

松辽盆地致密砂岩气藏水平井多级压裂现场实践

——以长深 D 平 2 井为例

张 应 安

中国石油吉林油田公司采油工艺研究院

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摘 要 松辽盆地南部长岭气田下白垩统登娄库组致密砂岩气藏具有储层埋藏深、温度高、物性差、地应力高的特点, 采用水平井开发和常规的直井压裂开发均难以实现稳产。为最大限度地增加泄油气面积、提高储层动用程度、提高单井产量, 在长深 D 平 2 井开展了水平井多级压裂开发现场实践: 采用裸眼封隔器滑套 10 级大规模压裂, 优化应用压前小型压裂测试、井下微地震和地面电位法压裂监测技术, 对 10 级人工裂缝方位及几何形态进行实时监测。目前, 长深 D 平 2 裸眼井多级压裂工艺技术的突破, 创造了水平井深层气井压裂级数最多、压裂规模最大、平均砂比最高等 3 项中石油压裂新纪录, 并取得了“生产压力高、产量高”的良好效果。该井压裂施工的成功, 表明了水平井应用裸眼完井套管压裂具有明显的技术优势, 为类似长岭 1 号气田登娄库组致密砂岩气藏水平井压裂开发提供了有力的技术保障。

关键词 松辽盆地 长岭气田 早白垩世 致密砂岩气藏 水平井 多级压裂 实践

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1 储层地质特征

松辽盆地长岭 1 号气田下白垩统登娄库组天然气分布主要受岩性和构造控制, 气藏为构造控制下的岩性低孔特低渗气藏, 边底水不发育。

1.1 沉积相特征

D3 砂层组沉积期工区的南部发育两条由南东向北西展布并近于平行的分支河道, 并在长深 102 井附近汇合, 在中西部形成大范围的分支河道沉积, 随后分支河道再次分叉, 在中部形成分支河道的交汇叠合区。可以看出 D3 沉积期分支河道的沉积规模水流所控制的范围较大。

1.2 孔隙结构特征

登娄库组的孔隙结构具有排驱压力较高(平均 2.67 MPa, 最小 2.04 MPa, 最高 3.16 MPa)、平均孔隙半径小(分布在 0.11 μm 左右)、退汞效率低(一般介于 28.5%~35%, 平均 30.7%)、孔隙度及渗透率均低(平均孔隙度为 5.3%, 平均渗透率为 0.175 mD)。长岭 1 号气田登娄库组储层属于 II、III 类孔隙结构。

1.3 储层物性特征

登娄库组气藏的岩性主要为细砂岩、含粉砂细砂岩、粉砂质细砂岩和粉砂岩, 储层岩性以细砂岩为主。该气藏岩心分析孔隙度一般介于 2.7%~6.6%, 平均为 5.2%; 渗透率介于 0.04~0.242 mD, 平均为 0.174 mD, 登娄库组储层整体上属于低孔、特低渗储层。

1.4 储层岩石力学特性

登娄库组致密砂岩储层的杨氏模量较高, 而净压力与杨氏模量成正比, 杨氏模量高时, 净压力则较高, 且施工时地面压力较高; 缝宽与杨氏模量则成反比, 杨氏模量越高, 压裂时形成的裂缝宽度较窄, 尤其是在近井摩阻较高时容易出现砂堵^[1]。

2 长深 D 平 2 井压裂技术思路

通过对致密砂岩气藏多段大规模压裂改造, 最大限度地增加水平井筒与地层接触面积, 以提高储层动用程度, 最大限度地减少储层污染, 达到提高单井产量的目的^[2-4]。①应用水平井分段压裂工艺技术进行多级压裂, 增大储层平面上纵向接触面积; ②以增加缝长

作者简介: 张应安, 1964 年生, 高级工程师, 博士研究生; 现在吉林油田采油工艺研究院从事油气藏改造技术研究工作。地址: (138000) 吉林省松原市长宁北街 618 号吉林油田采油工艺研究院。电话: (0438) 6336591。E-mail: cyyzya@yahoo.com.cn

为主导的大规模压裂,增加储层平面上横向接触面积;
③在水平井趾部和跟部受多裂缝缝间干扰小、施工流动阻力影响较小的情况下,进一步提高规模,增加缝长,以获得对产能的最大贡献;④最大限度地降低储层伤害,保护气层。

3 长深 D 平 2 井压裂优化设计

长深 D 平 2 井压裂施工采用裸眼封隔器完井滑套多级压裂工艺技术,压裂设计重点针对施工压力高,压裂级数多、规模大,工具多、通过性差等难点进行了优化(图 1)。结合 4 个流动单元的储层特征,采用横切裂缝以增加面积,优化每段压裂规模,重点提高端部

和趾部压裂规模。优化施工参数(表 1),重点提高压裂液效率,减少储层伤害。

- 1)压裂规模:10 级分压,每段间距 66~156 m。
- 2)压裂方式:套管注入、投球。
- 3)井口施工压力:39.0~45.0 MPa。
- 4)压裂井口:主要包括大四通、105 MPa 采气井口(双控阀门)、压裂投球器 3 个部分。
- 5)裸眼封隔器工具尺寸:∅139.7 mm。
- 6)工具技术指标:耐压差 82.7 MPa,耐温 218 ℃。
- 7)压裂液:水基冻胶压裂液。
- 8)压裂支撑剂:粒径 0.3~0.6 mm 30~50 目的 105 MPa 孚盛砂。

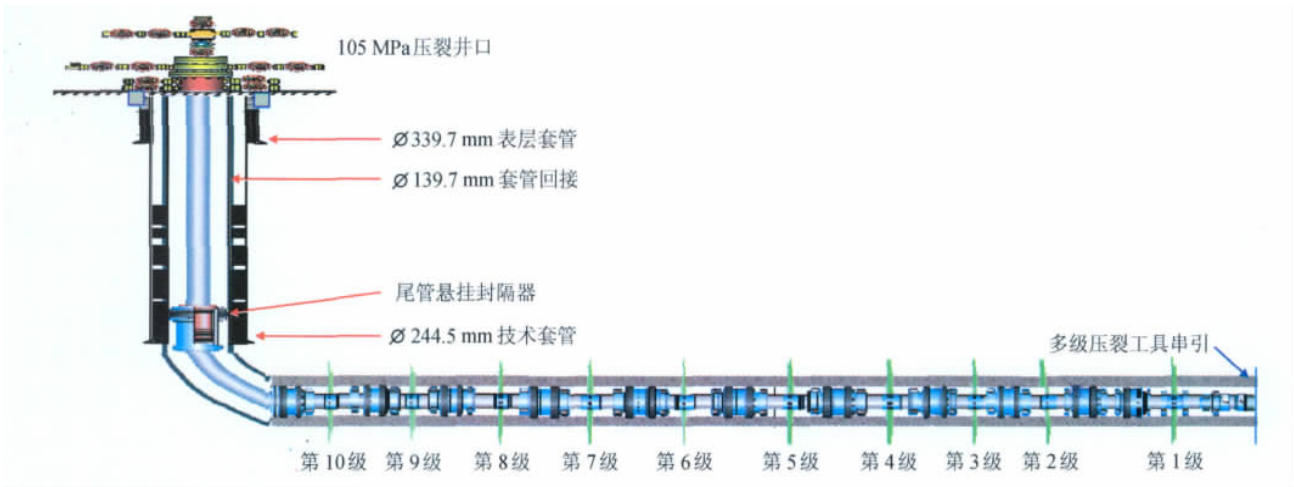


图 1 长深 D 平 2 井压裂工艺设计图

表 1 长深 D 平 2 井压裂施工参数设计表

参 数	1 级	2 级	3 级	4 级	5 级	6 级	7 级	8 级	9 级	10 级	总量
前置液/m ³	168	168	168	168	168	168	168	171	171	216	1 734
携砂液/m ³	246	246	246	246	246	246	246	255	255	324	2 556
液量/m ³	456.7	455.8	454.5	453.5	451.3	450.5	449.1	460.3	458.6	578.1	4 668
压裂砂量/t	107	107	107	107	107	107	107	111	111	139	1 110
平均砂比	29.40%	29.40%	29.40%	29.40%	29.40%	29.40%	29.40%	29.40%	29.40%	29.00%	
缝长/m	210	210	210	210	210	210	210	215	215	225	
缝高/m	71	71	71	71	71	71	71	71	71	70	
缝宽/m	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	
导流能力/D·cm	121	121	121	121	121	121	121	135	135	161	

4 长深 D 平 2 井多级压裂测试分析技术

1)应用压前小型压裂测试技术认识储层,调整主压裂施工参数(图 2)。

第 1、8、10 级小型压裂测试表明,储层存在较少的

天然裂缝特征,闭合应力为 58.6 MPa,基质渗透率为 0.15 mD,净压力为 2 MPa,压裂液效率为 38%,近井摩阻为 1.48 MPa。

2)利用井下微地震裂缝实时监测技术认识人工裂缝的扩展规律、裂缝几何形态及裂缝方位。

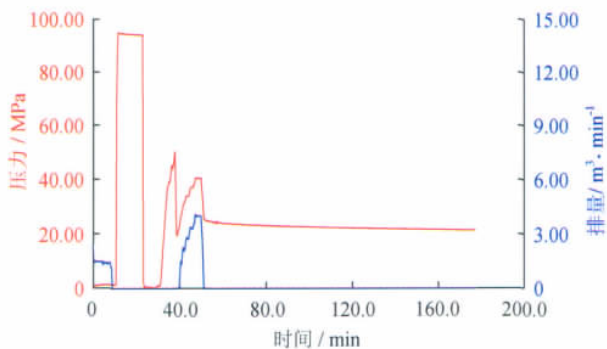


图2 长深D平2井小型测试施工曲线图

井下微地震裂缝监测表明,滑套位置对裂缝起裂位置没有影响,裂缝两翼扩展不对称,每级裂缝并不是完全平行,存在倾角,封隔器存在不能有效封隔储层的可能性。

5 压裂施工及效果

5.1 10级大规模压裂施工

长深D平2井压裂施工历时3 d,创造了中国石油压裂史上的3项纪录:①水平井深层气井压裂级数最多(10段);②单井总压裂规模最大(838 m³);③单级压裂规模最大(116 m³)(图3)。

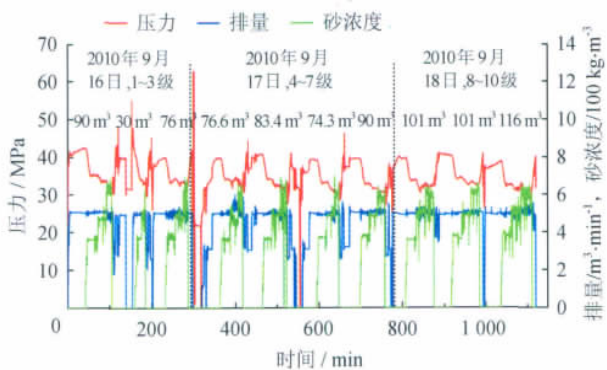


图3 长深D平2井压裂施工曲线图

- 1) 单井累计加入支撑剂 838 m³。
- 2) 水平井单段最大压裂规模 116 m³, 总计有 3 段压裂规模超过 100 m³。
- 3) 单日最多加入支撑剂 324.4 m³, 最快一天施工 4 段。
- 4) 平均砂比 34.4%, 最高加砂 1.8 m³/min。
- 5) 套管压裂降低 4 000 m 管程摩阻约 20 MPa。
- 6) 裸眼完井消除了固井完井近井摩阻, 滑套压裂减少了射孔孔眼摩阻, 共 10 MPa。

5.2 10级大规模压裂效果

长深D平2井多级压裂获得了巨大突破和成功, 取得了“生产压力高、产量高”的理想效果(表2)。

表2 长深D平2井排液求产数据表

油嘴/mm	井口压力/MPa	日产气/10 ⁴ m³
4	28.7	5.4
6	26.3	14.3
8	24.5	21.3
10	20.8	28.2
12	17.1	30.5

6 结论及认识

1) 该井水平井多级压裂取得 3 方面的技术突破: 压裂级数最多、压裂规模最大、平均砂比最高。

2) 水平井裸眼套管滑套分段压裂比直井固井射孔油管压裂具有较大优势: ①井筒摩阻小, 能实现高排量施工, 在相同加砂规模及砂比条件下, 缩短单级施工时间, 同时提高了压裂液效率; ②裸眼水平井套管分段压裂近井筒摩阻小, 基本不存在近井裂缝扭曲, 近井筒摩阻比常规直井固井射孔压裂相差 5~7 MPa, 同时裂缝复杂性小, 净压力在整个施工过程中变化不大。

3) 现场压裂实时监测能提供直观的裂缝扩展形态, 为压裂设计调整提供依据; 水平井裸眼滑套位置对裂缝起裂位置基本无影响, 裸眼封隔器位置的选择是关键。

4) 优质乳化压裂液体系和低密度孚盛砂有利于大规模压裂的顺利实施。

5) 该水平井多级压裂成功进一步认识了致密气藏的产能, 突破了产能关, 为类似致密岩性气藏提高产能明确了技术方向。

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NATUR. GAS IND. VOLUME 31, ISSUE 6, pp. 42-45, 6/25/2011. (ISSN 1000-0976; In Chinese)

Abstract: In recent years, the hydrocarbon exploration of reef and beach reservoirs is very successful on both sides of the "Kaijiang-Liangping" trough in the Sichuan Basin, with the discovery of many large gas reservoirs. Integrated interpretation of seismic facies and sedimentary facies plays a key role in the breakthrough of exploration of the Upper Permian bioherm and the Lower Triassic oolitic beach reservoirs. However, the exploration of the Lower Permian reservoirs of beach facies is still unsuccessful. Previous prediction of high-energy beach facies in the Lower Permian Qixia and Maokou formations was mainly based on geologic and logging data or through seismic inversion, and no research was performed on their seismic facies. Both the Qixia and Maokou formations are typical deposits formed on carbonate ramp which shows unique characteristics of seismic facies, thus integrated interpretation technique of seismic facies and sedimentary facies can be used to predict favorable paleogeography and sedimentary facies belts, and further to recognize zones with well-developed reservoirs of high-energy beach facies. The Lower Permian shows 3 major features of seismic facies, including the increase of reflection time-thickness; the increase of reflection events within the Lower Permian; and the obvious overlapping of the lower boundary of the Lower Permian on the Silurian. These three features of seismic facies are used to predict favorable areas for the development of high-energy beach reservoirs. The drilling results verify the accuracy of the prediction.

Key words: Sichuan Basin, west, north, Early Permian, seismic exploration, reservoir, oolitic beach, prediction

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Zhang Yanchong, senior engineer, born in 1959, has long been engaged in seismic interpretation of bioherm, oolitic beach and highly-steep complex structures.

Add: No. 1, Sec. 1, Huayang Avenue, Huayang Town, Chengdu, Sichuan 610213, P. R. China

Tel: +86-28-8297 5976 **E-mail:** zyc739@163.com

Multi-stage frac treatment in horizontal wells of tight sandstone gas reservoirs in the Songliao Basin: A case history of the horizontal well Changshen D2

Zhang Ying'an

(*Research Institute of Oil Recovery Technology, Jilin Oilfield Company, PetroChina, Songyuan, Jilin 138000, China*)

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Abstract: The tight sand gas reservoirs in the Lower Cretaceous Dengloulou Formation in the Changling Gas Field, southern Songliao Basin, are characterized by great burial depth, high temperature, bad petrophysical properties, and high in-situ stress, so steady production here is difficult to achieve by either horizontal well development or conventional vertical-well fracturing treatment. Therefore, in order to expand the oil/gas drainage area, improve the producing degree of pay zones, and enhance the per-well productivity, the multi-stage fracturing treatment was carried out on the horizontal well Changshen D2. Ten-stage large scale fracturing treatment was performed by use of external packer. The azimuth and geometry sizes of hydraulic fractures were real-time monitored through small pre-frac tests, downhole micro-seismic monitoring, and the electric potential. As a result, the horizontal well Changshen D2 has achieved good consequence with high productivity under high production pressure, by which three records have been set up in the PetroChina's history: the most multiple stages of deep fractured horizontal wells, the largest scale of per-well fracturing treatment, and the largest degree of single stage fracturing treatment. This achievement shows that this frac treatment by use of open-hole completion casings in horizontal wells has obviously comparable advantages, providing robust technical support for such frac treatment in the Dengloulou Formation tight sand gas reservoirs in the Changling-1 Gas Field.

Key words: Songliao Basin, Changling Gas Field, Early Cretaceous, tight sand gas reservoir, horizontal well, multi-stage frac, practice

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Zhang Ying'an, senior engineer, born in 1964, is studying for a Ph. D degree at the Daqing Petroleum Institute, being engaged in the research on fracturing technologies of hydrocarbon reservoirs.

Add: No. 618, North Changning Street, Songyuan, Jilin 138000, P. R. China

Tel: +86-438-6336 591 **E-mail:** zhangya-jl@petrochina.com.cn

Development and performance evaluation of a new efficient foam discharging agent LYB-1

Li Qianding, Lu Yongbin, Li Shanjian, Li Hengjuan

(College of Chemistry and Chemical Engineering, Xi'an Shiyou University, Xi'an, Shaanxi 710065, China)

NATUR. GAS IND. VOLUME 31, ISSUE 6, pp. 49-52, 6/25/2011. (ISSN 1000-0976; In Chinese)

Abstract: Liquid loading appears in most gas wells as many mature gas fields in China have entered the medium or post stage. As a result, regular foam drainage agent can not satisfy the requirement for natural gas exploitation. For this reason, the prime ratio is optimized by the orthogonal experimental design and a novel high-efficiency foam drainage agent LYB-1 is developed. The Ross-Miles evaluation method is used in laboratory tests. With the aid of formation water and condensate oil from the worksite, a systematic study and analysis is carried out on the capacities of foamability, unloading, temperature tolerance, oil resistance, methanol resistance, corrosion inhibition of the foam drainage agent and its compatibility with formation water. The test results show that this novel foam drainage agent has a good compatibility with formation water and a good corrosion inhibition. In addition, it is also proved to be environmentally friendly with a good temperature tolerance and a strong resistance of condensate oil & methanol.

Key words: foam drainage agent, methanol, condensate oil, corrosion inhibition, compatibility, preparation, evaluation, environmental protection

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Li Qianding, professor, born in 1959, is mainly engaged in teaching of basic chemistry and research of applied chemistry.

Add: No. 18, Dianzi'er Rd., Xi'an, Shaanxi 710065, P. R. China

Tel: +86-29-8838 2321 **E-mail:** qdli@xsyu.edu.cn

Application of plunger air lift in directional wells in the western Sichuan Basin

Dong Yaowen, Tan Mingwen, Zhou Xingfu

(West Sichuan Gas Production Plant, Sinopec Southwest Branch Company, Deyang, Sichuan 618000, China)

NATUR. GAS IND. VOLUME 31, ISSUE 6, pp. 53-55, 6/25/2011. (ISSN 1000-0976; In Chinese)

Abstract: Although plunger air lift is often applied in vertical wells, no such precedent cases have yet been found in directional wells at home and abroad. In view of this, plunger air lift tests were carried out in the ChuanXiao 601-4 well (with the maximum deviation angle of 38.49°) of a western Sichuan gas field. Through a good design of the length of tool string and operation procedures, down-hole equipments were installed successfully and the related technical parameters were optimized. After the installation of plunger air lift, the plunger operated normally, the differential pressure of tubing and casing pressure decreased obviously, and the production of natural gas was increased by $0.8 \times 10^4 \text{ m}^3/\text{d}$, which indicate that the drainage gas effect is significant and the test is successful. This first-time successful application shows that this technology is applicable in such a directional well with a deviation angle less than 40°. The application range of plunger air lift is thus extended and measures of water drainage and gas recovery are strengthened in gas wells of western Sichuan gas fields.

Key words: directional well, plunger air lift, drainage gas, parameter, design, optimization, Sichuan Basin

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Dong Yaowen, born in 1983, is mainly engaged in research of gas production technologies.

Add: No. 112, North Taishan Rd., Deyang, Sichuan 618000, P. R. China

Tel: +86-838-2400 632 **E-mail:** dongqinghappy@yahoo.com.cn

Adaptability analysis of horizontal well technology in the Tazhong-I Gas Field, Tarim Basin

Zhang Xuele¹, Li Baozhu¹, Zhang Shouliang², Fan Ru¹, Deng Xingliang³

(1. Petroleum Exploration & Development Research Institute, PetroChina, Beijing 100083, China; 2. Pet-