涩北气田气井产能试井分析及其在防砂效果评价中的应用

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摘　要　使用二项式产能解释模型、指数式气井产能解释模型、一般单点法气井产能解释模型、指数式单点法气井产能解释模型和二次单点法气井产能解释模型,分别对涩北气田气井产能试井资料进行解释与对比,筛选了适合于涩北气田的气井产能试井解释模型。利用防砂气井措施前后的产能试井资料拟合得到 IPR 曲线,评价了涩北气田 80 井次的防砂措施改善井底流动条件的效果,其评价结果与气井生产动态分析结果比较一致,具有较好的可信度,为涩北疏松砂岩气藏防砂效果评价找到了一种新的手段。

关键词　涩北气田　气井　试井　生产能力　防砂　评价

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1　气井产能试井解释模型

产能试井测得不同井底流压下的气井产量,通过解释分析可拟合 IPR 曲线并计算出无阻流量等参数,目前产能试井解释模型主要有以下 5 种[1-4]。

1.1　二项式产能模型

气井产能方程的二项式形式为:

$$p_r^2 - p_{wf}^2 = AQ_{sc} + BQ_{sc}^2 \tag{1}$$

式中:p_r 为平均气藏压力,MPa;p_{wf} 为井底流压,MPa;Q_{sc} 为地面标况下产气量,$10^4\ m^3/d$;A、B 分别为回归系数。

在使用产能试井资料 A、B 系数进而计算 IPR 曲线时,如果未知地层静压,需要首先根据测试资料先求出地层静压,然后再拟合系数 A、B。

绝对无阻流量(Q_{AOF})为:

$$Q_{AOF} = \frac{-A + \sqrt{A^2 + 4B(p_r^2 - 0.101^2)}}{2B} \tag{2}$$

1.2　指数式气井产能解释模型

Rawlins 和 Schelhardt 根据大量气井生产数据总结出气井产能方程的指数形式为:

$$Q_{sc} = C(p_r^2 - p_{wf}^2)^n \tag{3}$$

当 $n=1$ 时,气流入井相当于层流,井底没发生与流量相关的表皮系数,完全符合达西渗流规律;当 $0.5 < n < 1$ 时,表示气流入井符合非达西流动规律。

实际矿场应用中,根据指数方程直接计算 C 系数的做法很少。一般是根据系统试气或生产测试资料反求系数 C 和 n。对指数式产能方程两端取对数,使用一组 Q—p 资料的线性回归关系曲线,利用回归直线的斜率和截距可计算参数 C、n,进而绘制 IPR 曲线和计算绝对无阻流量。

$$Q_{AOF} = C(p_r^2 - 0.101^2)^n \tag{4}$$

1.3　一般单点法气井产能解释模型

一般单点法气井 IPR 模型为:

$$Q_{sc} = Q_{AOF}\frac{1}{6}\left[\sqrt{1 + 48\left(1 - \frac{p_{wf}^2}{p_r^2}\right)} - 1\right] \tag{5}$$

如果已知地层静压为 p_r,则方程中只有一个待定系数 Q_{AOF}。分别将测试数据点代入可线性拟合得到绝对无阻流量(Q_{AOF})。

1.4　指数式单点法气井产能解释模型

指数式单点法气井 IPR 模型为:

$$Q_{sc} = Q_{AOF}\left[1.0434\left(1 - \frac{p_{wf}^2}{p_r^2}\right)^{0.6594}\right] \tag{6}$$

1.5　二次单点法气井产能解释模型

二次单点法气井产能 IPR 方程为:

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$$Q_{sc} = Q_{AOF}\left[1.8\left(1 - \frac{p_{wf}^2}{p_r^2}\right) - 0.8\left(1 - \frac{p_{wf}^2}{p_r^2}\right)^2\right] \tag{7}$$

2　气井产能试井解释及模型筛选

目前涩北气田对于防砂井进行了大量的产能试井,得到了大量试井资料。使用上述 5 种模型分别对试井资料进行解释,分析其相关性,进而筛选合适的结束模型。以涩北气田涩 2-4 井为例进行试井解释和分析,该井在 2005 年 5 月 19 日防砂前和 2005 年 7 月 19 日防砂后分别进行了产能试井,试井数据如表 1 所示。

使用这 5 种方法对该井的试井资料进行解释分析并绘制气井的流入动态曲线,二项式模型在计算过程中由于有开方计算,在这两组数据进行计算过程中出现负值,不能正常进行计算,后 4 种模型计算得到的 IPR 曲线如图 1 所示。

表 1　涩 2-4 井两次产能试井数据表

2005 年 5 月 19 日产能试井				2005 年 7 月 19 日产能试井			
气嘴(mm)	气量(10^4 m^3/d)	流压(MPa)	静压(MPa)	气嘴(mm)	气量(10^4 m^3/d)	流压(MPa)	静压(MPa)
3.0	1.617 6	11.355 9	11.541 0	3.0	2.148 0	11.315 0	11.628
4.0	2.610 7	11.204 9	11.514 8	4.0	2.555 1	11.167 0	11.704
4.5	3.281 4	11.100 9	11.488 9	4.5	3.153 6	10.960 0	11.690
5.0	3.843 4	10.989 9	11.465 9	5.0	3.762 3	10.765 0	11.677
5.5	4.797 8	10.821 0	11.445 9	5.5	4.508 6	10.517 7	11.655

由图 1 可以看出不同的模型计算拟合出的IPR曲线不同,无阻流量的计算结果也不同,IPR曲线与横坐标的交点处即为无阻流量,不同计算模型中所计算出的回归系数,无阻流量及模型与实际数据点的相关系数如表 2 所示。

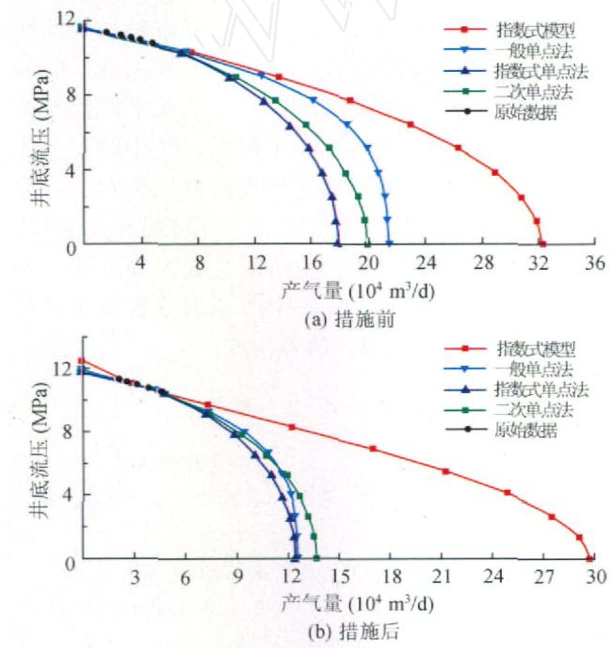

图 1　涩 2-4 井防砂措施前后流入动态曲线图

由计算结果可以看出成功计算的 4 种模型中指数模型的相关系数较低,一般单点法、指数式单点法和二次单点法的相关系数都比较高,说明对于涩北气田这 3 种模型的拟合效果较好,在进行产能试井解释时应优先选用这 3 种计算方法。使用其余 15 井次的产能试井资料解释并对比相关性,验证了上述结论。

3　产能试井分析在防砂井效果评价中的应用

涩北气田目前实施了 105 井次的防砂措施,对这些防砂措施进行客观准确的综合效果评价有利于总结成功的经验,探索失败的原因,进一步提高防砂效果。防砂措施对气井生产动态主要产生了挡砂作用、增产作用和改善井底流动条件作用。对应的防砂效果评价也分为挡砂效果评价、增产效果评价与改善井底流动条件效果评价3个层次。其中改善井

表 2　涩 2-4 井产能试井解释计算结果数据表

IPR 模型	2005 年 5 月 19 日产能试井			2005 年 7 月 19 日产能试井		
	回归系数	无阻流量(10^4 m^3/d)	相关系数	回归系数	无阻流量(10^4 m^3/d)	相关系数
指数式模型	0.35,0.92	32.311 20	0.892	0.02,1.51	29.671 21	0.889
一般单点法	18.006 9	18.006 17	0.958	12.493 8	12.493 27	0.955
指数式单点法	19.239 3	20.073 29	0.978	13.175 6	13.746 77	0.958
二次单点法	21.546 2	21.545 89	0.969	12.621 8	12.621 66	0.952

底流动条件效果评价可以真正体现防砂措施对气井生产动态的实质影响[5]。

根据防砂前后的产能试井资料计算出的无阻流量可计算相应的变化比,变化比的大小反应防砂措施改善井底流动条件的好坏。假设防砂前、后的气井无阻流量为 Q_{AOF0} 和 Q_{AOF1},则变化比(PI)为:

$$PI = \frac{Q_{AOF1} - Q_{AOF0}}{Q_{AOF0}} \tag{8}$$

气井无阻流量的变化比越大,防砂效果越好;反之,防砂效果越差。而气井的无阻流量需要根据产能试井资料解释气井流入动态关系曲线而得到[6]。

涩 4-9 井在 2003 年 9 月 28 日实施高压一次充填作业,并且分别在防砂前 2003 年 8 月 12 日和防砂后 2003 年 11 月 24 日进行了产能试井,对试井资料使用一般单点法、指数式单点法和二次单点法进行分析处理,得出措施前后的 IPR 对比曲线如图 2 所示。

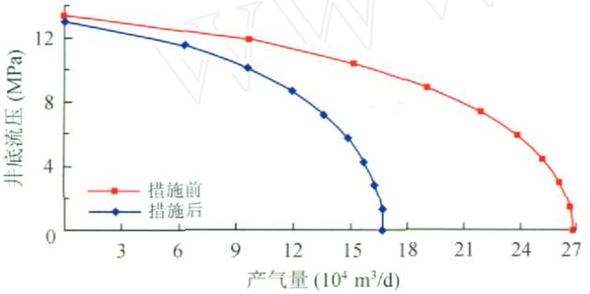

图 2　涩 4-9 井措施前后 IPR 对比曲线图

经计算该井措施前的无阻流量为 26.7 ×10^4 m³/d,措施后的无阻流量为 16.8 ×10^4 m³/d,无阻流量的变化比 PI = - 0.37。可以看出防砂措施后的无阻流量降低,说明措施增加了井底表皮系数,防砂效果差。

涩 3-7 井在 2002 年 10 月 12 日实施高压一次充填作业,并且分别在防砂前 2002 年 8 月 1 日和防砂后 2002 年 11 月 1 日进行了产能试井,对试井资料使用一般单点法、指数式单点法和二次单点法进行分析处理,得出措施前后的 IPR 对比曲线(图 3)。

经计算该井措施前的无阻流量为 20.2 ×10^4 m³/d,措施后的无阻流量为 31.3 ×10^4 m³/d,无阻流量的变化比为 0.55。可以看出防砂措施后的无阻流量增加,说明措施改善了井底流动条件,降低了表皮系数,防砂效果好。

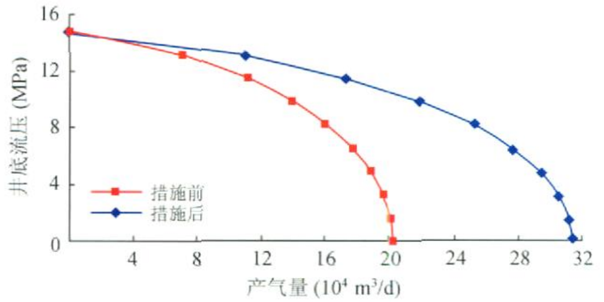

图 3　涩 3-7 井措施前后 IPR 对比曲线图

使用上述防砂措施效果评价方法,以产能试井资料解释为基础,评价了 80 井次的防砂措施改善井底流动条件效果,评价结果与气井生产动态分析结果比较一致,评价结果具有较好的可信度。

4　结论

通过使用 5 种主要的气井产能试井解释模型,分别对涩北气田气井产能试井资料进行解释与对比,筛选了适合于涩北气田的气井产能试井解释模型。适合于涩北气田气井的产能试井解释模型依次为一般单点法、指数式单点法和二次单点法。防砂效果评价也分为挡砂效果评价、增产效果评价与改善井底流动条件效果评价 3 个层次。其中改善井底流动条件效果评价可以真正体现防砂措施对气井生产动态的实质影响。以产能试井资料解释为基础,评价了涩北气田 80 井次的防砂措施改善井底流动条件效果,评价结果与气井生产动态分析结果比较一致,评价结果具有较好的可信度。

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analysis methods. Based on water source analysis, relative permeability curve was adjusted to fix the value of initial water saturation in the grid, the connectivity between gas and water layers, gas saturation of the boundary between gas and water layers were regulated to simulate and analysis on the water sources from gas wells in the Sebei gas field. In this way, the technology of water source identification can be improved in high accuracy so as to play an active role in preventing and controlling water breakthrough from gas wells in the Sebei gas field.

KEY WORDS: Sebei gas field, gas well, water breakthrough, water source identification, analysis

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The application of slicing technology in the Sebei gas field

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ABSTRACT: In view of the geological characteristics of long section and multiple producing layers of quaternary loose sandstone gas reservoirs in the Sebei gas field, the researches into the two-layer and three-layer slicing string, the technologies of matching testing and gas slicing production allocation optimization have been developed to achieve sand production prevention and production improvement of gas wells in loose sandstone gas reservoirs of this gas field, thus, forming a special highly-efficient gas production technology for the development of the Sebei gas field. The field application of slicing technology in 72 wells, involving technologies of separate production from casing and tubing, concentric integrated three-layer slicing, and eccentric running-pulling three-layer slicing, has decreased the interlayer span to the largest extent under the condition of pressure-control production, which not only favorably makes each gas layer's productivity into full play but also greatly improves single well productivity in the Sebei gas field.

KEY WORDS: Sebei gas field, slicing recovery, recovery method, test, production allocation

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A well test analysis of gas well productivity and its application in the evaluation of sand control in the Sebei gas field

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ABSTRACT: By using binomial, exponential, general single-point, exponential single-point and secondary single-point gas well productivity interpretation models respectively, interpretation and comparison of gas well productivity's well test data in the Sebei gas field have been done to screen out the suitable gas well productivity well test interpretation model for the Sebei gas field. The evaluation of sand control measures for improving bottom-hole flowing conditions of 80 wells in the Sebei gas field has been done by using the IPR curve that is obtained by productivity well test data simulation of sand-control gas wells. The evaluation results, in agreement with those of gas well production performance analysis, have higher reliability, thus providing a new approach for the evaluation of sand control effect in the loose sandstone gas reservoirs in the Sebei gas field.

KEY WORDS: Sebei gas field, gas well, well test, productivity, sand control, evaluation

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An analysis of coiled tubing sand washing operation in the Sebei gas field

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ABSTRACT: Sanding occurs easily during the production process in the Sebei gas field, so the sand must be washed out to release producing layers for resuming the normal production of a gas well. Due to low formation pressure, conventional sand-washing methods can easily cause formation pressure leakage, difficult reverse discharging and severe damage to formation, hardly achieving the purpose of improving production. After sand washing operation being carried out for 10 wells by using coiled tubing, the analysis of typical wells shows that the key to the sand-washing operation is to rationally control sand-washing displacement, wellhead pressure, pump fluid time, pump fluid volume and sand-washing speed to make the pressure sum of wellhead pressure, fluid/sand/gas column pressures and circulation pressure between tubing and coiled tubing annulus lower than bottom-hole formation pressure to let natural gas flow into shaft continuously, achieving the purpose of reducing formation damage. The study in this paper is of great guiding significance for the large scale coiled tubing sand washing operation of the Sebei gas field in the future.

KEY WORDS: Sebei gas field, coiled tubing, sand cleaning, production capacity, formation pressure

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The technical parameters of sand control by gravel packing in the Sebei gas field

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ABSTRACT: Based on large scale laboratory simulation experiment researches, using full-scale borehole sand production simulation experimental device, sand control simulation experiments were carried out in loose sandstone gas reservoirs of the Sebei gas field by different methods of sand control and under different parameters of sand control pipes. In addition, the evaluation