# 多重渗透介质油藏非稳态压力特征分析

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**摘要**　在多重介质油藏非稳态压力的半对数曲线上,往往会出现多条"直线段",但是由于其中各种介质的渗透性不同,使得曲线间存在各种差异,理论推导和曲线特征研究证明,在只有一种介质可以渗流的多重介质油藏的非稳态压力的半对数曲线上,才会出现多条相互平行的直线段,而在多种介质同时具有渗透性时,实际上只有最后的系统径向流段才能在半对数曲线上出现直线段,而其他部分则都是曲线。

**关键词**　多重介质　非稳态压力　试井解释　半对数曲线

## 前　言

前苏联的 Barrenblatt,美国的 Warren,J. E. 和 Root P. J,A. S. Odeh,H. Kazemi,A. de Swann O. 以及 K. Serra A. C. 等都对双重介质油藏的非稳态压力特征进行了深入的研究,其模型包括双重渗透介质和双重孔隙介质[1~6];姚军等对三重介质油藏的非稳态压力动态进行了分析,并在分析地质情况的基础上,建立了各种试井解释模型[7~13];但对于各种介质具有不同的渗透性时,非稳态压力特征之间的差异的研究,尤其是当多重渗透介质存在时的情况,还比较少见。本文在以上研究的基础上,对多重介质油藏中各种介质渗透性不同时的压力动态曲线特征进行了深入分析。

## 曲线特征分析

在双重介质或者多重介质、抑或是多层油藏的试井时,若存在两种以上的介质或两层以上的油藏都具有一定的渗透性时,可以称其为双重渗透或多重渗透介质。当进行试井测试时,若井筒存储较小或不存在,或者采用井下关井技术时,在其测试数据的半对数曲线上,会出现多条似乎平行的直线段,以双重渗透介质为例(见图 1)。

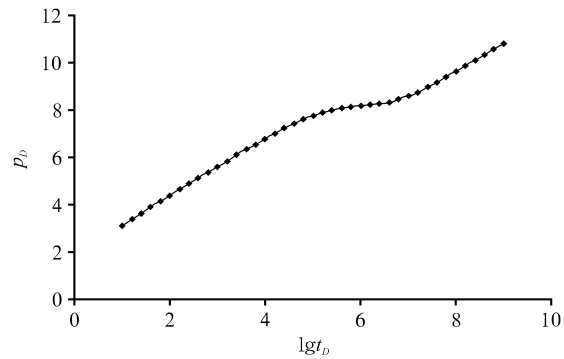


图1　双重渗透介质压力半对数曲线

若压力在半对数图上呈直线特征,则有

$$p_D = m\lg t_D + b \tag{1}$$

式中:$m$ ——斜率;

$b$ ——截距。

对(1)式关于 $\lg t_D$ 求导,则

$$\frac{\mathrm{d}p_D}{\mathrm{d}\lg t_D} = m \tag{2}$$

由于 $\lg t_D = \frac{1}{2.303}\ln t_D$,则有

$$\frac{\mathrm{d}p_D}{\mathrm{d}\ln t_D} = \frac{\mathrm{d}p_D}{\mathrm{d}t_D}t_D = p_D' t_D = \frac{m}{2.303} \tag{3}$$

在理论数据的半对数曲线上,径向流直线段的斜率为 1.1515,可以得到

$$p_D' t_D = \frac{m}{2.303} = 0.5 \tag{4}$$

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对上面的数据做压力导数的双对数曲线,并和双重孔隙介质进行对比(见图 2),由于在双重孔隙介质中只有裂缝渗流,所以其早期径向流阶段和晚期径向流阶段在该曲线上有两条水平线段。

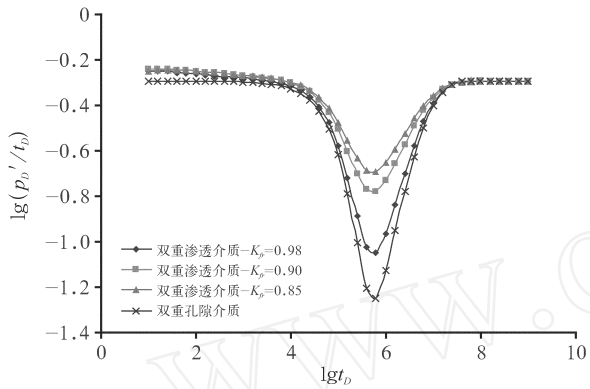


图2　双重孔隙和双重渗透压力导数双对数曲线对比图

由图 2 可以看出,几条导数曲线的后期径向流阶段的水平段完全重合;而在早期阶段,只有双重孔隙介质曲线上形成了水平线段,而双重渗透介质则形成了斜线,由此可以知道,双重渗透介质测试数据在该段半对数曲线上并非一条真正的直线(见图 3,图 4)。

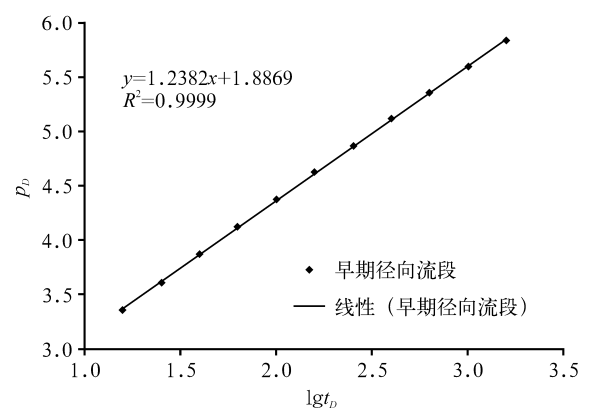


图3　双重渗透油藏早期径向流段线性回归

由图 3 和图 4 可以看出,双重渗透介质油藏早期几乎出现径向流直线段,其 $R^2$ = 0.9999,斜率为 1.2382;而后期则完全出现径向流直线段,$R^2$ = 1.00,斜率为 1.1515;可以看出,早期"直线段"的斜率明显的大于后者,所以若采用早期"直线段"对地层求参数,得出的解释结果偏小。

而对于溶洞 —井筒连通三重介质油藏,由于假设只有溶洞参与渗流,所以在早、中、晚期都可以形成径向流;而缝洞 —井筒连通三重介质的压力半对数曲线和压力导数双对数曲线与溶洞 —井筒连通三重介质模型相比,其差异类似于双重渗透介质和双重孔隙介质模型(见图 5,图 6)。

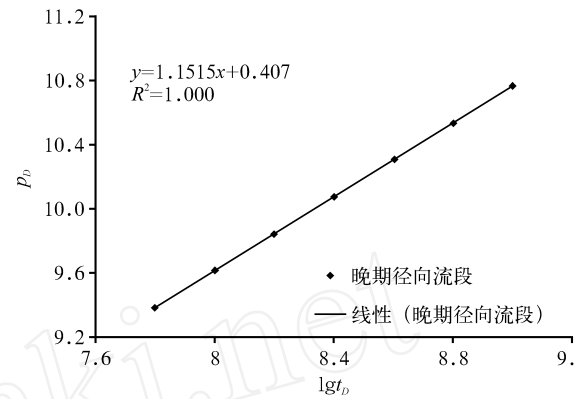


图4　双重渗透油藏晚期径向流段线性回归

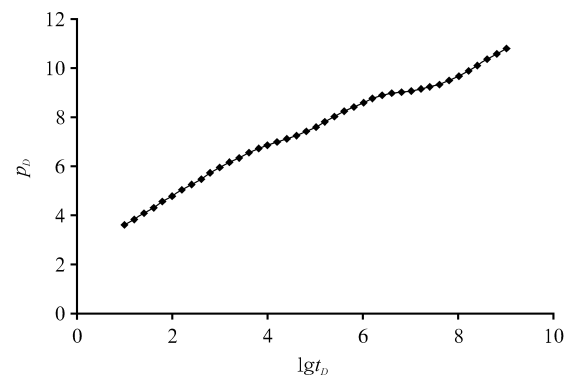


图5　缝洞—井筒连通三重介质压力半对数曲线

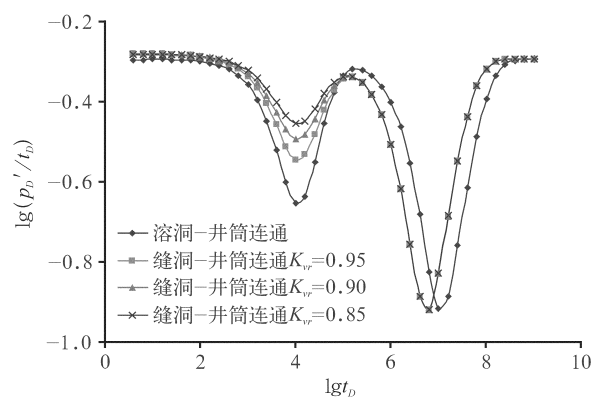


图6　溶洞—井筒连通和缝洞—井筒连通压力导数双对数曲线对比图

由图 5 和图 6 可以看出,在半对数曲线上三条近乎直线的部分,双对数导数曲线的对比可以发现,除了后期因窜流系数不同而引起的差异外,在早期阶段也出现了类似于双重孔隙介质和双重渗透介质之间的差异。

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运用类似的处理方法,可以进行等时试井与修正的等时试井,并做出相应产能方程。

## 结　论

1. 在高温高压凝析气藏测试过程中,当储层出现反凝析后,储层的渗透率和表皮等影响气井产能方程的主要储层参数都可能发生大幅变化,引起产能方程系数 $A$、$B$ 大幅变化,致使理想的干气产能方程不再适用于高温高压凝析气藏的产能试井解释和评价。

2. 高温高压凝析气藏产能方程应该是随渗透率等参数变化的变系数的表达形式,或是针对测试状况建立多个反映测试状态的独立的产能方程。这种产能方程能够反映气藏测试或生产状态特征,能够体现储层岩石物性与流体流动特征变化的四维性。因此,可以较准确地预测未来的生产状况。

3. 高温高压凝析气藏产能方程可以采用分压力段建模。即对多点测试中的相邻两点数据求出该测试状况下的斜率 $B$ 与截距 $A$,则可以建立多个独立的反映该测试状况下的产能方程。从而,对于不同生产阶段的高温高压凝析气井进行产能评价。

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## 结　论

当多重介质油藏中有两种或者两种以上的介质具有渗透性时,只有在系统径向流阶段的压力才会在半对数曲线上出现直线段,而半对数曲线上早期所谓的直线实际上是曲线,只是比较接近直线而已,所以不能用来准确的估算地层参数;若采用前一径向流段对渗透率进行估算,得到的结果将会偏小。

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# Abstracts

## ·Research of Theory & Method·

**The Feasibility Analysis of Well Test Design in Ultra-Low Permeability Reservoirs**. 2009, 18(1): 1～4

*Ma Sujun, Cheng Shiqing* (*CMOE Key Laboratory of Petroleum Engineering, China University of Petroleum* (*Beijing*)), *Zhao Jiyong, Chen Jianwen, He Yonghong* (*Changqing Oilfield Company*)

For solving the problem about how long the test in ultra-low permeability reservoirs should last, a method for judging whether the induced fracture of a well is closed is obtained by systematic well test design calculation firstly; then another method for determining the start-up pressure gradient in ultra-low permeability sandstone reservoirs by index curve analysis is provided; and, the feasibility and feasible working system for design of interference or impulse test in ultra-low permeability reservoirs are discussed in detail. The study indicates that systematic well test and impulse test can be run successfully in low or ultra-low permeability reservoirs, and by which the start-up pressure gradient and the parameters about connection between wells can be obtained.

**Key words**: ultra-low permeability reservoir, well test design, systematic well test, interference well test

**Pressure Derivative Type Curves of Swabbing Well in Heterogeneous Oil Reservoir**. 2009, 18(1): 5～6

*Liu Hong, Wang Xinhai* (*Geo-Science College of Yangtze University*), *Li Yujiao, Sun Jijun* (*Tarim Oilfield Company*)

Test model of swabbing well with well bore storage and skin effects in heterogeneous oil reservoir, under the condition of constant flow rate, has been built by numerical well test, and the mathematics problem of the model is solved by block-central-grid network, dispersing and software. The calculated pressure data are analyzed by log-log analysis of pressure derivative, and the pressure derivative type curves for swabbing well in different heterogeneous oil reservoirs under the condition of constant flow rate are obtained.

**Key words**: swabbing well, heterogeneous oil reservoir, numerical well test analysis, pressure derivative, type curve

**Comprehensive Study of Calculation Method about Fracture Pressure of a Well in Tight Reservoir in West of Sichuan Province**. 2009, 18(1): 7～9

*Yan Changhui* (*State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation*), *Chen Qing, Zhou Wen* (*Chengdu University of Technology*)

Xujiahe reservoir in West Sichuan is a deep and tight gas reservoir with low porosity, low permeability and high formation pressure. Fracture operations were conducted in 5 wells and 3 of them were failed. The highest bottom hole operating pressure is 159.6MPa. High fracture pressure affects the fracture stimulation. So it is necessary to calculate fracture pressure. Fracture pressures in 3 typical wells are predicted by integration of three methods, i.e. Eaton method, measuring method and log analysis, the results show that the fracture pressures of those 3 typical wells are in between 147.0 MPa and 163.7 MPa; and log analysis is convenient and easily popularized to predict the fracture pressure.

**Key words**: fracture pressure, Eaton method, fracture operation, log analysis, tight reservoir

**Analysis of Characteristics for Transient Pressure of Multi-Permeability Reservoirs**. 2009, 18(1): 10～11, 15

*Wang Zisheng, Yao Jun* (*China University of Petroleum*)

Several straight lines will appear at semi-log curve for transient pressure of the wells in multi-media reservoirs. The curves are different due to different permeabilities of the media. The theoretical study and the research of characteristics of curves show that several parallel straight lines appear at semi-log curve for transient pressure of the multi-media reservoirs only when flow happens only in one medium, and when flow happens in more than one medium, there is only one semi-log straight line appearing in the radial flow period in the last media, and in all other periods no straight lines appear.

**Key words**: multi-media, transient pressure, well test interpretation, semi-log curve

**Design of Working System and Differential Pressure for Well Test in Condensate Gas Wells With High Temperature and High Pressure**. 2009, 18(1): 12～15

*Shi Juntai, Li Xiangfang, Sui Xiuxiang, Liu Hua* (*CMOE Key Laboratory of Petroleum Engineering in China University of Petroleum*), *Zhu Libin* (*Well Testing Company, Huabei Oilfield*)

During well testing in condensate gas reservoir with high temperature and high pressure, after retrograde condensation appearing in reservoir, main reservoir parameters such as permeability and skin factor etc. influencing on deliverability equation of gas well will probably vary seriously, and so causes deliverability equation of ideal dry gas not suitable for that of condensate gas well with high temperature and high pressure. To deal with this kind of problem in condensate gas wells with high temperature and high pressure, several different models suited for different periods respectively should be built, and therefore several different deliverability equations suited for different periods respectively should be derived. These deliverability equations can describe characteristics of performance of the reservoir, reflect the physical properties of the reservoir and the variation of the fluid flow, and predict the performance more accurately.

**Key words**: high temperature and high pressure, condensate gas well, well test, working system, producting differential pressure

## ·Evaluation & Application·

**Application of Well Test Data in Oil or Gas Exploration and Reserves Calculation**. 2009, 18(1): 16～19

*Zhang Shaoli* (*Exploration and Production Company, PetroChina*), *Han Bin, Liu Yonghong* (*Well Testing Company, Huabei Oilfield*)

With well test data, not only early reservoir evaluation, but also geology reserves estimation for reservoir, especially for some very complicated reservoir, such as fissure reservoir, lithologic closed reservoir and fault block reservoir etc. can be done. By analyzing well test data of faulted