^2}$$

式中,P_D为无量纲压力;ΔP为压差,MPa; t_D为无量纲时间;t为开井生产时间,h; r_w为井半径,m; B为原油体积系数;K为地层渗透率,μm^2; h为地层厚度,m; μ为流体粘度,mPa·s; ϕ为地层孔隙度; q为井的地面产量,m^3/d; C_t为地层及其流体的综合压缩系数,1/MPa。

今假设一油井在理想无限大油藏中两夹角为θ的不渗透断层间以定产量 q生产,井到两断层的距离分别为 x_1, x_2。井点与断层交点连线与较近一条断层的夹角为 θ_1 (见图 1)。

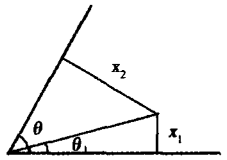

图 1　两夹角断层间一口井示意图

假设断层夹角可被 360 整除 ($N = 360°/\theta$,取整数),应用镜像映射和叠加原理即可求出油井压力和压力导数的表达式;由于油井在夹角断层间的位置不同对表达式的形式有所影响,故分 2 种情况进行分析:油井位于断层夹角平分线上和井不在夹角平分线上。

1.1　油井位于断层夹角平分线上时压力及其导数特征

此时 $\theta_1 = \theta/2$,求得无因次压力及压力导数

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表达式分别为式 (2)、(3):

$$P_D = -\frac{1}{2}\left\{E_i\left(-\frac{1}{4t_D}\right)+\sum_{i=1}^{N-1}E_i\left[-\frac{1}{t_D}\left(\frac{x_1\sin(i\theta/2)}{r_w\sin(\theta/2)}\right)^2\right]\right\} \tag{2}$$

$$P'_D\cdot t_D = \frac{1}{2}\left\{\exp\left(-\frac{1}{4t_D}\right)+\sum_{i=1}^{N-1}\exp\left[-\left(\frac{x_1\sin(i\theta/2)}{r_w\sin(\theta/2)}\right)^2/t_D\right]\right\} \tag{3}$$

为清楚表示断层对油井的压力及其导数的影响,利用压力及其导数表达式分别作出压力半对数曲线和压力导数双对数曲线 (见图 2、3)。

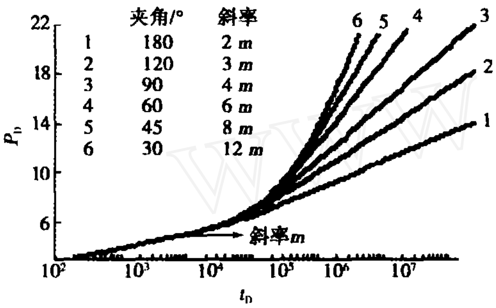

图 2　压力半对数图

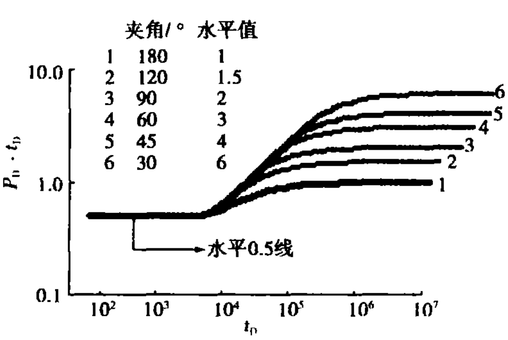

图 3　压力导数双对数图

分析图 2、3可以看出,开井生产早期压力半对数曲线上出现斜率为 $m = 1.151$的第一直线段,双对数曲线上出现水平 0.5直线段,反映出无限大地层径向流动特征。生产晚期压力半对数曲线上出现第二直线段,且其斜率为第一直线段斜率的 360 °/θ倍,双对数曲线上出现第二个水平段,且水平值为第一水平值的 360 °/θ倍,反映出夹角为 θ的两断层对油井压力及压力导数的影响。

1.2　油井不位于断层夹角平分线上时压力及其导数特征

当油井不位于断层夹角平分线上时,N值不同对映射产生较大影响,可分为 N取偶数和奇数2种情况。

1.2.1　$N = 360°/\theta$取偶数

镜像映射处理后,断层共 N条,油井共 N口,其中 1口真实井 $N - 1$口映像井,应用叠加原理求出无因次压力及压力导数表达式分别为

$$P_D = -\frac{1}{2}\left\{E_i\left(-\frac{1}{4t_D}\right)+E_i\left(-\frac{x_1^2}{t_D}\right)+\sum_{i=1}^{\frac{N}{2}-1}\left[E_i\left(-\frac{x_1^2\sin^2(i\theta)}{t_D r_w^2\sin^2\theta_1}\right)+E_i\left(-\frac{x_1^2\sin^2(i\theta+\theta_1)}{t_D r_w^2\sin^2\theta_1}\right)\right]\right\} \tag{4}$$

$$P'_D\cdot t_D = \frac{1}{2}\left\{\exp\left(-\frac{1}{4t_D}\right)+\exp\left(-\frac{x_1^2}{t_D}\right)+\sum_{i=1}^{\frac{N}{2}-1}\left[\exp\left(-\frac{x_1^2\sin^2(i\theta)}{t_D r_w^2\sin^2\theta_1}\right)+\exp\left(-\frac{x_1^2\sin^2(i\theta+\theta_1)}{t_D r_w^2\sin^2\theta_1}\right)\right]\right\} \tag{5}$$

假设油井到两夹角断层的距离之比 $P = x_2/x_1$,由几何关系易知:

$$\sin(\theta - \theta_1) = P\cdot\sin\theta_1 \tag{6}$$

由式 (6)利用数值方法可求出 θ_1,并将 θ_1带入式 (4)、(5)并作图得图 4、5。

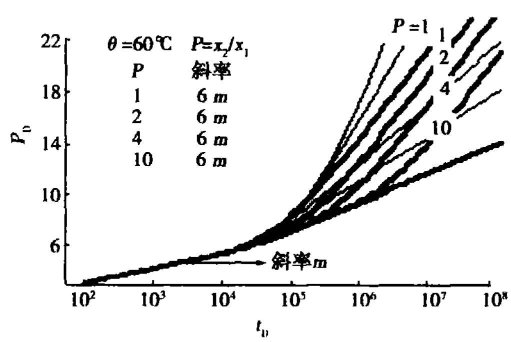

图 4　压力半对数图

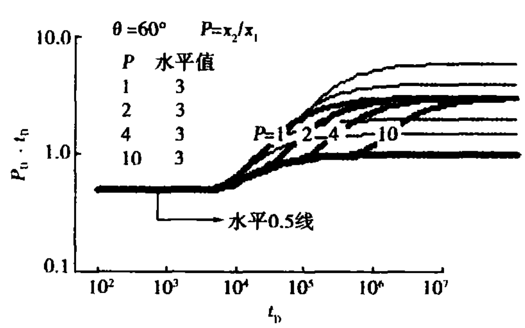

图 5　压力导数双对数图

分析两图可得出以下结论:

(1)尽管油井不位于断层夹角平分线上,但其压力曲线及导数曲线变化特征与油井位于断层夹角平分线上的情况相同,即:在压力半对数曲线上,第二条直线段的斜率是第一条直线段斜率的

$360°/\theta$倍;压力导数曲线上,第二个导数稳定值(边界稳定段)是第一个导数稳定值(均质稳定段)的 $360°/\theta$倍。

(2)油井在两夹角断层间的位置不会影响压力曲线和导数曲线的总体变化趋势,但是油井到两断层的距离之比增大(距离差增大),第一直线段向第二直线段的过渡时间将增大,且井到断层的距离差异很大时,曲线将首先明显反映出最近一条断层的影响。

1.2.2　$N = 360°/\theta$取奇数

如果 $360°/\theta$是奇数,镜像映射处理后,断层共 N条,油井共 $2N$口,其中 1口真实井 $2N-1$口映像井,式(7)、(8)分别为其压力及导数表达式

$$P_D = -\frac{1}{2}\left\{E_i\left(-\frac{1}{4t_D}\right) + E_i\left(-\frac{x_1^2}{t_D}\right) + \sum_{i=1}^{N-1}\left[E_i\left(-\frac{x_1^2\sin^2(\theta/2)}{t_D r_w^2\sin^2\theta_1}\right) + E_i\left(-\frac{x_1^2\sin^2(\theta/2+\theta_1)}{t_D r_w^2\sin^2\theta_1}\right)\right]\right\} \tag{7}$$

$$P_D' \cdot t_D = \frac{1}{2}\left\{\exp\left(-\frac{1}{4t_D}\right) + \exp\left(-\frac{x_1^2}{t_D}\right) + \sum_{i=1}^{N-1}\left[\exp\left(-\frac{x_1^2\sin^2(\theta/2)}{t_D r_w^2\sin^2\theta_1}\right) + \exp\left(-\frac{x_1^2\sin^2(\theta/2+\theta_1)}{t_D r_w^2\sin^2\theta_1}\right)\right]\right\} \tag{8}$$

开井生产早期,断层影响并未体现出来,此时油井井底的压力变化全部是由真实井自身的定产量生产引起的,反映在公式(7)、(8)中为:公式右端只有第一项起作用,其余各项幂积分函数(对于式(8)为指数函数)由于非常小均可忽略不计。油井生产较长时间后,夹角断层映射出的 $2N-1$口映像井在真实井井底产生的压力响应均不可忽略,此时 $2N$口井均匀(相对于断层的位置)分布于 N条断层间,每相邻两夹角断层间均有 2口井,真实区域也是如此,即有 2口产量为 q的油井同时生产。然而从实际情况考虑,真实区域地层的实际产出量为 q而非 $2q$,所以对于 $360°/\theta$是奇数的情况,镜像映射处理后如果直接应用公式(7)、(8)来分析油井压力及压力导数的变化情况将导致错误。例如,以断层夹角为 120 为例作图发现:夹角为 120 时压力响应却与夹角为 60 时的压力响应相同(见图 4、5)。

正确的处理方法为,在油井生产晚期将真实井的产量减半,之后所有映像井的产量随之改变,这们保证了与实际地层的产液量相等。经过这样的处理后油井压力及压力导数曲线将出现与 $360°/\theta$为偶数时所具有的相同规律。

最后需要着重指出的是,$360°/\theta$取奇数时油井开井生产后由径向流过渡到各映像井影响均体现出来的这一过程比较复杂,以上推导的公式(7)、(8)只能够对油井生产早期和晚期特征进行定量刻画但不能作为描述该过程的数学表达式,故该问题有待于进一步研究。

2　结论

(1)理想油藏中两夹角(要求夹角 θ可被 360整除)断层间一口油井定产量生产时,井无论是否位于断层夹角平分线上都有:在压力半对数曲线上,第二条直线段的斜率是第一条直线段斜率的 $360°/\theta$倍;压力导数曲线上,第二个导数稳定值(边界稳定段)是第一个导数稳定值(均质稳定段)的 $360°/\theta$倍。

(2)油井在两夹角断层间的位置不会影响压力曲线和导数曲线的总体变化趋势,但是油井到两断层的距离之比增大(距离差增大),第一直线段向第二直线段的过渡时间将增大,且井到断层的距离差异很大时,曲线将首先明显反映出最近一条断层的影响。

(3) $360°/\theta$为奇数时,油井开井生产后由径向流过渡到各映像井影响均体现出来的这一过程比较复杂,可用于描述该过程的准确的数学表达式有待于进一步研究。

参 考 文 献

1　Tiab D and Crichlow H B. Analysis of Multiple - Sealing - Fault Systems and Closed Rectangular Reservoirs by Curve Matching. Sot. Pet. Engr. J. , 1979: 378 - 392

2　Horner D R. Pressure Build - up in Wells. Proc. Third World Pet. Cong. E. J. Brill, Leiden, 1951: II503

3　Davis Grady E and Hawkins M F. Linear Fluid - Barrier Detection by Well Pressure Measurements. J. Pet. Tech, 1963: 1 077 - 1 079

4　Standing M B. Discussion of Linear Fluid - Barrier Detection by Well Pressure Measurement. Jour. Pet. Tech. , 1964: 259

5　Gray K E. Approximating Well - to - Fault Distance from Pressure Build - Up Tests. JPT, July 1965: 761 - 767

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in Yangxin Subsag

Gan Zhihong(Geological Scientific Research Institute, Shengli Oilfield Co. Ltd , SINOPEC, Dongying 257015, China). Fault-Block Oil & Gas Field, 2005, 12(6) :27-29

There are a lot of volcanics in Yangxin Subsag There is consanguineous connection between the volcanics and the petroleum. This paper analyzed the geology and seismic characteristics of the volcanics, and describe the volcanics distribution in the period when it occurred Volcanics development affected the distributing of the source rock, it also elevated the geothermal gradient, and changed the geochemical field of the source rock The volcanics may be good reservoir bed, and it can form some multi-hydrocarbon reservoirs, which is one of the prospect targets in Yangxin Subsag

Key Words: Yangxin Subsag, Volcanics, Time-space distribution, Hydrocarbon reservoir

Forecasting of the Oil and Gas Exploration Potential for Block 36 and Block 38 in Omen

Zhang Xinjian (Exploration & Development Research Institute of Zhongyuan Oilfield Company, SINOPEC, Puyang 457001, China) , Zhang Jianjun and Fu Mingxi et al Fault-Block Oil & Gas Field, 2005, 12 (6) :30-32, 53

Block 36 and 38 locate in southwest part of Oman covering an area of 36000 km^2. During 1953-2001, Omanani and some western petroleum companies conducted an exploration operation in this area Six exploration wells were drilled, in which two had oil or gas shows in Permian and Silurian formation Previous exploration mainly focused on strata above Silurian which lack of source rock, so the result was unsatisfied New geological evaluation based on gravity and seismic data suggests that this area has a similar depositional environment to that of Oman basin before Hercynian event and favorable source-reservoir-seal assemblage was also developed in Lower Cambrian-Pre-Cambrian So further geological research and exploration deployment may help us to find potential reservoirs of Palaeozoic in this area.

Key Words: Oman, Block 36/38, Oil and gas exploration, Prospecting

Relation of Reserve-Production Ratio and Decline Rate and Rationality Study in Lengjia Oilfield

Yuan Li (Research Institute of Exploration & Development, Liaohe Oilfield Company, PetroChina, Panjin 124010, China). Fault-Block Oil & Gas Field, 2005, 12(6) :33-36

Oilfield planners think unanimously that reserve-production ratio is closely related to decline rate. In order to study their correlativity, this paper derives 6 typical, theoretical, relational expressions of reserve-production ratio and decline rate by starting with their definitions, determines the method of rational reserve-production ratio limitation, which has been attempted in different oil reservoirs in Lengjia Oilfield and achieved good result It is point out that reserve-production ratio is an important index affecting decline rate The decline rate of this oilfield increases along with the decreasing of reserve-production ratio, and fluctuates around the theoretical relation. This provides reference to the study in other oilfields This paper combines calculated and practical reserve-production ratios, refers to concerned literatures, gives the cut-off value of reserve-production ratio of different oils in this oilfield, and analyzes the trend of stable production.

Key Words: Reserve-production ratio, Stable production trend, Decline rate.

Development of Research on the Phase of the Fluid in Porous Media Oil and Gas Reservoir

Zhang Wei(Southwest Petroleum Institute, Chengdu 610500, China), Guo Ping and Deng Shenghui Fault-Block Oil & Gas Field, 2005, 12(6) :37-40

This paper expatiates the rule of the phase behavior of fluid in the porous media oil and gas reservoir, and comparing the difference between the fluid in porous media and not This paper mainly discuss the condensate gas, and concluding the organic solid precipitation in the porous media which has researched very rarely recently. Finally, this paper put some worthy researching direction in the future.

Key Words: Porous Media, Phase Behavior, Condensate Gas, Solid Precipitation.

Study on the Influence of Two Interacting Sealing Faults on Oil Well 's Pressure and its Derivative

Zhao Xiucai(Petroleum Engineering Institute, China University of Petroleum, Dongying 257061, China), Yi Yanjing and Yao Jun. Fault-Block Oil & Gas Field, 2005, 12(6) :41-43

The mathematical expressions of bottom-hole pressure and its derivative for oil well which sites between two interacting sealing faults in ideal reservoir and is at constant production rate are established using mirror reflection and superposition principles The influence of interacting sealing faults on oil well 's pressure and its derivative is analyzed Conclusions can be made that pressure curves on semilog graph will show the second straight line of slope 360 °/θ times the first one corresponding to the radial flow and the derivative curves on log-log graph will show the second horizontal line with the value of 360 °/θ ×0. 5, no matter where the oil well sites between the two interacting aults

Key Words: Interacting faults, Mirror reflection, Pressure response.

Approach to the Method for Determination of Economic and Reasonable Well Spacing Density in Maturing Field