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# 低渗透油田压裂 注水 采油整体优化方法

闫建文<sup>1</sup>, 王群疑<sup>1</sup>, 张士诚<sup>2\*</sup>

(1. 大庆油田有限责任公司 采油工艺研究所, 黑龙江 大庆 163453; 2. 石油大学, 北京 100081)

**摘要:** 利用带有 0.3 ~ 0.8 mm 人工裂缝的三维两相油藏数值模拟模型、经济评价模型和整体优化软件, 对五点法和反九点法井网中人工裂缝与井排夹角为 0° 和 45° 的油藏开采进行动态模拟。根据油藏参数和开发要求实现对井网、压裂、注入、采出参数的整体优化, 进行多因素、多目标、多方案的优化决策。压裂、注水、采油整体优化方法在大庆朝阳沟油田长 42-10 区块应用, 取得了较好的效果。

**关键词:** 整体压裂; 注水; 采油; 数值模拟; 优化设计; 软件

中图分类号: TE348

文献标识码: A

低渗透油田合理开发方案的确定, 需要人工裂缝参数(缝长、方位、导流能力)、注入参数(井底压力、井口压力)和采出参数(井底流压)与地层的最佳匹配。本文通过整体优化方法来探索确定合理开发方案的有效途径。

## 1 低渗透油田合理开发整体优化方法的原理

根据低渗透油田的生产特点和人工裂缝的渗流特征, 在电解模型和平面物理模型实验的基础上, 建立油藏与裂缝耦合的物理和数学模型, 由人工裂缝和油藏之间的接触面满足压力相等和流量相等的原则, 建立裂缝和油藏之间的内边界条件, 通过五点法和反九点法井网单元的简化, 根据对称原理得到油藏的计算单元和外边界条件。五点法井网分为裂缝处于有利和不利 2 种方位, 反九点法井网分为裂缝和井排之间夹角为 0° 和 45°。

### 1.1 物理模型

(1) 五点法井网, 裂缝方位处于有利方位(图 1)和不利方位(图 2), 根据井网单元对称性和渗流场流线封闭的特点, 可取单元的 1/4 来代替整个单元来模拟。

(2) 反九点法井网, 裂缝方位与驱替方向成 0° 和 45° (图 3, 图 4)。

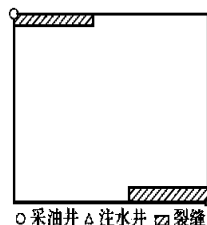


图 1 五点法井网裂缝处于有利方位

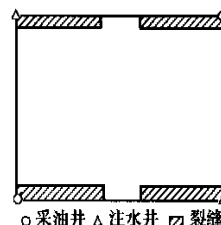


图 2 五点法井网裂缝处于不利方位

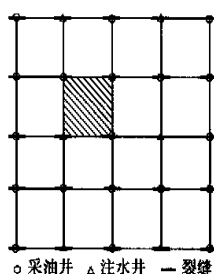


图 3 裂缝与反九点法井网井排成 0° 角

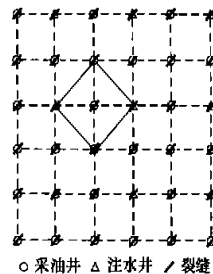


图 4 裂缝与反九点法井网井排成 45° 角

由于注水开发油田需要保持油层压力且低渗透油藏含气量少, 所以只考虑三维油水两相的流动, 并假设: 油层水平, 渗透率各向异性, 压缩系数保持不变, 油藏流体的粘度保持常数, 忽略重力和毛管力的影响, 油藏内部压力梯度很小。

由于水力裂缝的宽度很小, 研究水力裂缝时建立

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作者简介: 闫建文 (1967 - ), 男, 河北正定人, 工程师, 现从事采油工程研究工作。

\* 从事本项研究工作的还有大庆油田有限责任公司采油工艺研究所的谢朝阳, 于浩波, 薛凤云, 罗美娥。

二维两相模型, 并假设: 裂缝垂直、均质、各向同性、形状为长方体, 裂缝微可压缩, 裂缝中的流动为达西渗流, 不考虑裂缝随时间延长的失效性, 不考虑流体在缝宽方向上的流动, 只考虑缝长和缝高 2 个方向的流动。

油藏与裂缝耦合的数学连接模型为

$$Q_R = Q_F$$

式中  $Q_R$ ——油藏与裂缝之间的交换量;  $Q_F$ ——裂缝与油井之间的交换量。

## 1.2 数学模型

### (1) 确定评价指标体系

指标体系应选用最具有评价意义的指标作为依据。各项指标构成评价指标集:  $X_i = (i = 1, 2, \dots, n)$ , 对于整体优化, 评价的指标有: 第 30 天的产量, 第三年的产量, 最大采油速度, 最终采收率, 无水采收期, 无水采收率, 注水体积倍数, 净现值, 最大投资利润率, 投资回收期, 共 10 个 (即  $n = 10$ )。

### (2) 确定理想方案及各方案的满意度

所谓理想方案就是一个设想的最佳方案, 它的各个指标值都达到各候选方案中的最好值。用  $C_i (i = 1, 2, \dots, n)$  表示理想方案的指标参数。

若  $U = \{u_1, u_2, \dots, u_m\}$  是一个油气田的  $m$  个开发方案, 其中  $u_k = \{u_{k1}, u_{k2}, \dots, u_{kn}\}$ 。那么方案  $u_k$  的第  $i$  个指标相对于理想方案的满意度由 (1) 式给出为

$$h(u_{ki}) = 1 - \frac{|u_{ki} - C_i|}{u_{kimax} - u_{kimin}} \quad (1)$$

$$k = 1, 2, \dots, m; \quad i = 1, 2, \dots, n$$

### (3) 确定各项指标的权重

确定指标的权重采用层次分析法 (即特征向量法), 把  $n$  个指标作两两对比, 设第  $i$  个指标对第  $j$  个指标的相对重要性的估计为  $r_{ij}$ , 并近似认为这是指标  $i$  的权  $w_i$  与指标  $j$  的权  $w_j$  的比  $w_i/w_j$ 。  $n$  个指标比较的结果构成一个  $n \times n$  阶的判断矩阵, 表示为

$$R = \begin{pmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nn} \end{pmatrix} = \begin{pmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{pmatrix} \quad (2)$$

由上式可得:  $RW = \lambda_{\max} W$ , 式中  $\lambda_{\max}$  为矩阵  $R$  的最大特征值, 而  $w$  则为其对应的特征向量,  $w$  的各个元素则为相应指标的权重。

### (4) 模糊积分评价

对于一个开发方案, 当论域  $U = \{u_1, u_2, \dots,$

$u_n\}$  时, 设  $w_i (0 < w_i < 1, i = 1, 2, \dots, n)$  为其对应指标的权重, 且满意度有  $h(u_1) < h(u_2) < \dots < h(u_n)$  为单调序列, 此时评价价值 ( $\mu$ ) 为

$$\mu = \int_0^1 h(U) \cdot w(U) dU \quad (3)$$

用上式算出的评价价值的大小, 直接表征了该方案的优劣。

## 2 整体优化多目标方案设计

利用正交试验优化设计整体优化方案, 以减少数值模拟次数。在低渗透油田整体优化方案设计中, 如果裂缝方位一定时, 影响优化结果的主要因素有: 井网类型、井距大小、注采井裂缝长度、导流能力、生产压差和注水压差。根据生产实际, 每个参数取 5 个变化值, 采用 6 因子 5 水平的正交表设计整体优化方案。

## 3 整体优化软件

在单变量优化的基础上进行方案的整体优化设计。单变量优化研究井网类型、井网密度、注采井缝长比、水力裂缝导流能力、注水压差、生产压差等因素变化对油藏开发效果的影响程度, 做敏感性分析并优化出最佳值; 以不同经济指标为依据整体方案经济评价及多目标非线性的整体方案模糊决策为手段的整体优化设计, 则是单变量优化的最终归宿; 在单变量优化时, 可绘制相应的敏感性曲线、不同时间油藏区块的压力分布曲线及含水饱和度分布曲线, 为单变量的敏感性曲线变化给出渗流力学上的解释。

软件分为整体压裂油藏模拟子系统、注水子系统、采油子系统、整体经济评价决策子系统等 4 个基本功能模块, 各模块通过对数据进行不同的处理, 完成各自相对独立的功能。油藏数值模拟运算耗时长, 采用 Fortran 语言编写完成。数据的输入、结果的浏览、曲线的绘制、图表的生成、输出打印等采用 Visual Basic 5.0 简体中文版及 VBA for office 等语言编制完成。

## 4 现场应用实例

依据上述方法, 对长 42—长 10 区块进行设计, 进行不同参数组合, 共设计 20 个方案。

### 4.1 井网密度优化

压裂规模、注水井井底压力、采油井井底压力、导流能力相同的情况下, 对采用不同井网密度的方案进行对比 (表 1)。随着井网密度的减小油井见水时

间延长, 当井网密度为 300 m × 300 m 时, 油井的投资利润率最大, 见水时间最长, 4 号方案为最优方案。

表 1 井网密度优化方案

方案号	井网密度 (m × m)	初期产能 (m <sup>3</sup> /d)	3 年末产能 (m <sup>3</sup> /d)	投资利润率 (%)	见水时间 (d)
1	200 × 200	2.37	1.25	0.032 4	478
2	200 × 300	2.37	1.13	0.021 5	476
3	200 × 350	2.35	1.10	0.023 8	497
4	300 × 300	3.04	1.33	0.056 1	1 090

## 4.2 压裂规模优化

开发方案描述该区块天然裂缝不发育, 所以本方案模拟计算没有考虑天然裂缝的影响。水井压裂规模为 0.3 缝长比。在井网密度、注水压力、采油井井底压力、导流能力相同的情况下, 对采用不同压裂规模的压裂方案进行了对比 (表 2)。随着压裂规模增大, 油井产能增加, 但见水时间缩短。在产能及见水时间均能满足的情况下, 4 号方案投资利润率最大, 为最优方案, 即压裂规模应为边井 1 缝长比为 0.3, 边井 2 缝长比为 0.4, 角井缝长比为 0.4。

表 2 压裂规模优化方案

方案号	注水井缝长比	边井 1 缝长比	边井 2 缝长比	角井缝长比	初期产能 (m <sup>3</sup> /d)	3 年末产能 (m <sup>3</sup> /d)	投资利润率 (%)	见水时间 (d)
4	0.3	0.3	0.4	0.4	3.04	1.33	0.056 1	1 090
5	0.3	0.2	0.3	0.3	2.66	1.30	0.047 3	1 730
6	0.3	0.3	0.3	0.3	2.85	1.32	0.053 8	1 100
7	0.3	0.4	0.3	0.3	3.01	1.31	0.046 6	715
8	0.3	0.2	0.4	0.4	2.85	1.31	0.049 4	1 730
9	0.3	0.4	0.4	0.4	3.20	1.33	0.048 6	701

## 4.3 导流能力优化

井网密度、压裂规模、注水压力、采油井底压力相同的情况下, 进行导流能力优化对比 (表 3)。随着导流能力的增加, 油井见水时间缩短, 但影响不大, 当导流能力为 30 μm<sup>2</sup> · cm 时投资利润率最大, 因此, 4 号方案为最优方案。

表 3 导流能力优化方案

方案号	导流能力 (μm <sup>2</sup> · cm)	初期产能 (m <sup>3</sup> /d)	3 年末产能 (m <sup>3</sup> /d)	投资利润率 (%)	见水时间 (d)
10	20	2.77	1.26	0.042 3	1 270
11	25	2.91	1.30	0.046 6	1 250
4	30	3.04	1.33	0.056 1	1 090
12	35	3.13	1.36	0.052 3	1 060

## 4.4 注采压力系统压力参数优化

在井网密度、压裂规模、采油井井底压力、导流能力相同的情况下, 进行注水井井底压力优化。各方案设计注水压力分别为 18 MPa、20 MPa、29 MPa 和 33 MPa。随着注水井井底压力的增加, 油井产能增加, 投资利润率增加, 油井见水时间缩短。在满足见水时间要求情况下, 4 号方案投资利润率最大, 为最优方案, 即注水井井底压力应为 20 MPa。在井网密度、压裂规模、注水井井底压力、导流能力相同的情况下, 进行采油井井底压力优化, 各方案设计油井井底流压分别为 0.8 MPa、1.8 MPa、3.0 MPa、4.4 MPa 和 5.3 MPa。随着采油井井底压力降低, 油井产能增加, 投资利润率增加, 其中 20 号方案投资利润率最高, 投资利润率为 0.059 1 %, 见水时间为 1 050 d, 为最优方案, 即采油井井底压力最优值为 0.8 MPa。

在上述分析的基础上, 对 20 个方案进行模糊积分评判, 评判结果排序前 4 位分别为方案 1、16、15、20, 该区块渗透率较低, 地层条件较差, 而延长无水采油期对此类油田开发至关重要, 因此, 20 号方案为最佳方案。

## 5 结 论

整体优化方法对低渗透油田压裂、注水、采油整体方案设计参数进行了定量描述, 为经济评价提供了依据。通过大庆朝阳沟油田长 42-10 区块的现场应用取得了较好的效果。

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of advanced log interpretation technique of low resistivity reservoirs by a high resolution processing of normal log and a compound inversion of resistivity log.

**Key words :** low resistivity reservoir ; log interpretation ; inversion ; high resolution processing ; Daqing Oil Field ; Study

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#### LOG RESPONSE MECHANISM OF THE CALCIUM BEARING RESERVOIRS IN LONGHUPAO OIL FIELD

Liu Chuanping<sup>1</sup>, Shi Long<sup>2</sup>, Li Zhengchen<sup>1</sup> (1. Exploration and Development Research Institute of Daqing Oil Field Company Ltd., Daqing 163712, China; 2. Development Department of Daqing Oil Field Company Ltd., Daqing 163453, China)

**Abstract :** Basing on the petrophysical study, this paper analyzes the effect of calcium ingredient on log response using experimental analysis and theoretical model. It proposes the electrical conduction mechanism of calcium sandstone and provides a theoretical basis for the evaluation of this kind of reservoir using log data.

**Key words :** calcium bearing reservoir ; log response ; litho-electric experiment

**Article ID :** 1000-3754 (2000) 05-0039-03

#### NEURAL-NETWORK LITHOLOGY IDENTIFICATION TECHNIQUE OF SEISMIC ATTITUDE ANALYSIS AND ITS APPLICATION

Jiang Yan<sup>1</sup>, Zhou Zailin<sup>2</sup>, Qin Yueshuang<sup>2</sup> (1. Marine Geology Department of Tongji University, Shanghai 200092, China; 2. Exploration and Development Research Institute of Daqing Oil Field Company Ltd., Daqing 163712, China)

**Abstract :** This paper optimizes seismic parameters through analyzing the relativity of seismic attitude characteristic and geologic characteristic. Then it changes the seismic attitude data with neural-network method so that the identification indexes can fully indicate reservoir lithologic information. This technique is used in the reservoir description of Block Tai-19 of the peripheral Daqing Oil Field.

**Key words :** attitude parameter ; neural-network ; lithology identification ; reservoir prediction

**Article ID :** 1000-3754 (2000) 05-0042-02

#### DEVELOPMENT AND APPLICATION OF A NEW TYPE OF DRILLING FLUID

Liu Xueqin, Song Ruihong, Wang Shuhua (Research Institute of Drilling of Daqing Petroleum Administrative Bureau, Daqing 163413, China)

**Abstract :** According to the reservoir property of the peripheral "three low" oil fields, a new type of drilling fluid-formate drilling fluid system is determined to protect the reservoirs with low pressure and low

permeability. Compared with the performance of  $K_2SO_4$  drilling fluid, both of them are suitable drilling fluid system to protect low pressure and low permeable reservoirs. Their application in Block Zhou 13 and Block Hailaer shows a strong suppression and protection ability with a nice effect of test.

**Key words :** low pressure and permeable oil field ; drilling fluid ; reservoir protection ; borehole stability ; system engineering

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#### A TECHNIQUE OF OPTIMIZING DRILLING PARAMETERS OF SLIM HOLE DEVELOPMENT WELLS IN THE PERIPHERAL DAQING OIL FIELD

Huang Lindong, Wei Dong (Research Institute of Drilling of Daqing Petroleum Administrative Bureau, Daqing 163413, China)

**Abstract :** According to the characteristic of slim hole drilling of development wells, a single-factor drilling rate equation is constructed through field test. The slim hole drilling is used as a dynamic system to construct a theoretical model of mechanic drilling rate and bit wearing. The theory of multi-object optimization is used to perform an optimized designation of slim hole drilling parameters. The coincidence rate is proved to exceed 90%, and the average mechanic drilling rate reaches or exceeds the level of the normal wells in the same block. Now this technique is applied in the slim hole drilling in Daqing Oil Field.

**Key words :** slim hole ; development well ; drilling parameter ; optimized selection

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#### APPLICATION OF MICROBIAL RECOVERY TECHNIQUE IN CHAOYANGGOU OIL FIELD

Xing Baoli, Xu Qi, Guo Yonggui (No. 10 Oil Production Company of Daqing Oil Field Company Ltd., Daqing 163315, China)

**Abstract :** This paper illustrated the mechanism of microbial huff and puff and microbial flooding and introduces the pilot test effect and economic benefit of the application of microbial recovery in Chaoyanggou Oil Field, providing experience and evidence for the application of microbial recovery technique in low permeable oil fields.

**Key words :** microbial recovery technique ; Chaoyanggou Oil Field ; application ; low permeable ; primary recognition

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#### AN OVERALL OPTIMIZATION METHOD OF FRACTURING, WATER INJECTION AND OIL PRODUCTION IN LOW PERMEABLE OIL FIELDS

Yan Jianwen<sup>1</sup>, Wang Qunyi<sup>1</sup>, Zhang Shicheng<sup>2</sup> (1. Research Institute of Oil Production Technique of Daqing Oil Field Company Ltd., Daqing 163453, China; 2. Petroleum University, Beijing 100081, China)

**Abstract :** This paper performs a dynamic modeling of the reservoir with an angles of 0° and 45° between artificial fractures and well arrays in five-spot and inverted nine-spot patterns using a 3D two-phase reservoir numerical simulation model with artificial fractures of 0.3 - 0.8mm, economic evaluation model and overall optimization software. It carries out an overall optimization of the parameters of patterns, fracturing, injection and production according to the reservoir parameters and development requirement. The overall optimization method of fracturing, water injection and oil production is applied in Block Chang 42 - 10 of Chaoyangou Oil Field and obtains a nice effect.

**Key words :** overall fracturing; water injection; oil production; numerical modeling; optimization design; software

**Article ID :** 1000-3754 (2000) 05-0053-03

#### **EFFECT OF POLYMER DEPTH PROFILE CONTROLLING OF MEDIUM AND HIGH WATER CUT PERIOD IN LOW PERMEABLE OIL FIELDS**

Song Caiwa, Zheng Songyu, Sui Xiaobin (No. 9 Oil Production Company of Daqing Oil Field Company Ltd., Daqing 163853, China)

**Abstract :** This paper studies the application of polymer depth profile controlling technique in Longhupao and Aogula oil fields. Then it determines the feasibility of this technique in medium and high water cut in low permeable oil fields, interlayer and lateral conflict regulation after its application and the effect of extending the swept volume and improving the displacement efficiency within the swept area. It plays a conductive role for improving the oil field development in the medium and high water cut period of low permeable oil fields.

**Key words :** low permeable oil field; polymer depth profile controlling; swept volume; displacement efficiency

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#### **COMMINGLED PRODUCTION TECHNIQUE OF PUTAOHUA-FUYU RESERVOIRS OF LONG SPAN IN DAQING OIL FIELD**

Xue Fengyun<sup>1</sup>, Bai Yu<sup>2</sup>, Wang Dejin<sup>2</sup> (Research Institute of Oil Production Technigne of Daqing Oil Field Company Ltd., Daqing 163453, China; 2. No. 8 Oil Production Company of Daqing Oil Field Company Ltd., Daqing 163514, China)

**Abstract :** This paper introduces the techniques of commingled production and zonal injection in the long spanned reservoirs in the peripheral Daqing Oil Field, and analyzes the advantages and shortcomings of various techniques. The technique of long spanned zonal commingled production can be used in the peripheral low productive oil fields and also the 2 layer's zonal production and synchronous pumping of the wells in different pressured in the oil area within the placanticline. It can effectively liberate the low pressured reservoirs in the interlayer conflict.

**Key words :** Putaohua and Fuyu reservoir; commingled production; zonal injection; production technique; long span

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#### **APPLICATION OF BAILING PRODUCTION TECHNIQUE IN LOW PRODUCTIVE OIL FIELDS**

Li Changlu, Cui Baowen (Toutai Oil Field of Daqing Oil Field Company Ltd., Daqing 151300, China)

**Abstract :** This paper takes Toutai Oil Field as an example to analyze the production benefit of low productive wells in the pumping unit and bailing status and gives the economic limit of pumping production and bailing production. Combining with the practice of bailing production, it shows that to substitute pumping production with bailing production is an effective method to improve the development benefit of low productive wells.

**Key words :** bailing production; economic benefit; application limit

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#### **STUDY AND APPLICATION OF PARAFFIN REMOVER AND INHIBITOR IN THE PERIPHERAL DAQING OIL FIELDS**

Lin Sen, Feng Tao, Wu Di (Oil Field Construction and Design Research Institute of Daqing Oil Field Company Ltd., Daqing 163712, China)

**Abstract :** According to the serious paraffin deposit in Daqing Oil Field and the surface technique gathering and transferring flow used in the oil field, a kind of paraffin remover and inhibitor is studied to substitute the well-flushing technique in the peripheral oil fields. Its application proves that it can prolong the paraffin removing period and reduce the well-flushing times with an apparent economic benefit.

**Key words :** Daqing Oil Field; low permeable oil field; paraffin inhibitor; paraffin remover; study; application

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#### **A STUDY OF OIL BEARING SEWAGE PROCESSING TECHNIQUE IN LOW PERMEABLE OIL FIELD**

Cheng Jishun, Xu Hongjun, Chen Zhongxi (Oil Field Construction and Design Research Institute of Daqing Oil Field Company Ltd., Daqing 163712, China)

**Abstract :** A new type of oil bearing sewage processing equipment with small volume and high efficiency is studied for low permeable oil fields through pilot tests. It reduces the settling equipment from 2 grades to 1 grade and reduces the settling time. The filtering is reduced from 3 grades to 2 grades without the reduction of filtering rate. The technique flow is simplified to reduce the engineering investment.

**Key words :** oil bearing sewage processing; DTH coalescence oil remover; cross flow slant plate separator; lateral flow coalescence oil remover

汉译英 张玉玮  
审校 马启贵