

# 大庆高台子油层闭合酸化技术

蒋建方

(中国石油勘探开发研究院廊坊分院, 河北廊坊 065007)

肖丹凤 王贤君 于景波

(大庆油田有限责任公司, 黑龙江大庆 163453)

**摘要** 闭合酸化技术是碳酸盐岩酸化压裂后, 对人工裂缝进行再改造的补救性措施, 通过解除对裂缝造成的伤害, 提高裂缝的导流能力, 增大扫油效率, 提高油井产量。针对大庆西部高台子复杂岩性地层的特征及水力支撑压裂情况, 进行了措施方案分析, 扩大了常规闭合酸化技术的应用范围, 提出了在水力支撑裂缝中进行酸化解堵的新观点, 研究了适应该地层的压裂液配方和酸化解堵剂, 现场进行2口井试验, 闭合酸化效果较水力压裂效果明显, 产量平均增加50%以上。

**关键词** 闭合酸 酸化压裂 支撑裂缝 压裂液伤害 导流能力

大庆西部高台子油层岩性复杂, 渗透率特低, 地质储量大。因无工业经济开发价值, 未得到有效开发。随着油藏改造技术的进步, 提出了对此类油藏的开发。以往对高台子油层进行了水力压裂和酸化解堵措施, 但效果不理想。分析认为, 应对该区先进行水力加砂压裂, 解决产量对低渗、特低渗油藏渗流规律的要求, 再通过酸化解堵, 解除压裂液对支撑裂缝和裂缝壁面基质的伤害, 形成先水力压裂再解堵酸化的新型闭合酸化技术。

## 1 储层的物性、岩性

齐家南地区高台子油层孔隙度主要分布在10%~15%, 平均孔隙度为12.2%, 渗透率主要分布在 $(0.1 \sim 0.5) \times 10^{-3} \mu\text{m}^2$ , 平均渗透率为 $1.18 \times 10^{-3} \mu\text{m}^2$ 。样品分散, 储层非均质性强, 使储层横向变化快, 连通性差。该区砂岩薄, 含泥含钙重, 泥质含量5%~30%, 钙质含量0~40%。粘土矿物以伊利石为主, 其次是绿泥石, 含少量伊蒙混层。取心分析古933井目标层碳酸盐岩含量为11%~16%。

以前对高台子探区进行过水力加砂压裂的油藏改造措施, 统计分析认为, 压裂施工规模较大, 施工水平不低, 但压后效果不好, 说明储层物性差, 存在压裂液和支撑剂破碎等造成的伤害。

## 2 措施方案分析

油藏改造措施主要是水力压裂、酸压和基质酸

化技术。大庆高台子油层碳酸盐岩含量低, 渗透率特低, 非均质性强, 横向变化快, 连通性差, 水力压裂技术是该油藏改造的主要措施。从该油层现场水力压裂情况看, 尽管施工工艺参数较高, 规模也大, 但效果不理想, 分析原因主要有2个: 一是储层物性差, 泥质含量较高, 对各种入井液造成的伤害很敏感, 因此认为以往压裂液对裂缝壁面的基质形成了伤害; 二是压裂液存在对支撑裂缝导流能力的伤害, 伤害程度一般大于30%, 严重时可达90%。所以在该区单纯采用水力压裂技术进行改造存在压裂液对人工裂缝和裂缝壁面基质的严重伤害。

闭合酸化技术通常是酸压动态缝闭合后, 向裂缝中注入一定量的酸液, 将破碎的、未起支撑作用的碳酸盐岩溶蚀掉, 增大裂缝的渗流能力。酸和氧化剂是植物冻胶很好的破胶剂, 能有效解除压裂液对支撑裂缝的伤害, 恰当配方的酸液又能解除压裂液对基质的伤害。因此形成了先进行水力压裂, 再进行酸化解堵压裂液伤害的新型闭合酸化技术。

## 3 压裂液及添加剂优选

### 3.1 稠化剂优选

植物胶是水基压裂液的主要稠化剂, 其性能主要以其增粘能力、交联能力和水不溶物多少来表征。通过对大庆采油工艺研究所送的4个样品进行评价, 认为3#稠化剂较好。稠化剂颗粒98%过120目筛网。稠化剂性能评价结果见表1。

表1 稠化剂性能评价结果

稠化剂	含水率/%	水不溶物/%	1%胶液粘度/mPa·s	pH值	交联性能
1#	9.05	18.42	312	7.0	良好能挑挂
2#	8.42	3.84	756	7.0	良好能挑挂
3#	6.70	14.5	312	7.0	良好能挑挂
4#	9.80	13.39	216	7.0	良好能挑挂

### 3.2 助排剂评价

助排剂通过降低处理液的表面张力和油水界面张力及增大与岩石表面的接触角,来降低处理液在地层流动中的毛管阻力,消除“水锁”效应,减少地层损害,提高压裂效果。助排剂性能评价结果见表2。由表2可知DL-8性能较好。

表2 助排剂性能评价结果

名称	用量/%	表面张力/mN·m <sup>-1</sup>
1#助排剂	0.1	27.44
	0.2	27.05
2#助排剂	0.1	28.74
	0.2	29.44
DL-8助排破乳剂	0.2	23.70

### 3.3 粘土稳定剂评价

粘土稳定剂的选择由粘土矿物含量和类型及水敏性强弱而定。氯化钾不仅具有良好的粘土稳定作用,还具有抑制或消除高pH值对储层碱敏性的影响。其评价结果见表3。由表3可知,应选用1.0%KCl或2.0%KCl。

表3 岩心膨胀试验结果(大庆混合岩心)

粘土稳定剂	膨胀量/mm
清水	0.236 00
0.5%KCl	0.001 14
1.0%KCl	0.000 61
2.0%KCl	0.000 38
0.5%BCS-851	0.000 75

### 3.4 交联剂的选择

主要选择稠化剂交联性能良好并适用于储层温度的交联剂。BCL-61有机硼交联剂有3大特性:①可控延迟交联作用,时间1~12min;②耐高温能力强,温度可达150℃;③易破胶,对支撑裂缝导流能力伤害小。因此选择该胶联剂为大庆高台子油藏压裂液体系的交联剂,可满足大规模水力压裂的要求。

### 3.5 破胶剂的选择

NBA-101胶囊破胶剂可达到延缓释放、保持粘度的目的,裂缝闭合后通过挤压可大量释放过氧化物,达到快速破胶的目的。在高台子油藏压裂液配

方体系中采用常规破胶剂与胶囊破胶剂相结合,可保证压裂施工过程中具有较好的流变性能和施工结束后良好的破胶性能。

### 3.6 pH值调节剂及其它添加剂

溶液pH值是影响植物胶溶胀、增粘和交联的重要因素。使用碳酸钠和碳酸氢钠缓冲体系控制胶液pH值,满足交联压裂液耐温能力的需要。高台子油藏储层温度90℃,应选用碳酸钠、碳酸氢钠和氢氧化钠为pH值调节剂。选甲醛为杀菌剂。

### 3.7 压裂液配方体系

基液:0.5%3#稠化剂+1%KCl+0.2%2#助排破乳剂+0.1%甲醛+0.1%Na<sub>2</sub>CO<sub>3</sub>+0.12%NaHCO<sub>3</sub>+0.05%NaOH;交联液:V(BCL-61A):V(BCL-61B)=8:1;交联比为100:0.3;在混砂车上追加NBA-101胶囊破胶剂和过硫酸钾。

## 4 酸液配方

酸液的主要作用是使交联液进一步破胶,溶解滤饼和消除滤液的危害,为此设计了如下酸化工作液配方。

前置酸:10%HCl+5%HAC+1.0%B125缓蚀剂+1.0%DL-8破乳助排剂+1.0%A-25粘土稳定剂+0.5%CA+75~100kg过硫酸铵

主体酸:10%HCl+5%HAC+0.5%~0.8%HF+1.0%B125缓蚀剂+1.0%DL-8破乳助排剂+1.0%A-25粘土稳定剂+0.5%CA

后置酸:5%~10%HCl+5%HAC+1.0%B125缓蚀剂+1.0%DL-8破乳助排剂+1.0%A-25粘土稳定剂+0.5%CA

顶替液:3%NH<sub>4</sub>Cl

## 5 单井设计、现场施工及其效果

金10井1997年5月17日进行了水力压裂,压后试油日产油0.25t,25d累计产油1.69t。分析认为该井有一定产能,但存在压裂液对裂缝和基质的伤害,需进行酸化。按照酸化优化设计,用酸量120m<sup>3</sup>,泵压在低于16MPa下尽量提高排量。现场施工中泵压下降了4.5MPa,排量由0.6m<sup>3</sup>/min增加到1.3m<sup>3</sup>/min。酸化后进行了返排和试油,试油一个半月,由初期的1.2t/d稳产到1.1t/d,达到了该特低渗储层所要求的工业油流,且产量是压裂后酸化前产量的4.4倍,效果明显。

古301井为新井。根据储层、压裂液和支撑剂

# 新型水玻璃单液法耐酸硬性堵剂

李启清 宋显民 马静荣 李占联 武明超 张瑞旺  
(冀东油田采油工艺研究所, 河北唐海 063200) (华北石油管理局井下作业公司, 河北任丘 062552)

**摘要** 概述了新型水玻璃单液法耐酸硬性堵剂的堵水机理、室内试验及现场应用情况。该堵剂克服了以往该类堵剂强度低、封堵率低、耐温性差等缺点, 因初凝与终凝时间长, 能确保带工具施工的安全, 同时添加剂的加入保证堵剂不突进, 形成堵塞较均匀, 强度高, 耐酸性好, 使用该堵剂可避免以后生产过程中对油井解堵施工需下封隔器保护堵层。该堵剂耐温性好, 有效期长, 粘度低, 既适用于油井封堵水层, 也可通过控制排量实现对底水油层选择性堵水。与其它堵剂相比施工压力低, 这对于套管强度低的老井和薄夹层油井堵水更有特殊意义。该堵剂还具有耐酸性, 可实现对层间矛盾突出的水井进行高渗层封堵和低渗层酸化增注, 达到调整注水剖面的目的。

**关键词** 新型水玻璃堵剂 化学反应 固化时间 溶解率 封层

冀东油田地质条件复杂, 断块破碎, 层间矛盾突出, 层段跨度大, 温度  $60 \sim 150^{\circ}\text{C}$ , 堵水难度大, 现有堵剂不能完全满足堵水工艺需要。以往的水玻璃单液法堵剂耐温性差, 强度低, 只适合于  $80^{\circ}\text{C}$  以下的油层堵水, 矿场应用受到限制。为发挥它成本低、货

源广、碱溶解性好的优点, 对水玻璃单液法堵剂做了进一步研究, 提出了水玻璃单液法的基本配方, 以满足  $60 \sim 150^{\circ}\text{C}$  油水井的堵水要求。

## 1 基本原理

等相关参数, 采用 Fracpro 软件进行了压裂优化设计和酸化设计, 裂缝半长 140m, 平均砂比 33%, 最高砂比 50%, 支撑剂平均  $14\text{m}^3/\text{层}$ , 排量  $2.6\text{m}^3/\text{min}$ ; 用酸量  $120\text{m}^3$ , 要求泵压低于 16 MPa 下尽量提高排量。该井先进行了水力压裂施工, 压后返排和短期产产。产量稳定后又进行酸化施工, 酸化后进行了返排和试油。压后稳定至日产油 2t, 达到了该特低渗储层对压裂作业所要求的工业油流; 酸化后试油至稳定日产油 2.8t, 是压后酸前产量的 1.4 倍。无论是压裂, 还是酸化, 效果都比以前有明显的提高。

## 6 认识与结论

(1) 高台子油层物性、岩性差是油藏改造措施效果差、常规压裂液对储层的伤害程度大的根本原因。

(2) 对特低渗储层的改造应坚持水力压裂寻求长缝的技术方向。

(3) 闭合酸化技术可作为水力压裂后产能低或产能下降快井的一种补救措施, 在酸液配方中增加

了破胶剂, 有利于解除压裂液的危害。

(4) 现场试验证明, 压裂液对地层的伤害较严重, 研制清洁压裂液并降低成本是压裂液研究的一个方向。

## 参 考 文 献

- [1] M J 埃克诺米德斯, A D 希尔, 金友煌译. 石油开采系统. 北京: 石油工业出版社, 1998: 312~320
- [2] Michael J. Economides 著, 康德泉等译. 油藏增产措施. 北京: 石油工业出版社, 1991: 228~232
- [3] 李道品. 低渗透砂岩油田开发. 北京: 石油工业出版社, 1997: 125~137
- [4] Michael W Conway, Robert D Barree. Hydraulic Fracture Stimulation Design and Well Performance in Non-Conventional Reservoirs. SPE 49 080. 1998: 421~429
- [5] W F J Deeg. High Propagation Pressures in Transverse Hydraulic Fractures: Cause, Effect, and Remediation. SPE 56 598, 1999: 467~474

(收稿日期 2002-10-18)

[编辑 姚晓喻]

**作者简介:** 李启清, 1993 年毕业于江汉石油学院, 2001 年毕业于石油大学(华东)油气田开发工程专业, 获硕士学位, 现在作业四区工作。  
武明超、张瑞旺分别为第 3、第 4 作者。

with viscous crude and crude oil of high freezing point, it is suggested to adopt in-situ heat fracturing liquids to avoid the cold damage to formation by injecting cold fluid. In-situ heat fracturing liquids are made based on common water-base fracturing liquids, with some  $\text{NaNO}_2$ ,  $\text{NH}_4\text{Cl}$  and  $\text{HCl}$  added into the base fluid. When the additives are mixed and react, much heat will give out. A mathematical model of wellbore temperature profiles during in-situ heat fracturing treatment based on heat-balance equation is established in this paper, and a computing software was developed. Finally based on a case history of Liaohu oilfield, the effect of surface injection temperature, injection rate and concentration of catalytic agent on concentration of heat-generation agents was investigated by means of orthogonalizing design technique, and developed optimization methods on concentration of heat-generation agents in in-situ heat fracturing treatment.

**Key words** In-situ heat fracturing treatment heat-balance equation wellbore temperature profiles concentration of heat-generation agents orthogonalizing design optimization methods  
**AUTOMATIC MATCHING MODEL AND METHOD FOR DETERMINING HYDRAULIC FRACTURE PARAMETERS**

Guo Dali, Zhao Jinzhou (Southwest Petroleum Institute), et al

**Abstract** The effect of hydraulic fracturing depends highly on the extent of understanding formation. In order to understand reservoir and evaluate the quality of fracturing treatment, considering fracture conductivity variation during producing process, a mathematical model that describes fluid unsteady flow in the formation and fracture is established, which is iteratively solved by means of utilizing the alternative direction implicit for solving flow models in formation and utilizing prediction-correction method for solving flow models in fracture. An optimization model of automatic matching production history to determine fracture parameters is put forward, which is solved by the sequential quadratic programming method. The credibility and applicability of these models and methods are proved by sample calculation.

**Key words** fracturing fracture parameter fracture conductivity automatic matching flow in porous media

**SKIN FACTOR PREDICTION OF FORMATION DAMAGE DUE TO ASPHALT DEPOSITION**

by Wang Weiyang, Zhang Gongshe (Jiashan Petroleum Inst.)

**Abstract** Asphalt deposition is one of the important causes for formation damage and production reduction. Asphalt deposition is affected by such factors as formation temperature and pressure, and their influences may be displayed through the solubility of asphalt in the crude. State equilibrium theory and Flory-Huggins theory of the asphalt solubility in the crude were used to investigate the solubility of asphalt in the crude oil in different pressure and temperature conditions. The theory proposed by Kumar, which is on how the suspending fines block the formation pores was applied to calculate the formation damage skin factor because of asphalt deposition. By studying the case history of asphalt deposition in Suizhong 36-1 Oilfield, it can be concluded that this prediction method is feasible.

**Key words** asphalt deposition formation damage skin factor equilibrium

**FORMATION PROTECTION IN ACID TREATMENT OF NIU 35 BLOCK**

by Ma Hongxing (Research Inst. of Oil Production Technology, Shengli Oilfield Ltd.), Xiao Chijun, et al

**Abstract** This paper represents formation protection and its results in low permeable sandstone acid treatment of Niu 35 block.

Simulated acid tests showed that acid treatment could effectively improve the core permeability in lab, but no effect in the filed acidizing. Through analysis of formation and its fluid propensity, low permeable sandstone acidizing, employing thin mud acid systems and optimum selection of acid additives, effectively prevented damage in low permeable sandstone acidizing and significantly improve the formation permeability of Niu 35 block.

**Key words** acid treatment formation damage prevention low permeability clay stabilizer anti-sludge agent cleanup additive emulsion preventative surfactant

**ENCLOSED ACIDIZING TECHNOLOGY IN GAOTAIZI RESERVOIR IN DAQING**

by Jiang Jianfang (Langfang Branch of Exploration and Development Inst.), Xiao Danfeng, et al

**Abstract** Closure acidizing is usually used in carbonate reservoir, which is a kind of remedy method to the formed acid etched fracture. Because the damage by the partially solved particles to the fracture is removed, the acid etched fracture conductivity and its efficiency are enhanced in order to finally enhance the oil production. The study, which to the feature of flexible mineralogical composition and the past hydraulic fracture of the Gaotai layer in the western Daqing Oilfield, analyzed the stimulation project, enlarged the application extent of the closure acidizing technology which gave the novel opinion about acidizing removed the damage by the fracture fluid in the hydraulic fracture, and study the fracture fluid and the acidizing fluid system formulations suit to the reservoir. Two oil wells have been stimulated in the closure acidizing technology, and the oil production after closure acidizing is higher 50% than that of hydraulic fracture. It is advised to further stimulate other oil wells to test this method and technology.

**Key words** closure acid acidizing fracturing supporting fracture fracturing fluid damage flow conductivity

**NOVEL ACID RESISTANT HARD BLOCKING AGENT MADE OF WATER GLASS BY SINGLE FLUID METHOD**

by Li Qiqing, Song Xianmin (Research Inst. of Oil Production Technology, Jidong Oilfield Co.), et al

**Abstract** The working mechanism, laboratory test and field using of a novel water glass blocking agent is described, and it is made of water glass using single fluid method. In contrary to the conventional blocking agent, which has poor strength, low blocking rate and poor temperature tolerance, the new blocking agent has many advantages. It has long initial and terminal setting time, which ensures the safety operation with tools in the hole. By adding a certain kind of additive, the blocking agent can form even blocking without onnushing, and it has higher strength and good acid resistance, this eliminates the use of packer for formation protection during plugging resolving operation. Further more, it has high temperature tolerance, long valid period and low viscosity, thus it is suitable for sealing the water zones and can also be used for selective water blocking to bottom water production zones by controlling pumping rate. As compared with other water blocking agents, it needs lower operation pressure, which is good for water blocking in the depleted wells with casing of low strength and in the wells with thin-bedded reservoirs. In addition, for wells of extensive inter-formation inconsistencies, the higher acid resistance of the blocking agent makes it possible to conduct water blocking operation to the high permeable formations and acidizing operation to the low permeable formations, thus realizes the aim of adjusting water injection profiles.

**Key words** water glass water blocking agent chemical