

文章编号:1673-064X(2007)01-0072-03

缝洞型油藏试井解释方法在塔河油田的应用

Application of the well test interpretation method for fracture-vug reservoir in Tahe Oilfield

王子胜¹,姚军¹,戴卫华²

(1. 中国石油大学(华东)石油工程学院,山东 东营 257061; 2. 中海石油天津分公司 技术部,天津 300452)

摘要:结合塔河油田的实际地质资料,建立了裂缝和溶洞-井筒连通的试井解释模型和相应的数学模型.提出了利用遗传算法进行缝洞型油藏试井自动拟合的解释新方法,并编制了一套缝洞型油藏试井解释软件.运用本文研究方法及所编制的软件准确地解释了塔河油田多口井的测试资料,并综合试井解释结果成功预测出了储层缝洞发育分布.

关键词:塔河油田;缝洞型油藏;试井解释;自动拟合

中图分类号:TE353 **文献标识码:**A

缝洞型油藏在国内外陆续大量投入开发,对这类油藏试井解释的研究不仅具有重要的理论价值,也具有突出的实际意义.1983年,吴玉树、葛家理等学者曾将一些含有洞穴的裂隙介质归结为三重介质地层^[1],并将基岩分为两类,即高渗基质的孔隙系统和低渗基质的孔隙系统^[1-2].本文将根据塔河油田实际地质资料,建立缝洞型油藏的试井解释模型并进行求解,提出多参数试井解释新方法解释多口井的测试资料,并在此基础上预测缝洞发育分布.

1 塔河油田储层特征及试井测试

塔河油田是一个特殊类型的岩溶缝洞型复杂油藏.根据测井、岩心和铸体薄片观察结果,其油藏有效储集空间可归纳为5类:第一类为大型洞穴,其直径大于100 mm;第二类为溶蚀孔洞,直径为5~100 mm;第三类为溶蚀空隙,孔径0.01~2.00 mm;第四类为风化裂缝;第五类为构造裂隙.

开发实践表明,塔河油田储层主要的储集类型为裂缝-溶洞型,基质岩块致密,基本为非储集层,

裂缝和溶洞既作为储集层又是渗流的主要通道.洞对储层的贡献较大,尤其是裂缝系统连通的洞对储层物性改善的贡献最大,各高产井大都归因于钻遇了溶洞发育的储层.

到目前为止,塔河油田仍处于开发初期,对油田地质情况和开发特征的认识还存在着很大的不确定性.为了更清楚地认识油藏的储集空间类型、储层的非均质性以及油水边界情况,对油田进行了试井测试,取得了大量的测试资料.

2 缝洞型油藏试井模型的建立和求解

为方便试井建模及求解,作如下的假设:油井以定产量生产;地层流体为单相,流体和岩石为微可压缩,且压缩系数为常数;油井测试前,地层中各点的压力均匀分布;忽略重力和毛管力的影响,并设地层中的压力梯度比较小;每种介质(基岩、裂缝和溶洞)的孔隙度与另一种介质的压力变化相对独立.

塔河油田的油藏主要储集类型为裂缝-溶洞型,裂缝和溶洞系统发育良好,基岩致密且渗透性

收稿日期:2006-07-25

基金项目:国家十五重大攻关项目“中国油气资源发展关键技术”所属专题,专题名称:塔北地区碳酸盐岩大型油田勘探开发关键技术研究(项目编号:2001BA605A-03-03-01)

作者简介:王子胜(1980-),男,博士,主要从事试井解释和数值模拟方法的研究.

差.基于流体力学相似理论,在建立渗流物理模型时,考虑裂缝和溶洞均与井筒连通,流体可通过裂缝和溶洞直接流入井筒,基岩相当于“源”项,不断地向

裂缝和溶洞系统发生拟稳态窜流^[2].

由上述模型假设,可得到无因次渗流方程^[3-4]

$$\begin{cases} K_f^* \frac{1}{r_D} \frac{\partial}{\partial r_D} \left(r_D \frac{\partial p_{Df}}{\partial r_D} \right) + m_f (p_{Dm} - p_{Df}) - v_f (p_{Df} - p_{Dv}) = f \frac{\partial p_{Df}}{\partial t_D}, \\ K_v^* \frac{1}{r_D} \frac{\partial}{\partial r_D} \left(r_D \frac{\partial p_{Dv}}{\partial r_D} \right) + m_v (p_{Dm} - p_{Dv}) + v_f (p_{Df} - p_{Dv}) = v \frac{\partial p_{Dv}}{\partial t_D}, \\ - m_f (p_{Dm} - p_{Df}) - m_v (p_{Dm} - p_{Dv}) = m \frac{\partial p_{Dm}}{\partial t_D}. \end{cases} \quad (1)$$

上述渗流方程和下列定解条件组成完整的数学模型.

$$\text{内边界条件:} \begin{cases} C_D \frac{d p_{wD}}{d t_D} - \left(K_f^* \frac{\partial p_{Df}}{\partial r_D} + K_v^* \frac{\partial p_{Dv}}{\partial r_D} \right)_{r_D=1} = 1, (t_D > 0), \\ p_{wD} = \left(p_{Df} - S \frac{\partial p_{Df}}{\partial r_D} \right)_{r_D=1} = \left(p_{Dv} - S \frac{\partial p_{Dv}}{\partial r_D} \right)_{r_D=1}; \end{cases} \quad (2)$$

$$\text{外边界条件:} \lim_{r_D \rightarrow \infty} p_{Dj}(r_D, t_D) = 0; \quad (3)$$

$$\text{初始条件:} p_{Dj}(r_D, 0) = 0, (1 \leq r_D < \infty). \quad (4)$$

其中, $r_D = \frac{r}{r_w}$, $t_D = \frac{3.6(k_f + k_v)t}{\mu r_w^2(\phi_m C_m + \phi_f C_f + \phi_v C_v)}$, $K_j^* = \frac{K_j}{k_f + k_v}$,

$$p_{Dj}(r_D, t_D) = \frac{(k_f + k_v)h}{1.842 \times 10^{-3} q \mu B} [p_i - p_j(r, t)].$$

式中, $j = m, f, v$ 分别表示孔、缝、洞介质; r 为径向距离, m ; r_w 为井筒半径, m ; t 为时间, h ; t_D 为无因次时间; k_j 为渗透率, μm^2 ; K_j^* 为介质的渗透率比; p_i 为初始压力, MPa ; p_j 为压力, MPa ; p_{Dj} 为无因次压力; C_D 为无因次井筒存储系数; S 为表皮系数; ϕ_j 为介质的弹性储容比; m_f, v_f, m_v 分别为孔缝、洞缝以及孔洞之间的窜流系数; p_{wD} 为无因次井底压力.

联立式(1) —(4), 利用 Laplace 变换方法可以求得拉氏空间的无因次压力解^[3], 见式(5), 然后利用 Stehfest 数值 Laplace 反演方法求得真实空间压力解.

$$\overline{p_{Dv}}(r_D, s) = 1 / \left\{ s C_D + D(s) / \left[S + K_1^0(j_1) \right] + E(s) / \left[S + K_1^0(j_2) \right] \right\}, \quad (5)$$

其中, $K_1^0(j) = \frac{K_0(j)}{1 K_1(j)}$, ($j = 1, 2$); $D(s) = \frac{(a_2 - 1)(K_f^* a_1 + K_v^*)}{(a_2 - a_1)}$; $E(s) = \frac{(a_1 - 1)(K_f^* a_2 + K_v^*)}{(a_1 - a_2)}$,

$$a_j = 1 + \frac{1}{m_f + \frac{m_f m_v}{m_s + m_f + m_v}} \left(v_s - K_v^* \frac{?}{j} + \frac{m_v m_s}{m_s + m_f + m_v} \right), (j = 1, 2).$$

式中, s 为拉氏变量, j_1, j_2 为与孔洞缝三者窜流有关的参数, K_0 和 K_1 为贝塞尔函数.

3 多参数试井解释方法及软件编制

缝洞型油藏试井解释的参数较多, 有井筒存储系数、表皮系数、裂缝和溶洞渗透率、孔缝洞三类介质之间的窜流系数、孔缝洞的弹性储容比以及井到边界的距离. 很显然, 用人工拟合的方法非常困难. 近些年形成的遗传算法具有全局收敛性, 是一种不用梯度信息的自适应非线性优化算法. 本文利用遗传算法进行缝洞型油藏试井解释自动拟合获得成功^[4], 算法的遗传编码是一个长度为 10 的数串($C,$

$S, k_f, k_v, m, f, m_f, v_f, m_v, L$), 其中 C 为井筒存储系数, L 代表井到边界的距离. 研究表明此方法能极大地提高拟合的速度和精度. 运用本文所提出的试井解释模型和方法, 成功编制了缝洞型油藏试井解释软件.

4 缝洞型油藏试井解释在塔河油田的应用

利用本文所提出的试井解释方法及研制的软件, 成功解释了塔河油田 16 口井的试井测试资料.

4.1 实例研究

S74 井是塔河油田的一口开发井,该井于 2000 年 9 月进行了压恢测试,共测得 236 h 的数据. 基岩孔隙度为 1.9%,岩石压缩系数为 $22.6 \times 10^{-4} \text{ MPa}^{-1}$,原油体积系数为 $1.2746 \text{ Nm}^3/\text{m}^3$,油层有效厚度为 24 m,原油地下黏度为 $80.717 \text{ mPa}\cdot\text{s}$,测试前地面产量为 $120 \text{ m}^3/\text{d}$.

选择试井解释模型为“裂缝和溶洞 - 井筒连通 + 井筒存储 + 表皮系数 + 两条平行不渗透边界”. 试井解释结果: C 为 $0.1253 \text{ m}^3/\text{MPa}$, S 为 -3.12 , k_v 为 $2.12 \mu\text{m}^2$, k_f 为 $1.85 \mu\text{m}^2$, v_f 为 9.941×10^{-6} , m_v 为 2.116×10^{-7} , m_f 为 1.236×10^{-7} , v_v 为 1.001×10^{-3} , 为 0.9812 , 并到断层的距离 149 m. 图 1 所示为该井的压力及压力导数双对数拟合图. 井筒存储影响之后,导数曲线第一个下凹段为裂缝向溶洞窜流段,第二个下凹段为基岩向缝洞系统窜流段,由于不渗透边界的影响掩盖了基岩窜流段特征,基岩窜流段不明显. 解释结果和现场资料吻合,证明了该方法的正确性.

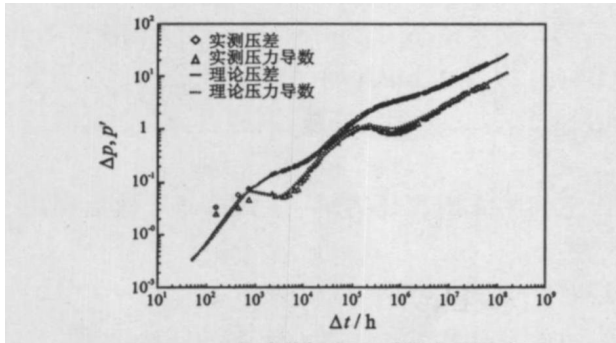


图 1 S74 井试井解释双对数曲线拟合图

4.2 利用试井解释成果预测缝洞发育分布

缝洞型油藏的裂缝和溶洞渗透率以及弹性储容比的大小反映了裂缝和溶洞的发育程度. 综合运用塔河油田的试井解释成果,成功预测了区块的缝洞发育分布,与其他研究成果有较好的一致性. 如图 2、图 3 所示.

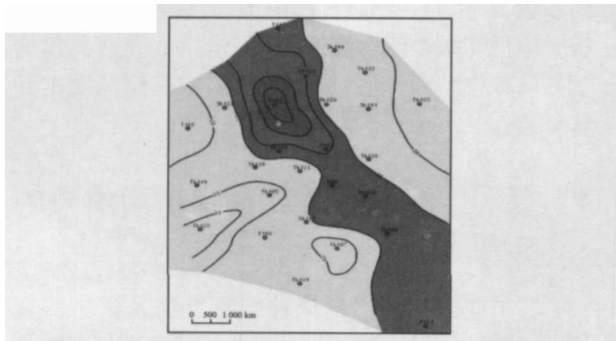


图 2 塔河 4 区裂缝发育指数平面分布图

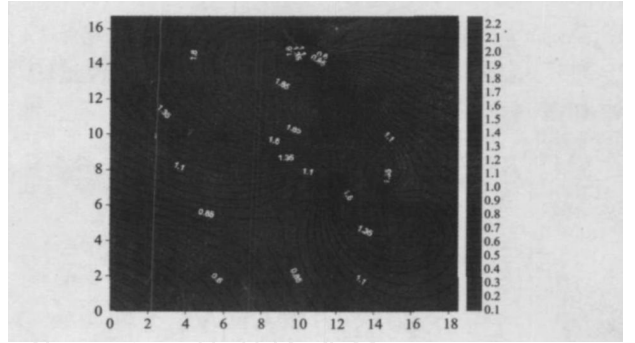


图 3 塔河 4 区裂缝渗透率平面等值图

5 结论

- (1) 结合塔河油田实际地质资料,提出了裂缝和溶洞-井筒连通试井解释模型,并进行了求解.
- (2) 提出了利用遗传算法进行缝洞型油藏试井自动拟合解释新方法,并编制了实用解释软件.
- (3) 利用所编制的软件解释了塔河油田多口井的试井测试资料,并在此基础上成功预测了储层缝洞发育分布. 解释结果可靠,该方法具有一定的实用价值.

参考文献:

- [1] 吴玉树,葛家理. 三重介质裂 - 隙油藏中的渗流问题[J]. 力学学报, 1983, 14(1): 81-84.
- [2] Gurbinar O, Kalbus J. Numerical Modeling of a Triple Porosity Reservoirs[C]. SPE 57277, 1999.
- [3] 姚军,李爱芬. 求解双重孔隙介质油藏压力的一种新方法[J]. 石油大学学报:自然科学版, 1999, 23(4): 42-44.
- [4] Denning P J. Genetic Algorithm[J]. American Societist, 1992(10): 12-14.

编辑: 贺元旦

Study on the mechanism and performance of the condensate water producing from abnormal high-temperature gas wells

Abstract : Based on the phase equilibrium theory of oil-gas-water multi-phase ,the phase varying characteristics of the hydrocarbon and water in formation and well-bore under the original gas reservoir condition with abnormal high-temperature and in production process are studied by simulation ,and the process and mechanism of the condensate water producing from the gas wells are analyzed. The contents of the saturated condensate water in condensate gas under different temperatures and pressures are calculated ,the production performance of the condensate water is obtained. The law and the source of the early condensate water producing of two practical gas wells are analyzed. It is shown that the mechanism of the condensate water producing is the multi-phase equilibrium of hydrocarbon and water under different temperatures and pressures ,the production law of the condensate water can be used for the preliminary judgment of the water source in gas wells and the analysis of the water producing performance of gas wells. The correct recognition of the water producing law of high-temperature gas wells is important to the reasonable design of gasfield development plan.

Key words : high-temperature gas well ;condensate gas reservoir ;condensate water producing mechanism ;condensate water producing performance

TANG Yong^{1,2}, SUN Lei², DU Zhi-min², SUN Liang-tian², LI Shi-lun² (1. Post-doctoral Research Center ,Chengdu University of Technology ,Chengdu 610500 ,Sichuan ,China ;2. State Key Laboratory for Oil Reservoir Geology and Development Engineering ,Chengdu 610500 ,Sichuan ,China) JXS YU 2007 V. 22 N. 1 p. 68-71

Application of the well test interpretation method for fracture-vug reservoir in Tahe Oilfield

Abstract : Based on the geological data of Tahe Oilfield ,the well test interpretation model of the reservoir with the fracture and vug which are connected with well-bore is established. The method for solving the model by using genetic algorithm is put forward , and the corresponding software is developed. The well test interpretation model is used in the well test interpretation of several wells of Tahe Oilfield ,and the development and distribution of fracture and vug in the reservoirs are successfully predicted by using the well test interpretation results.

Key words : Tahe Oilfield ;fracture-vug reservoir ;well test interpretation ;automatic fitting

WANG Zi-sheng¹, YAO Jun¹, DAI Wei-hua² (1. Faculty of Petroleum Engineering ,China University of Petroleum (East China) ,Dongying 257061 ,Shandong ,China ;2. Technology Department of Tianjin Branch Company ,CNOOC ,Tianjin 300452 ,China) JXS YU 2007 V. 22 N. 1 p. 72-74

Three-dimensional visualization of steering drilling information

Abstract : The modeling ,display and human-machine interaction in the visualization of a 3-D object are discussed thoroughly ,and they are applied to the three-dimensional visualization of steering drilling information. Thus ,the 3D visualization of the formation ,real well track ,target point and designed well track in steering drilling can be implemented. A case is presented. By the visualization of drilling information ,drilling workers can clearly understand the structure of formation and the characteristics of reservoir ,increase the control ability of drilling bit and thus can improve drilling success rate.

Key words : steering drilling ;virtual reality ;visualization of information ;Java 3D

LI Yan-hua, XU Ying-zhuo (College of Computer ,Xi 'an Shiyou University ,Xi 'an 710065 ,Shaanxi ,China) JXS YU 2007 V. 22 N. 1 p. 75-78

Application results of two vertical drilling systems in Talimu Oilfield and their comparison

Abstract : Inclining prevention and drilling-speed enhancing is a pair of contradiction in drilling well in mountain front steep structural formation. The inclination angle of the mountain front structural formation in Talimu Basin generally ranges from 15° to 80°. In order to solve the contradiction ,three internationally advanced vertical drilling systems are introduced. Two of them ,VTK drilling system and Power-V drilling system are applied in Talimu Oilfield. The application results of them in Kelu4 well show that ,they can all effectively control hole inclination and increase drilling speed ,but the performance of Power-V drilling system is better than that of VTK drilling system. Some problems existing in the field applications of them are proposed and some improvement suggestions are given.

Key words : Talimu Oilfield ;steep inclined structure ;vertical drilling system ;rotary steering drilling tool ;application result

LIU Lei^{1,2}, LIU Zhi-kun¹, GAO Xiao-rong¹ (1. College of Petroleum Engineering ,Xi 'an Shiyou University ,Xi 'an 710065 ,Shaanxi ,China ;2. Talimu Shengli Drilling Company ,Kuerle 841000 ,Xinjiang ,China) JXS YU 2007 V. 22 N. 1 p. 79-81 ,86

Effect of reaction temperature on the product of aromatization reaction of FCC gasoline narrow fraction

Abstract : In order to make the content of alkene in FCC gasoline meet the requirements of the national new standard ,the alkene in FCC gasoline must be transferred into isobutene and aromatic hydrocarbon. The catalytic gasoline narrow fraction of Lanzhou Refinery being used as experimental material ,and small-size fixed-fluidized bed reactor as reaction unit ,the effect laws of reaction temperature on the increasing rates and yields of all the components of the product ,the composition of gas product and the composition of liquid product of the aromatization reaction are experimentally studied. The experimental results show that ,to some narrow fraction ,under the same carbon number the increasing rates of all the components of the product increase with the going-up of reaction temperature ,and the higher the reaction temperature ,the more the increase of the components ;to some narrow fraction ,the yields of dry gas ,