油气井试井资料的价值及作用

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摘要　油气井试井测试及解释是油藏工程研究的一个重要课题。通过试井解释可以获得储层参数,了解开发现状,制定增产措施。然而目前业界对试井资料的重视和利用程度远远没有达到预期的价值,大部分的试井资料存在着解释率低、利用率低的问题,不能有效反应出地层及生产信息,造成资源和资金的浪费。在论述油气井试井测试工艺和试井资料解释的重要性和应用前景前提下,提出试井资料存在的问题及其应用,达到提高油气井试井资料利用率的目的。

关键词　试井分析　试井数据　油气藏评价　试井的作用　试井的价值

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0　引　言

油气井试井资料分析方法的研究早在 20 世纪 40 ~ 50 年代就已经开始了。首先是不稳定试井解释理论和方法的研究,当时普遍使用半对数分析方法进行试井资料的解释,但是这类分析方法存在着局限性。直到 20 世纪 80 年代,基于压力及其压力导数典型曲线拟合解释图版的产生和应用大大地提高了试井解释的准确性和可靠性,根据地层流体不同的流动方式,对应不同的解释图版,从而得到更加准确的储层参数[1 - 3]。

在过去 30 年中,针对试井技术,国内外学者进行了大量测试和解释方法的研究,并且取得了较丰富的成果,包括一些特殊情况的试井资料处理方法,例如: 低渗透早期试井[4 - 7]和反卷积方法[8 - 10]。但是目前业界对试井资料的重视和利用程度远远没有达到预期的价值,大部分的试井资料存在着解释率低、利用率低的问题,不能有效反应出地层及生产信息,造成资源和资金的浪费。

因此,针对这一现状,本文旨在论述油气井试井测试工艺和试井资料解释的重要性和应用前景,达到提高油气井试井资料的解释率和利用率的目的。

1　试井资料存在的问题

油气井试井测试及解释是油藏工程研究的一个重要课题。虽然学者和油藏工程师已经进行了一定的研究,获得了夯实的理论基础[11],但是其应用仍旧存在较大的问题,试井资料普遍没有发挥出应有的价值和作用。通过对国内各大油田进行的服务并对其试井资料进行分析统计,认为目前国内各油田试井资料普遍存在的问题主要包括以下三个方面:

1.1　测试工艺的质量问题

这一方面的问题主要体现在测试仪器和测试工艺两个方面。测试仪器方面,主要是由于压力计测试精度较低,容易在连续时间点上获得相同的压力数据,体现在压力测试数据图上即为一段水平直线。另一方面,进行试井测试时,最好是压力计下入后稳定生产一段时间然后进行井下关井或井口关井测压。但在实际测试时,经常会出现关井后一段时间再下入压力计的情况,这样会造成关井后下入压力计前这段时间内压力数据缺失,而这段数据又恰恰是试井解释中最重要的信息。

1.2　油气藏储层特性的复杂性

试井解释的一大难点是结合地质构造信息获得相对准确的储层信息。但在实际试井解释过程中,不同的压力测试数据可能有相类似的双对数图,从而造成试井解释的多解性增大。因此,对储层地质构造足够的了解,准确地选择模型是进行油气井试井解释、获得准确储层参数的基础。

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1.3　井况及生产历史的复杂性

同样，除了储层地质构造的复杂性，井况引起的变井储效应和目标井生产历史也会造成试井解释的多解性。例如，变流量历史的井和定流量史的井就会得到不同的解释结论。又例如: 如果关井前生产时间比真实时间小会导致本该水平的压力导数，变成上翘的压力导数; 如果关井前生产时间比真实时间大则会导致本该水平的压力导数，变成下坠的压力导数。因此，对单井生产历史的掌握也会带领我们更快更好的进行油气井试井解释、获得储层参数。

由于这些原因的影响，造成目前国内各油田测试资料的解释率低，许多关键信息没有解释出来，试井曲线特征分析困难; 同时，测试资料的利用率也非常低，试井知识普及较差，即使试井资料解释出来，仍然无法实现有效地应用。

2　试井资料的主要应用

下面分别说明试井资料的常规应用和深化应用内容。目前业界测试公司或者测试队完成的试井解释内容一般情况下只限于下述的常规应用内容。为了提升试井资料的应用水平，建议油公司或者采油厂进行二次试井资料的精细解释，可以极大地挖掘试井资料的应用价值。下面分别说明试井资料的常规应用和深化应用的内容。

2.1　试井资料的常规应用

一般来说，试井测试分为稳定试井和产能试井，因此，通过试井的测试和解释，可以得到的信息主要包括: ①储层渗透率计算; ②地层压力确定; ③污染评价; ④裂缝半长和水平段有效长度评价; ⑤不渗透边界和河道宽度评价; ⑥诊断天然裂缝情况; ⑦动态储量计算(探边测试) ; ⑧产能评价(产能测试) 。

2.2　试井资料的深化应用

2.2.1　渗流特征研究

通过试井可以研究油水气运动规律及渗流规律。类似在实验室里做岩心实验，试井相当于把井周围的地层看成一个“大岩心”做实验。不同的试井技术探测的范围不同，其价值不同，但比岩心实验更接近实际油藏情况。例如: 从 RFT 和 MDT 井壁探针电缆地层测试(WFT) 、到穿套管地层测试器(CHDT) ，从开采初期的 DST 试井或者钻杆地层测试、到开采过程中的压力恢复试井，试井探测范围从几米到几百米，甚至上千米。过套管井壁打眼测试技术可以实现类似岩心流动实验的两端测压分析。

2.2.2　增产措施评价

利用试井资料判断措施效果主要有两种方法[12]: 一是定量分析，利用措施前后试井求出的油层物性参数，例如: 流动系数、表皮系因子和污染半径等进行对比分析; 二是定性分析，利用措施前后压力恢复曲线形态特征分析。

2.2.3　聚合物驱效果评价

试井资料可以全面地用于注聚合物效果评价，其中包括判断油水井间的整个地层堵塞和窜流[13]。

2.2.4　井间连通性、注采平衡分析与计算单井注采比

试井解释可用于进行注采平衡[14]，其中主要包括: ①利用一次试井资料进行注采平衡分析; ②利用多次试井资料进行注采平衡分析; ③利用一井组多口井的同期试井资料进行注采平衡分析。这也是一种判断井间连通性方法。

通过建立注水开发多井油藏中的一口生产井压力恢复分析方法，不仅可以解决受多井或邻井影响下的平均地层压力、流动系数和表皮因子等基本参数的求解问题，还求得到以往试井分析时无法得到的单井注采比[15]。

2.2.5　优势水流通道分析

通过试井曲线可以识别优势水流通道，试井解释的二次压力导数图(SLPD 图) (详见 Swift 试井分析软件模型诊断图) ，越过 1 线可以指示优势水流通道的存在。

2.2.6　水驱效果评价

运用试井资料描述和预测储能系数和流动系数可以用压力双对数曲线和压力导数曲线方法 。如果导数曲线中期偏离水平线，则说明测试层的动态参数发生了变化。它主要反映储能系数($\Phi C_t h$) 、流动系数(Kh/μ) 的变化。利用试井分析的储能系数和流动系数的预测可以确定油水前沿的位置及前沿的推进速度，预测前沿突破的时间，预测储层的动用状况。

2.2.7　指导调堵调剖工艺措施(确定层位)

通过试井不仅可以落实堵塞层位，而且可以落

实储层内部的高渗透通道,以便指导工艺措施。业界广泛应用 PI 指数决策技术就是基于注水井井口压降曲线计算所得的压力指数(PI)进行决策的,但属于试井技术的简单应用。实际上试井在调剖调驱方面可以有更大的用途,可以实时指导深度调驱措施,也就是可以建立一套边测边调边解释边决策边施工的一体化调剖工艺技术,实现注入井调剖工艺技术与测试工艺技术的充分地结合,达到可靠地实施调剖工艺措施。调前的压力落差测试资料,建立注水量和产液量之间的分析模型,对模型进行求解并验证,形成了利用动态数据评价井间连通的技术,对调前调后注水井压力测试资料进行分析可以落实可靠的调剖方式和配注量配方等。

2.2.8 试井在油藏描述中的应用(确定剩余油分布)

通过解析试井可以计算剩余油饱和度[16],通过数值试井可以计算剩余油分布。

2.2.9 合理配注量的确定

通过试井可以确定储层合层或者多层分层的渗流能力[17]和产能,以及确定相应层位的吸水指数和采液指数,进而可以实现单井配注量计算以及分层配注量计算。

2.2.10 合理井网井距的优化

通过试井可以确定测试井控制范围或者易流动半径,根据这个范围可以落实合理的井网井距[18]。

2.2.11 不稳定压力试井对管外窜流的诊断和描述

对于被不渗透地层隔离开的两个层系,测试层与临近层系,由于中间封隔区块受损导致的邻近层通过管外窜流到生产层,通过实测压力曲线的压力导数双对数图以及产量历史拟合图可以识别管外串流以及预估参数。窜流量作为时间的函数也可以通过计算封隔区的压力传导系数来进行估算。一般出现窜流,那么在产量历史拟合图上通过测试层与邻近层对总产量的相对贡献就可以判断出,根据压力导数双对数图可以得到受损区水泥层的传导系数,从而可以计算出管外窜流量[19]。另外,通过观察试井压力导数曲线特征变化可以诊断注水井套管外层间窜流与注水强度的关系[20]。

2.2.12 油井合理间歇开采工作制度优化

试井解释可用于油井合理间歇开采工作制度优化。通过试井资料对各单井压力恢复数据进行分析,并对不同工作制度下的产量进行模拟,最终可以确定合理间歇开采工作制度,笔者研究了一种方法已经在延长油田进行了应用。

3 结 论

试井资料在油田开发的关键指标计算方面具有重要作用,在一些关键决策方面是不可缺少的资料,是油藏内部渗透特征的直接证明资料。加强改进试井测试工艺可以提高油气井试井资料测试的精确性,进行二次试井资料解释工作可以极大地提升试井资料解释的可靠性和解释率,进而拓展试井资料的应用范围和应用效果,最终获得更高的经济效益。

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解释结果: $p_R = 42.18$ MPa，$K = 17.1$ mD，$S = 505$，$C = 0.91$ m^3/MPa，垂向与径向有效渗透率之比为 0.348。

2.4　试采测试

2.4.1　产能试井分析

2007 年 4 月 2 日 ~5 月 5 日系统试井测试，工作制度采用 4.76 mm、6.35 mm、7.94 mm、9.53 mm 回压试井方式(见表 1)。

表 1　不同工作制度下气井日产气量统计表

油嘴 (mm)	日产气量 ($10^4 m^3/d$)	流压 (MPa)	地层压力 (MPa)
4.76	10.78	38.86	42.03
6.35	16.06	35.89	42.03
7.94	22.24	31.88	42.03
9.53	26.43	28.13	42.03

经计算，该井的指数式产能方程为:

$$Q = 2650.77(p_i^2 - p_{wf}^2)^{0.668742}$$

无阻流量 $Q_{AOF} = 39.28 \times 10^4 m^3/d$。

二项式产能方程为:

$$\Psi(p_i) - \Psi(p_{wf}) = 0.0347994Q + 3.36281 \times 10^{-7} Q^2$$

无阻流量 $Q_{AOF} = 41.35 \times 10^4 m^3/d$。

2.4.2　压力恢复试井

2007 年 6 月 27 日 ~8 月 4 日，该井进行压力恢复试井，解释模型选用“变井储 + 部分射开 + 无限大模型”符合地质情况，解释中采用的产气层有效厚度仍取 100 m，气层射孔厚度为 49 m。解释结果: $p_R = 41.99$ MPa，$K = 12.71$ mD，$S = 220$，$C = 2.99$ m^3/MPa。

系统试井阶段，压力恢复试井得到表皮系数为 505。随着生产时间的持续增加，试采测试阶段，得到表皮系数为 220，有明显的解堵现象。这进一步说明，该地层污染堵塞十分严重。

3　结　论

(1) A 井火山岩储层物性好，渗透率高，厚度大，具备高产的物质基础。通过产能方程，计算平均无阻流量为 $40.32 \times 10^4 m^3/d$。

(2) 在模型诊断中应该结合地质情况，保证试井解释模型的正确。该井选择试井模型为部分射开模型，证明火山岩储层纵向上是连通的。试采测试解释地层压力为 41.99 MPa。

(3) 在试井解释时发现表皮系数非常大，对地层污染堵塞十分严重，应该严格执行平衡钻井或欠平衡钻井技术标准，并且缩短钻井周期。

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(上接 40 页)

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reservoirs are produced by multilayer or oil & gas production. There is a contradiction between the multilayer well, and it is easy to form fluid in the wellbore of the oil and gas wells. By testing and analysis to a well, it shows that the lower part of the well reservoir with smaller, the oil output from the upper reservoir, then deposit in the bottom hole, which result in abnormal pressure at the bottom of the well test curve. When the nozzle is gradually enlarged, increasing production, the lower reservoir contribution increased, carry out the most fluid in wellbore, which make the shut in pressure recovery tester lower than the value of the deliverability test pressure. It can determine reservoir contribution, provide a reliable basis for mining suggestions,when analysis of abnormal test pressure.
Key words: oil and gas production, multi-layer production, productivity, test

Application of Uncertainty Analysis for Reservoir Numerical Simulation in Well Test Interpretation. 2016,25(4):23 – 25
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Through the uncertainty analysis for reservoir numerical simulation, it can help to identify the reason causing buildup pressure curve abnormal shapes and sort the order of the influencing factors. The theoretical pressure buildup curve by numerical simulation can provide important guidance for identification of flow stage and improve the reliability of interpretation results. By means of combination of numerical simulation and well testing interpretation,the value of poorer quality of the test data can be fully excavated which can provide new method to resolve the problems about abnormal curve shapes and the radial flow stage not occurring by poor quality of the test curve during well testing interpretation.
Key words: abnormal curve shape, well testing interpretation, reservoir numerical simulation, uncertainty analysis, theoretical pressure

Application of Binary Compound Storage Model in Well Test Interpretation for Halahatang Carbonate Rock. 2016,25(4):26 – 28,32
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The carbonate reservoir of Halahatang oilfield is high temperature and high pressure,whose fluid properties and flow mechanism are complex,well test curve of it has the characteristics of diversity,complexity and multiple solutions. Current commonly used analytical well test model includes double orifice and double permeability,radial composite type,all having certain limitations application. Binary compound storage model is point to a analytical well test interpretation model at where of a closed reservoir system after a half of seepage boundary, under the condition of quasi steady state flows to the second enclosed reservoir system,its interpretation results show that the "beaded" structure of the seismic interpretation can be connected to each other under certain conditions. According to the geological characteristics and the seismic data in the study area,the binary composite storage model has a good applicability in the region,which provides a reasonable dynamic parameters and the theory basis for dynamic development in the gas reservoir of this region.
Key words: binary compound storage model, carbonate rock, well test interpretation, Halahatang oilfield

Analysis of Influencing Factors on Productivity after Multistage Fracturing to Tight Oil of Horizontal Well. 2016,25(4):29 – 32
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The multistage fracturing has been an important technique to improve the productivity of low permeability reservoir and solve the problem of hard reserves producing, which has been widely used in oil and gas field exploration and development. How to optimize the setting of multi section cracks in horizontal wells, determines the selection about fracturing process and tool, eventually related to the effect of fracture. Taking the fractured horizontal well in rectangular reservoir as studied subject, on the basis of fracture morphology of horizontal well fracturing, the physical model and mathematical model of reservoir and fracture are established to which of the differential solution and programming has be done. The model is applied to predict the productivity of X, the result is in good agreement with real yield, confirmed that the established numerical simulation model is feasible. The mathematical simulation method is used to study the geological and engineering factors that affect the productivity of horizontal well. The effects of reservoir permeability, fracturing segment number, bottom hole flowing pressure, fracture half length and spacing on the capacity of the reservoir are analyzed, and fracture parameters for horizontal well fracturing are optimized, so as to better guide the design optimization of horizontal well fracturing, improve the efficiency and success rate of horizontal well fracturing.
Key words: multistage horizontal well fracturing, numerical simulation, capacity influencing factors, fracturing optimization

A Successful Attempt of Using Well Testing to Verify Casing Channeling. 2016,25(4):33 – 35
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Y16x is a well at the structure high of X structure in Fushan oilfield, whose cement bond log is interpreted as poor bonding at pay zone. Then the conventional well testing is performed. The log-log curve of testing shows the signature of partial perforation. After comprehensive analysis, the conclusion has been drawn that the testing zone is not partially perforated and this signature is caused by vertical flow due to channeling behind pipe, which is very similar with the spherical flow caused by partial perforation mechanism. Combined with static data, this similar signature can be used to justify casing channeling. Then a channeling detection operation conducted later in well Y16x has verified that the channeling exists. This successful attempt promotes that well testing data could be used to find engineering problems and help to find solutions.
Key words: Fushan oilfield, cement bond quality, well testing curve signature, casing channeling

Discuss on Several Issues about Three Open Swabbing of Well Test. 2016,25(4):36 – 37
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For the low permeability reservoirs, the conventional well test process cannot obtain the ideal evaluation data, and three open swabbing is an important way to provide data of water-oil ratio, yield and liquid material in low permeability oil and gas layer. Through analysis and discuss on the applied scope of the three open swabbing and the practical application, it has a certain help to raise the quality of acquiring well test data.
Key words: well test, three open swabbing, acope of application, analysis and discuss

Value and Function of Oil & Gas Well Testing Data. 2016,25(4):38 – 40,43

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Well testing interpretation is an important subject in reservoir engineering. It can be used for obtaining reservoir parameters, as well as understanding development situation and making stimulation plans. However, the importance and degree of use are far less than the expectation, and most of the well testing data cannot be well interpreted, useful information about reservoir and production cannot be provided, which leads to the waste of resources and money. Under the basis of discussing the importance and further application of well testing process and interpretation, problems and its application existing in well testing data are presented in order to reach the goal of improving well testing interpretation quality.

Key words: well test analysis, well test data, reservoir evaluation, well test function, well test value

Applied Study on Well Testing Interpretation to A Well in Volcanic Rock Gas Field. 2016,25(4):41-43

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Through data interpretation and analysis on a well in D gas field of open hole test, well test, system well testing and production test, it is thought that the volcanic rock of this well has good reservoir physical properties of high permeability and large thickness and higher yield. Combined with geological condition, partial perforated model is selected to well test interpretation to prove that the longitudinal connectivity of the volcanic rock reservoir. The skin factor is very large, that shows the mud and killing fluid invaded the formation in the process of drilling and completion to cause the formation seriously pollution, which severely restricts the play of gas well's natural productivity. With the continuous increase of production time, skin factor gradually becomes smaller, having a clear solution blocking phenomenon. In the process of drilling, in order to avoid damage of the mud for volcanic formation, firstly, drilling cycle should be shortened, the mud soak time is lowered to reduce the chance of mud invasion formation. Secondly, balance drilling or under-balanced drilling technology standards should be carried out strictly.

Key words: stable well testing, unstable well testing, volcanic rock, well testing interpretation

Relationship to Optimize Shut-in Time and Flow Time in Well Productivity Testing. 2016,25(4):44-45

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Based on modern well testing interpretation theory, a relationship between permeability and combination of shut-in time and flow time in well productivity test has been derived. This relationship varies in different reservoir formations and requires longer both shut-in and flow time in relatively low permeability formation. By integrated with regional data, this relationship can help to determine an optimized shut-in time and flow time, hence to increase the efficiency of testing and reduce the risk of invalid testing.

Key words: productivity testing, flow time, shut-in time, permeability

· Field Technology ·

Successful Sand Fracturing on Deep/High Temperature Carbonate Reservoir. 2016,25(4):46-49

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Acid fracturing is the main naturally and effectively technology enhancing production for carbonate reservoir. For the deep/high temperature reservoir, because of the high formation temperature and big closure pressure, short distance of acid-rock reaction and not deep enough of effective fracture, most acid fracturing results , especially the stable production effect are not as good as expected. Sand fracturing technique, which is the mature conventional sand fracturing technology, is applied to high temperature deep carbonate reservoir, using technical routes including small diameter proppant, low damage fracturing fluid, sand concentration starting with a low point, smaller step, multi-step, controlling the highest concentration of pump injection program, sand fracturing technology has been success. After 10 years of follow-up study, it is showed that increased oil is 10.3 x 104 m3, natural gas is 0.51 x 108 m3, and sand fracturing technology has obtained the good effect of yield and stable yield, which provides a new thinking and a way to increase production and transformation for high temperature deep carbonate reservoir.

Key words: high temperature, deep layer, carbonate reservoir, sand fracturing

Technique of Fishing Broken Slick Line in Ultra-Deep High H_2S High Pressure Gas Well and Its Application. 2016,25(4):50-52

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Fishing broken slickline in high H_2S and high pressure gas well has problems of the complicated distribution of broken slickline, being hard to estimate state of fish and to salvage, high production of gas well, high formation energy, being difficult to kill well, high H_2S content, and higher required standards of safety for both equipment and personnel. Techniques of combination of anti-H_2S wireline with slickline detector and combination of inner drags have been developed to meet the need of fishing broken slickline in well bore by considering the broken feature and down-hole conditions. Moreover, direct kill well with solid-free well control fluid, kill well in conjunction with tank, and monitoring on real time well, could satisfy the requirement of cleaning and safely controlling well. Anti-H_2S equipment has to be used for safety issue. Application of integrated procedure in well YB121H solved the problem of fishing broken slickline in this high pressure high H_2S well successfully l.

Key words: ultra deep gas well, high pressure, H_2S, slick line, fishing, well control

Application of Sectional Fracturing Technique with Coiled Tubing and Bottom Packer in Dongsheng Gas Field. 2016,25(4):53-55

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Dongsheng gas field belongs to low-porosity and low-permeability reservoir and requires fracturing treatment for industrial gas. In early stage, the sectional fracturing treatment with open hole packer gained some effect but the less pertinence of fracturing cannot satisfy the require of fracture-height controlled fracturing in He2 section. The sectional fracturing technique with coiled tubing and bottom packer, with its sand blasting perforation, annulus sand fracturing, bottom packer and mechanical accurate positioning, is characterized by multiple stages fracturing by only one string trip. The operating principle of this technique, tool set and procedures has been illustrated, and the successful implement of it provides a new and effective method for multi-stage hydraulic fracturing of horizontal wells.

Key words: Dongsheng gas field, horizontal well, coiled tubing, bottom packer, staged fracturing

Application of Intelligent Water Zone Identification and Water Shut-off in Horizontal Wells in Bohai Offshore Oilfield. 2016, 25(4):56-57