凝析气井测试曲线压力导数凹陷的研究

刘曰武* 刘俊丽 郑 威 吴英明
(中国科学院力学所) (塔里木石油勘探开发指挥部开发研究中心)

摘要 根据凝析气的特征, 分析了凝析气的流动机制, 建立了新的凝析气井试井分析理论模型, 克服了以往凝析气井试井资料分析上的一些困难, 排除了现场由于压力变化类似于裂缝性油藏而不敢实施注气开采的疑虑。经在实际井资料分析中应用, 获得了较好的结果。

主题词 凝析气 理论模型 试井解释 分析方法 双重介质 均质油藏

前 言

凝析气田是一种具有很高经济价值的特殊气田, 为了合理地设计和制订凝析气田的开发方案和技术政策, 需要取得有关凝析气田的原始资料, 了解凝析气层的地层参数及生产能力, 从而确定气井的合理工作制度。然而, 凝析气井稳定试井资料的整理方法迄今仍然沿用气井稳定试井资料的整理方法。实践证明, 这种方法不能确切地表征凝析气井的地下真实情况。

要进行凝析气井试井分析, 需要解决如下难点:

①流体性质变化。随着油气藏的开发, 地层压力降低, 凝析气中的重烃组分析出, 形成液相。在一定的时期凝析液可以与气相一同产出, 但对于高凝析含量的凝析气田, 则凝析液有一定的部分附着在孔道壁上, 因此流动的凝析气的组分发生变化, 从而导致流体性质的变化。

②地层中流体分布复杂。依据地层内压力分布特点, 整个地层的液态凝析油的分布不均一, 近井筒某一区域凝析油的饱和度相对高, 远离井筒的区域凝析油的饱和度相对低。

③流体流动状态难以确定。对于凝析油的流动极限情况可以概括为以下几种: a. 纯凝析油流动; b. 凝析油与凝析气的两相分离流动; c. 凝析油与凝析气的两相混合流动; d. 凝析气携凝析油的两相流动; e. 凝析气的单相流动。

④地层中流体的相变过程难以描述。由于压力变化不同, 凝析与反凝析的程度不同, 因此难以定量描述相变的过程和相变的程度。

在凝析气井的生产过程中, 当井筒压力低于露点压力时, 有凝析油析出, 这种情况下, 如果凝析油占有相当的比例, 计算时液量部分就不能忽略不计。过去是设法将井口得到的凝析油量折算成相应凝析气量, 然后用二项式或指数式来整理稳定或不稳定试井资料[1, 2]。处理凝析气的主要方法有三类: 一是修正法, 二是拟压力法, 三是近似法。这些方法在文献[3]中已有较好论述。本文根据凝析气的特征, 通过分析凝析气的流动机制, 建立了一个新的凝析气井试井分析理论模型。

* 刘曰武, 男, 博士后, 1997 年毕业于中科院渗流所, 获博士学位, 主要从事渗流力学基础理论研究、油气井测试理论和资料解释工作。地址: 北京市海淀区中关村路 15 号, 邮政编码: 100080。

凝析气井试井分析理论模型

1. 物理模型

(1) 油藏状况: 均质、各向同性、水平板状无限大油藏, 原始地层压力大于临界凝析压力(双重介质、各向异性、倾斜地层, 原始地层压力小于或等于临界凝析压力)。

(2) 井况: 井位于油藏内, 井筒全部贯穿地层, 裸眼完井, 井以定产量生产。

(3) 流体状况: 在一定时间范围, 根据凝析气性质的不同, 析液程度不同(本文就是以此流体相变基本原则为核心建立的数学模型)。

(4) 流动特征描述: 在整个地层流动的区域存在一定的凝析现象, 地层中的流动以径向层流为主。

(5) 由于假设整个地层是等温过程, 对于其它因素的影响忽略不计。

2. 数学模型及其 Laplace 空间解

(1) 基本的数学模型

控制方程为

$$\frac{\partial^2 p_D}{\partial r_D^2} + \frac{1}{r_D}\frac{\partial p_D}{\partial r_D} + q_{nD} T_{nD}\left[p_D - T_{nD}\int_0^{t_D} p_D \mathrm{e}^{-T_{nD}(t_D-\tau)}\mathrm{d}\tau\right] = \frac{\partial p_D}{\partial t_D} \tag{1}$$

内边界条件

井底流量条件

$$q_D = -\left.\frac{\partial p_D}{\partial r_D}\right|_{r_D=1} \tag{2}$$

井储条件

$$C_D\frac{\mathrm{d}p_{wD}}{\mathrm{d}t_D} + q_D = 1 \tag{3}$$

表皮条件

$$p_{wD} = p_D - S\left.\frac{\partial p_D}{\partial r_D}\right|_{r_D=1} \tag{4}$$

外边界条件

$$p_D(\infty, t_D) = 0 \tag{5}$$

初始条件

$$p_D(r_D, 0) = 0 \tag{6}$$

式中: p —— 压力, MPa; r —— 离开井点的距离, m; q —— 产量, m^3/d; q_n —— 凝析强度, m^3/MPa; T_n —— 凝析延迟时间, h; t —— 时间, h; C —— 井筒储存常数, m^3/MPa; p_w —— 井底流压, MPa; S —— 表皮系数; 下标 D —— 无量纲。

(2) 数学模型的解

通过 Laplace 积分变换, 可以得到方程(1)～(6)的解为

$$\overline{p_{wD}} = \frac{K_0(fs) + S\cdot fs\cdot K_1(fs)}{s\{fs\cdot K_1(fs) + C_D\cdot s\cdot[K_0(fs) + S\cdot fs\cdot K_1(fs)]\}} \tag{7}$$

其中

$$fs^2 = s\frac{s + T_{nD}(1 - q_{nD})}{s + T_{nD}}$$

式中: $K_0(\cdot)$、$K_1(\cdot)$ —— 修正 Bessel 函数; fs —— 中间变量; s —— Laplace 变量。

3. 理论图版的制作及影响因素分析

(1) 理论图版的制作

根据公式(7), 利用 Stefest Laplace 数值反演算法, 可以计算出凝析气井试井分析的理论曲线(见图 1), 基本计算参数 T_{nD} = 0.0001, q_{nD} = 1.95。

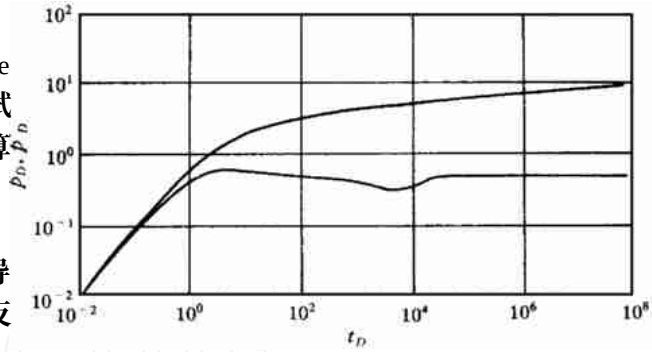

图 1 凝析气井试井分析理论曲线

(2) 影响因素分析

①凝析延迟时间 T_{nD}: 影响压力导数异常波动出现的早晚, 说明凝析或反凝析作用发生的早晚。

②凝析强度 q_{nD}: 影响压力导数异常波动的大小, 说明凝析或反凝析作用强烈程度, 与凝析油的含量和凝析临界压力以及生产压差有着紧密的关系。

实 例 分 析

通过对我国某凝析气田的 23 井层的实际测试资料分析, 本文理论得到了很好的应用, 解决了该凝析气田的注气开发疑虑问题和开发方案设计时是否进行储层改造措施等问题。现给出其中两例加以说明。

例 1: 本井完井层段为细砂岩地层, 从所取得的岩芯看无裂缝发育, 所以判断该地层不构成裂缝—孔隙地层结构, 非双重介质地层。地层厚度 10.5 m, 孔隙度 18.0 %, 为上第三系地层。主要分析结果为: 地层渗透率 32.3×10^{-3} μm^2, 表皮系数 0.14, 凝析强度 0.00162 m^3/MPa, 凝析延迟时间 0.01024 h, 其双对数及导数拟合结果如图 2 所示。探测范围内无任何边界反映。

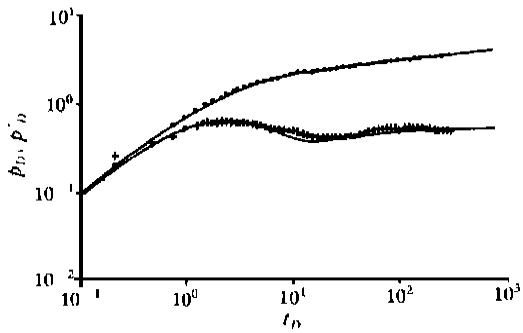

图 2 实例 1 双对数及导数拟合图

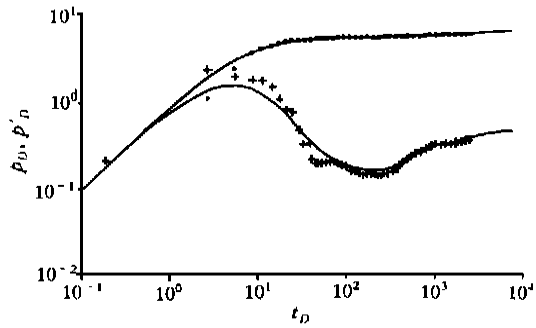

图 3 实例 2 双对数及导数拟合图

例 2: 该井完井井段为粉砂岩, 从所取得的岩芯看无裂缝发育, 所以判断该地层不构成裂缝—孔隙地层结构, 非双重介质地层。地层厚度 4 m, 孔隙度 12.5%, 为上第三系地层。主要分析结果为: 地层渗透率 28.3×10^{-3} μm^2, 表皮系数 0.36, 凝析强度 0.00327 m^3/MPa, 凝析延迟时间 0.01284 h, 其双对数及导数拟合结果见图 3。探测范围内无任何边界反映。

结　　论

1. 给出了一种新的凝析气试井分析理论和方法。

2. 分析了凝析气试井理论曲线的影响因素及影响特征变化。

3. 解决了均质砂岩储层凝析气井测试曲线表现为双重介质特征的问题, 为注气开发解除了后顾之忧。

4. 通过对我国某凝析气田的 23 井层的实际井例分析得到了较好的结果, 并获得了现场应用认可。

5. 建议凝析气田开发评价时使用本文介绍的凝析气试井分析理论和方法。

6. 本研究成果已与其它的凝析气井试井分析理论相结合, 形成了一套凝析气井分析的分析软件系统。

参 考 文 献

1. 张树宝, 张国刚: 凝析气井不稳定试井资料整理方法, 石油钻采工艺, 1985(6): 49～56。
2. 赵焕欣: 凝析气井稳定试井资料分析方法, 试采技术, 1985(4): 34～44。
3. 欧阳良彪, 孔祥言: 凝析气井试井研究现状, 天然气工业, 1993(5): 59～61。
4. J. R. Jones and R. Raghavan: Interpretion of Floeing in Gas Condensate Wells, SPE 14024.

本文收稿日期: 1999- 01- 31　编辑: 王　军

(上接 5 页)

参 考 文 献

1. Olarewaju, J. S. and Lee, W. J.: A New Pressure Transient Analysis Model for Dual-porosity Reservoirs, SPE 15634.
2. 贾永禄, 李允: 不等厚横向非均质复合油藏试井分析模型及压力特征, 油气井测试, 1996(3)5。
3. Olarewaju, J. S. and Lee, W. J.: An Analytical Model for Composite Reservoir Produced at Either Constant Bottomhole Pressure or Constant Rate, SPE 16763.
4. Olarewaju, J. S. and Lee, W. J.: A Study of Pressure Behavoir of Layered and Dual-porosity Reservoirs in the Presence of Skin, Wellbore Storage and Phase Segregation, SPE 17302.
5. Cinco, L. H. and Samaniego, V. F.: Pressure Transient Analysis for Naturally Fractured Reservoir, SPE 11026.
6. Olarewaju, J. S. and Lee, W. J.: A Comprehensive Application of A Composite Reservoir Model to Pressure Transient Analysis, SPE 16345.
7. 李允, 张大枢: 计算机辅助下的双重介质油气藏试井分析方法, 西南石油学院学报, 1990(2)。
8. 贾永禄: 考虑表皮和井筒储集效应的双重介质封闭地层有效井径模型及样板曲线, 天然气工业, 1994(5)。

本文收稿日期: 1997- 12- 22　编辑: 王　军

WELL TESTING (YOUQIJING CESHI)
Vol. 8 No. 1 (Serial No. 55) 1999

Abstracts

. Research of Theory & Method

Well Testing Analysis Model and Numerical Solution for a Composite Reservoir with Non-uniform Thickness and Double Media 1999 (1) 8: 1～5

Guo Jianchun, Xiang Kaili (*Department of Petroleum Engineering, Southwest Petroleum Institute*)

For more truely representing the damage conditions and heterogeneity of the formation itself in course of drilling, completion and production of fissured reservoir, a mathematical model to well testing analysis of effective amatheatical model to well tisting analysis of effective wellbore radius for a composite reservoir with non-uniform thickness and double media is created. This model generally takes into account the characteristics of double media, fluid properties and variation of formation thickness as well as the effect of skin factor, wellbore storage effect etc. The implicit finite difference approach is used to find out solution of the mathematical model, new typecurves are created, the effect of wellbore storage coefficient interporosity flow coefficient, storativity ratio and other parameters on the generation of derivative curves is also analyzed. The numerical calculation method of the model is simple, the calculation result is stable. The composite reservoir model with uniform thickness and double media and individual bounded double medium composite reservoir model are considered as special cases of the model, therefore the scope of application of the model will be more extensive.

Subject heading: dual media, heterogeneous reservoir, mathematical model, typical curve

A Study of Depression on Pressure Derivative of Well Testing Curve from Condensate Gas Wells 1999 (1) 8: 6～9

Liu Yuewu, Liu Junli (*Institute of Mechanics, the Academy of Sciences of China*), *Zheng Wei, Wu Yingming* (*The Headquarters of Tarim Petroleum Exploration and Development*)

In accordance with the features of condensate gas, this paper analyzes flowing mechanism of condensate gas, creates a new theoretical model for well testing analysis of condensate gas wells, that overcomes some difficulties in the previous analysis of well testing data from condensate gas wells and dispels doubts for field technicians not to dare to conduct gas injected production due to pressure variation similar to fissured reservoir. Analysis of actual data obtained pretty good results.

Subject heading: com densate gas, theoritical model, well test interpretation, analytical method, dual media, homogeneous reservoir

Computation of the Parameters Pertinent to Nitrogen Gas Misable Fracturing 1999 (1) 8: 10～11

Wei Jianjun, tag Yuling, Zhang Tianwen (*Production Section of Tuba Downhole Technique Headquarters, Shanshan, Xinjiang*)

Through theoretical derivation and computation of nitrogen gas dryness fraction, wellbore hydrostatic pressure, minimum flowing back dryness and other parameters pertinent to nitrogen gas misable fracturing, a systematic basis of theoretical design is provided for computating nitrogen gas volume injected and pump rate of fracturing operation, verification of actual application proves that coincidence rate is high.

Subject heading: fracturing, nitrogen injection, back flow volume, low permeability pools

Case Analysis or Well Zhou 17 to Increase Oil Production Rate and Shorten Early Production Test Time 1999 (1) 8: 12～14

Ma Yanling, Zhao Qinru (*Geologic Branch of Daqing Well Testing Company*)

It's quite cold in winter in the Daqing area, long time early production test costs much. For that reason, it was decided to conduct early production test on well Zhou 17 by taking 3 % oil reserves as average oil production rate. Through analysis of the pattern of bottom hole flowing pressure changes vs time, change pattern of productivity index, interpretation results, comprehensive curves, well particularity and other early product ion test information for well Zhou 17 after early production test, it indicates that it is applicable to increase flow rate of early production test well and shorten early production test time. Through 92 days test, the aim of early production test was attained, providing a basis for cold areas to shorten the time of early production test.

Subject heading: extreme frigid region, elastic drive, production test, flowing pressure, productivity index

Preliminarily Diagnose Bottom Hole Flow State of Gas Wells by Use of Wellhead Pressure 1999 (1) 8: 15～17

Yan Mingqiang, Lu Shuzhu (*Well Testing Department, Jilin Oilfield*)