

裂缝性油藏等效渗透率张量的边界元求解方法

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摘要:等效渗透率张量是裂缝性油藏渗流分析的重要参数,应用边界元算法可计算裂缝性油藏的等效渗透率张量。根据流量等效原理,考虑每条裂缝的空间分布和属性参数对流动的影响,建立了求解裂缝性多孔介质等效渗透率张量的数学模型,并给出了数学模型的边界元求解方法。实例研究表明,边界元法数值计算结果与解析结果较为一致;裂缝对介质的渗透能力有重要影响,忽略渗透率张量的非对角线元素将产生较大误差;等效渗透率张量能够反映裂缝性多孔介质的非均质性和各向异性。

关键词:裂缝性油藏;等效渗透率张量;连续介质;边界元方法;周期边界条件;数学模型

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裂缝性油藏在中国油气资源中占有重要的地位^[1],由于裂缝性油藏内在的复杂性、模型基本假设、裂缝识别技术和计算机硬件等因素的限制^[2-3],传统的双重介质模型^[4-5]和近年出现的离散裂缝网络模型^[6-7]都有其局限性。等效连续介质模型则结合了两者的优点,具有广泛的研究前景。等效渗透率张量用来表征裂缝性油藏的非均质性和各向异性,是等效连续介质模型的重要参数。

渗透率张量理论由 Snow^[8]提出,以解决裂缝含水介质渗透各向异性的问题,这种基于优势节理组统计特征的渗透率张量计算方法在实际工程中得到广泛应用,但由于该方法不考虑实际裂缝的连通情况及空间分布情况,计算结果存在误差。Long^[9]利用连续介质理论计算了裂缝性岩体的等效渗透率张量,没有考虑基岩的渗透性。Teimoori等^[10]应用边界元方法计算裂缝性油藏的等效渗透率张量,将裂缝假设成一维线形裂缝。

笔者根据等效连续介质模型的原理,建立求解裂缝性油藏等效渗透率张量的数学模型,利用边界元方法求解模型,并进行了实例研究。

1 渗透率张量

渗透率是岩石的固有属性,是表征油藏非均质性和各向异性的重要参数,具有二阶张量形式。二

维情况下的渗透率张量可表示为

$$k = \begin{bmatrix} k_{xx} & k_{xy} \\ k_{yx} & k_{yy} \end{bmatrix} \quad (1)$$

式中: k 为渗透率张量, μm^2 ; k ($, = x, y$) 为渗透率张量的分量, μm^2 ; x 为渗流速度方向; y 为位势梯度方向。

为保证渗透率张量具有物理意义,其应为对称张量^[11],即 $k_{xy} = k_{yx}$ 。

当渗透率主轴方向与坐标轴方向平行时, k 为对角形式

$$k = \begin{bmatrix} k_x & 0 \\ 0 & k_y \end{bmatrix} \quad (2)$$

式中: k_x 和 k_y 分别为 x 和 y 方向的渗透率主值, μm^2 。

对于裂缝性多孔介质,其等效渗透率张量综合考虑了网格块中基岩和裂缝对整个系统渗透性的影响,可描述任意裂缝分布和几何形态储层的岩石特征。

2 数学模型

2.1 模型假设

实际储层中的裂缝分布极为复杂,研究流体在其中的渗流规律,建立储层的理论模型,须对裂缝系

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统进行简化。裂缝在三维空间表现为具有一定厚度的不规则面,矩形面或圆形面,在二维空间表现为直线或弧形。笔者采用 Tamagawa 等^[12]提出的方法,即假设在裂缝发育区域,裂缝都为垂直于水平面且具有一定开度的矩形面,裂缝的纵向切深等于所研究区域的厚度,忽略重力影响,此时油藏退化为二维油藏,裂缝等价于二维空间中的线形裂缝。

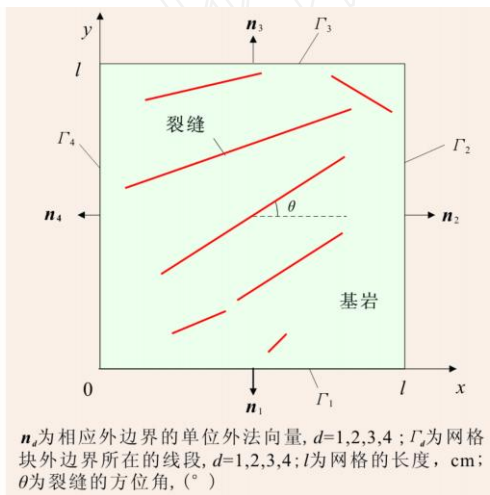
2.2 等效渗透率张量计算原理

设单位粘度流体通过含裂缝的基岩网格块(图 1),根据广义达西定律,网格块中的渗流速度与压力梯度的关系为

$$v_s = -k_s \cdot p_s \quad (3)$$

$$p_s = (\partial_x p_s, \partial_y p_s) \quad (4)$$

式中: v_s 为网格块中的渗流速度, cm/s ; k_s 为网格块的等效渗透率张量, μm^2 ; p_s 为对网格块施加的压力梯度, 10^{-1}MPa/cm ; p_s 为网格块的压力, 10^{-1}MPa 。



n_d 为相应外边界的单位外法向量, $d=1,2,3,4$; Γ_d 为网格块外边界所在的线段, $d=1,2,3,4$; l 为网格的长度, cm ; θ 为裂缝的方位角, $(^\circ)$

图 1 裂缝性多孔介质网格块

若对网格块施加的单位压力梯度为 $(1, 0)$, 则该压力梯度下的流速为 $-(k_{xx}, k_{yx})$, 可见, 裂缝性多孔介质等效渗透率张量的第一列分量对应于单位压力梯度下的流速, 从而可求出 k_{xx} 和 k_{yx} 。同理, 当对网格块施加的单位压力梯度为 $(0, 1)$ 时, 可求出等效渗透率张量的其他 2 个元素。

2.3 数学模型的建立

通过求解接触边界条件和周期边界条件下的单相稳定渗流方程, 可得到裂缝性多孔介质的等效渗透率张量。

连续性方程 假设单位密度的流体在基岩和裂缝中的渗流为单相稳定流动, 满足达西定律和质量守恒定律, 则基岩和第 i 条裂缝中的渗流综合微分

方程分别为

$$k_m \frac{\partial^2 p_m}{\partial x^2} + k_m \frac{\partial^2 p_m}{\partial y^2} + q_{m_i} = 0 \quad (5)$$

$$k_{fi} \frac{\partial^2 p_{fi}}{\partial x_i^2} + k_{fi} \frac{\partial^2 p_{fi}}{\partial y_i^2} - q_{m_i} = 0 \quad (6)$$

式中: k_m 为基岩渗透率, μm^2 ; p_m 为基岩的压力, 10^{-1}MPa ; q_{m_i} 为基岩和所有裂缝之间的窜流量, cm^3/s , 其值为 $\sum_{i=1}^N q_{m_i}$; N 为所研究区域内的裂缝总条数; k_{fi} 为第 i 条裂缝的渗透率, μm^2 ; p_{fi} 为在第 i 条裂缝与基岩接触面处裂缝的压力, 10^{-1}MPa ; x_i 和 y_i 为第 i 条裂缝所在的局部坐标; q_{m_i} 为第 i 条裂缝与其周围基岩之间的窜流量, cm^3/s 。

接触边界条件 在裂缝与基岩的接触面上采用连续性条件, 即接触面上压力连续且法向速度连续, 则第 i 条裂缝与基岩的接触边界条件为

$$p_{fi} = p_{mi} \quad (7)$$

$$v_{fi} \cdot n = v_{mi} \cdot n \quad (8)$$

$$q_{m_i} = \int_{fi} (v_{mi}^+ \cdot n - v_{mi}^- \cdot n) dS \quad (9)$$

式中: p_{mi} 为在第 i 条裂缝与基岩接触面处基岩的压力, 10^{-1}MPa ; v_{fi} 为在第 i 条裂缝与基岩接触面处裂缝的渗流速度, cm/s ; v_{mi} 为在第 i 条裂缝与基岩接触面处基岩的渗流速度, cm/s ; n 为接触面的单位外法向量; v_{mi}^+ 和 v_{mi}^- 为裂缝两相对壁面的渗流速度, cm/s ; S 为裂缝与基岩接触面的面积, cm^2 。

周期边界条件 边界条件对于等效渗透率张量的求解非常重要, 采用周期边界条件可以保证得到对称正定的渗透率张量^[11]。在含有裂缝的正方形基岩网格块中, 网格块的周期边界条件可表示为

$$\begin{cases} p(x, y=0) = p(x, y=l) - \partial_y p & 1, 3 \\ v(x, y=0) \cdot n_1 = -v(x, y=l) \cdot n_3 & 1, 3 \\ p(x=0, y) = p(x=l, y) - \partial_x p & 2, 4 \\ v(x=0, y) \cdot n_2 = -v(x=l, y) \cdot n_4 & 2, 4 \end{cases} \quad (10)$$

由式(5)~式(10)构成了求解裂缝性多孔介质等效渗透率张量的数学模型, 利用边界元方法可对其进行求解。

3 数学模型的边界元解法

由于计算网格内含有大量裂缝, 即求解区域存在大量内部边界, 而边界元方法^[13]只对边界进行离散, 使问题的维数降低了一维, 极大地降低了计算成

本,同时提高了计算精度。因此,采用边界元方法求解该方程组。

基岩和裂缝渗流方程即式(5)和式(6)本质上是泊松方程,形如

$$k^2 p_b = Q \tag{11}$$

式中: k 为基岩或裂缝的渗透率, μm^2 ; p_b 为边界节点 j 处的裂缝压力或基岩压力, 10^{-1}MPa ; Q 为窜流量, cm^3/s

利用第二格林公式和函数的性质,通过极限过程推导出研究区域边界上任意点的边界积分方程,其表达式为

$$c^j p_b^j + v_b^* p_b^* d = v_b p_b^* d + Q p_b^* d \tag{12}$$

其中

$$c^j = \frac{\pi}{2} \tag{13}$$

$$p_b^* = \frac{1}{2} k \ln \frac{\sqrt{k}}{r} \tag{14}$$

$$v_b^* = k \frac{\partial p_b^*}{\partial n_b} \tag{15}$$

式中: c 为无量纲系数; v_b^* 为 Laplace 方程基本解的外法向导数与渗透率的乘积, cm/s ; v_b 为边界节点 j 处的外法向裂缝速度或基岩速度, cm/s ; p_b^* 为 Laplace 方程的基本解, 10^{-1}MPa ; d 为求解区域; d 为求解区域的边界所在段; d 为由边界节点 j 向两侧所作切线围成的夹角,弧度; r 为求解单元距积分单元的距离, cm ; n_b 为边界节点 j 处的单位外法向量。

分别采用三角形单元和常单元对求解区域及其边界进行离散,并对边界积分方程进行离散,假设外边界共有 n_m 个节点,内边界共有 n_f 个节点,每个节点含有未知数 p_b 和 v_b ,因此有 $2(n_m + n_f) + 2n_f$ 个未知数。压力微分方程提供 $(n_m + n_f) + n_f$ 个方程,周期边界条件提供 n_m 个约束条件,接触边界条件提供 $2n_f$ 个约束条件,因此共有 $2n_m + 4n_f$ 个方程,方程组可以求解。

4 应用实例

笔者应用 2 个实例验证等效渗透率张量求解模型的正确性。对于含有单条裂缝的网格块,计算了在裂缝处于不同方位角时网格块的等效渗透率张量,并与理论计算值进行比较;对含多条裂缝网格块的等效渗透率张量也进行了计算,以证明该模型对

多条裂缝同样有效。

4.1 单条裂缝

当基岩网格块中只含 1 条裂缝时(图 1 中方位角为 θ 的裂缝),假设网格的长度为 1m ,基岩渗透率为 $1 \times 10^{-3} \mu\text{m}^2$,裂缝长度为 0.6m ,开度为 $100\mu\text{m}$,根据立方定律,裂缝的渗透率为 $833.3 \mu\text{m}^2$ 。计算不同方位角 $(0^\circ \sim 90^\circ)$ 下的等效渗透率张量。理论证明^[14],含单条裂缝的基岩网格块的等效渗透率张量与裂缝方位角 θ 和水平裂缝网格块的渗透率张量的渗透率主值 k_x 和 k_y 有关,可表示为

$$k = \begin{bmatrix} k_x \cos^2 \theta + k_y \sin^2 \theta & (k_x - k_y) \sin \theta \cos \theta \\ (k_x - k_y) \sin \theta \cos \theta & k_x \sin^2 \theta + k_y \cos^2 \theta \end{bmatrix} \tag{16}$$

由此可求得等效渗透率张量的理论值。

通过对数值计算结果与理论计算结果进行对比分析可以发现(图 2),数值计算结果与理论值基本一致;当渗透率主轴方向与坐标轴方向不平行时 $(0^\circ < \theta < 90^\circ)$,等效渗透率张量的非对角线元素 k_{xy} 和 k_{yx} 不为 0,当 θ 为 45° 时, k_{xy} 和 k_{yx} 为极大值, Fan-chi^[14] 通过研究发现,此时若忽略这 2 个元素,则由达西方程计算的流量误差可达 45%。因此,在建立坐标系时应尽量避免坐标系与渗透率主轴方向夹角等于或接近 45° ,以减少模拟误差。

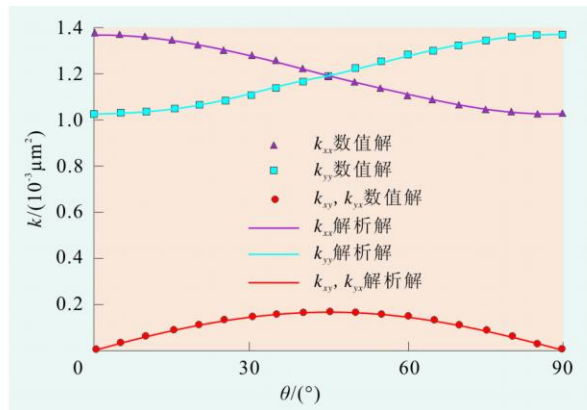


图 2 等效渗透率张量数值计算结果与理论值对比

4.2 多条裂缝

在二维裂缝性油藏中(图 3),油藏长度为 450m ,

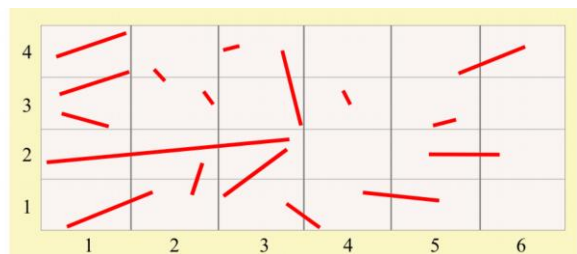


图 3 二维裂缝性油藏

宽度为 180m, 含有 17 条裂缝, 基岩渗透率为 $1 \times 10^{-3} \mu\text{m}^2$, 裂缝的渗透率为 $1 \times 10^3 \mu\text{m}^2$ 。将油藏离散为 4×6 个网格, 通过计算求得各个网格的等效渗透率张量。

对各个网格的等效渗透率张量的椭圆形式分布进行了分析 (图 4), 其中椭圆的长短轴方向代表渗透率主轴方向, 椭圆面积代表该网格的平均渗透率大小。比较图 3 和图 4 可以发现, 裂缝系统影响着渗透率椭圆的分布特征, 渗透率椭圆的方向与裂缝方向大体一致, 长裂缝对网格的等效渗透率张量起主要控制作用, 如网格 (2, 1) 和 (2, 2); 短裂缝的作用则相对较小, 如网格 (3, 4); 不含裂缝的网格块的等效渗透率张量即为基岩渗透率, 渗透率椭圆为一圆形, 面积较小, 如网格 (1, 6); 裂缝密度对等效渗透率张量有较大的影响, 裂缝密度大的地方, 网格平均渗透率大, 反之较小, 如网格 (2, 3) 和 (3, 4)。

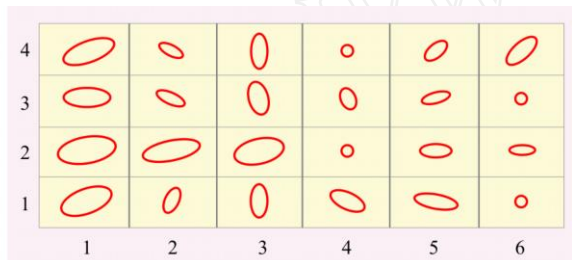


图 4 网格等效渗透率张量椭圆分布

5 结论

建立了求解裂缝油藏等效渗透率张量的数学模型, 通过求解接触边界条件和周期边界条件下的边界积分方程, 得到裂缝性多孔介质网格块的等效渗透率张量。实例研究表明数值计算结果与理论值较为一致; 裂缝对介质的渗流能力有重要影响, 所求得的等效渗透率张量能够反映裂缝的空间分布和属性参数对油藏渗透特性的影响, 而忽略渗透率张量的非对角线元素将产生较大误差; 边界元方法降低了计算成本, 提高了计算精度, 是求解裂缝性油藏等效

渗透率张量的有效方法。

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tant was researched based on apparatus detecting and theoretical analysis, as well as its compatibility with polymer and the influence of Na_3PO_4 on the interfacial tension. The experimental results show that the optimal combination ratios of the SB4 to SB1 are 96:4, 95:5 and 94:6, where the ultralow interfacial tension (10^{-3} mN/m) between the system and Daqing crude oil can be obtained under the system concentration of 0.05%, 0.1% and 0.3%. And the interfacial tension decreases first and then increases with the time. When the Na_3PO_4 is added to the combination system, a lower interfacial tension can be obtained, with the optimal Na_3PO_4 concentration of 0.2%. Compared with "SB4/SB1" combination, the "SB4/SB11" system has a lower interfacial tension and better oil displacement result with the polymer added.

Key words: sulphate betaine; ultralow interfacial tension; surfactant; combination system; Daqing crude oil

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Yan Jianwen, Zhang Yurong, Cai Cheng. Experimental study on profile control agent for high salinity formation. *PGRE*, 2009, 16(6): 70–72

Due to the high formation water salinity, poor adaptability and short validity period of general profile control agent, there is certain difficulties in the application of profile control and water-shutoff in high temperature and high salinity oil reservoirs. Therefore, a new kind of profile control agent, which plays an effective role at the specific places of reservoirs, was developed for the high salinity oil reservoirs. The profile control agent, with sodium silicate solution as host agent, was injected into formations in the form of water-in-oil emulsion, and reacted chemically with the calcium and magnesium ions in formation water after demulsification, then formed chemical precipitation to plug the high permeability zones. After the laboratory experiments of the profile control agent's stability, rheological property and sealing property, it showed that the profile control agent in every system composed of emulsion profile control agent has the characteristics of controllable plugging times, plugging rate as high as 98.5% and long validity period of plugging. At 10 times of pore volume in water injection, the permeability remained constant, and the profile control agent was prior to entering into the high permeability zones and plugged it well. The profile control agent suitable for high salinity oil reservoirs plugged the high permeability zones and played a role on increasing oil production and decreasing water production in field application.

Key words: profile control; high salinity; water-in-oil emulsion; thermal stability; rheological property; sealing characteristics

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Zhang Hongshan. Experimental study on the physical simulation of sewage polymer flooding in Class II reservoirs—a case study of west Duandong block, Bei 1 area, Daqing Oilfield. *PGRE*, 2009, 16(6): 73–75

Compared with major reservoirs, Class II reservoirs in west to the east block of north area 1 of Daqing Oilfield have the features with smaller thickness, lower permeability, limited lateral development scale, significant heterogeneity and shorter development time. It has no accurate forecast on the index of oil displacement after putting into production of Class II reservoirs. It is very important for understanding the development law of Class II reservoirs, especially the oil displacement efficiency made with sewage polymer flooding. Based on physical simulations in laboratory, compatibility between the Class II reservoirs and polymer prepared by sewage (mother fluid made up with clean water and polymer diluted by sewage) was researched, and inaccessible pore volume of polymer flooding was clear. According to the study of lab experiments and injection-production patterns, the oil displacement efficiency and adaptability of sewage polymer flooding of Class II reservoirs were evaluated comprehensively. Experimental results show that the gyration radius of polymer molecule is relatively small and has good compatibility with Class II reservoirs in simulated sewage system. As long as the reasonable polymer flooding parameters are selected, recovery factor will also be higher. After comprehensive consideration, fresh water prepared polymer is recommended and the diluted polymer solution with produced water of 1 500mg/L, the sizes of injected slugs are 0.6PV or so.

Key words: Class II reservoirs; sewage; polymer flooding; radius of gyration; inaccessible pore volume

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Han Jie, Tang Dazhen, Zhang Jinyue et al. Research of the compatibility and oil displacement result of molecular deposition membrane agent and polymer. *PGRE*, 2009, 16(6): 76–79

Molecular deposition membrane is a new kind of nano-drive oil agent. Its viscosity is equivalent to water, so it neither has capability of flow control nor can improve reservoir heterogeneity. The main role of polymer is to improve the viscosity of aqueous solution, and to enhance the swept volume. After this molecular deposition membrane was compound with polymer, the best compatibility conditions of the molecular deposition membrane agent and polymer system was confirmed. At 85 °C, the experiment of thermal stability was made for the purpose of selecting suitable polymers and examining the stability of the molecular membrane. The mixture of selected polymers and molecular membrane was assessed on the characteristics of compatibility, thermal stability and viscosity. The suitable concentration range of polymers and molecular membrane was screened out. The oil displacement experiments of the polymer, the molecular membrane, and the mixed system show that the most stable system was obtained with the mixed system of film and polymer concentration is 1 700mg/L: 1 000mg/L. The ultimate oil displacement efficiency was 22.6% in physical simulation experiment, which was higher than the pure polymer and the molecular membrane.

Key words: molecular deposition membrane; polymer; compatibility; oil displacement efficiency

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Yao Jun, Li Yajun, Huang Zhaoqin et al. Calculation of equivalent permeability tensors of fractured oil reservoirs using boundary element method. *PGRE*, 2009, 16(6): 80–83

Equivalent permeability tensors (EPTs) are essential parameters for the flow analysis in the fractured oil reservoirs, which can be calculated by boundary element method. Based on equivalent flow rate theory, the influence of spatial distribution and attribute parameters of each frac-

ture was considered. Then a mathematical model of equivalent permeability tensors for fractured porous media was established, which could be solved with the boundary element method. The case study presents that the result of boundary element method and analysis is almost the same. The fractures have important influence on the permeable capacity of the media. Great error will occur if off diagonal elements of the permeability tensors are neglected. The equivalent permeability tensors can reflect the heterogeneity and nonisotropy of the fractured porous media.

Key words: fractured oil reservoirs; equivalent permeability tensor; continuous medium; boundary element method; periodic boundary condition; mathematical model

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Deng Yuzhen. Forecasting method of production decline law of the ultra-low permeability oil reservoirs with abnormal pressure. *PGRE*, 2009, 16(6): 84–87

Ultra-low permeability oil reservoirs with abnormal pressure are mainly developed with artificial fracturing for achieving high productivity. This type of oil reservoir has enough natural energy for development and is difficult for water flooding. The productivity is affected by many factors, such as the formation energy declining, pressure sensitive effect, actuating pressure and the decreasing of fracture flow capacity. Semi-analytic method and mathematic model of fluid-solid coupling flow were established based on the influencing factors and time invariant seepage. Numerical simulation method can be used for forecasting production decline law in the ultra-low permeability oil reservoirs with abnormal pressure. The two methods were applied to the matching and prediction of production decline laws in 12 wells, Block Gao89 in Boxing Depression. When bottom pressure is defined at 13MPa, cumulative oil production is the highest.

Key words: ultra-low permeability oil reservoir; abnormal pressure; pressure sensitive effect; starting pressure; fluid-solid coupling; production decline law

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Zhao Chunming, Hu Jingshuang, Huo Chunliang et al. Sandbody interconnectivity architecture and development characteristics of meandering river and braided river deposits—a case study of Qinhuangdao 32-6 Oilfield, Bohai area. *PGRE*, 2009, 16(6): 88–91

During the Neogene period, fluvial sedimentary system was well developed in Bohai area. Different types of fluvial sand bodies have various interconnectivity architecture and development characteristics. Based on the core observation and data of infill well patterns, the sandbody interconnectivity architectures of high-sinuosity meandering river and sandy braided river were deeply studied respectively by means of analytical hierarchy process, and the connectivity models of the two types of sand bodies were established subsequently in Nm formation, Neogene, Qinhuangdao 32-6 Oilfield, Bohai area. Generally there are 30 to 200 lateral accretion sand bodies in a point bar. The thickness of a single lateral accretion is 1 to 3m. The upper 4/5 thicknesses of the sand bodies is not connected, while the lower 1/5 thickness is connected. The scour-infill structure is present in the braided-river sand bodies, and the thickness of a single river unit is 2 to 5m. As the rapid and frequent swing of the river, the sand body units with multi-origin connect with each other in the vertical and lateral. Therefore a wide range of connectivity of thick sand body is formed. Through the analysis of behavior characteristics, development indexes of oil production rate, recovery ratio and so on of the braided river sand bodies are superior to that of the meandering river sand bodies.

Key words: meandering river; braided river; sand body architecture; development characteristics; Qinhuangdao 32-6 Oilfield; Bohai area

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Ye Juenan, Tang Hongming, Wu Xiaogang et al. The matching relation between the pore throat parameters of reservoirs and the particle diameters of suspended particles. *PGRE*, 2009, 16(6): 92–94

The contents and particle diameters of suspended particles are the key indexes of injected water quality, and also the important factors of formation damage. There is no unified and subdivided water quality standard for the reservoir with the permeability above $600 \times 10^{-3} \mu\text{m}^2$ in domestic standards. Rational standards must be known and the matching relation between the pore throat and the particle diameters of the suspended particles should be researched for effective reservoir protection. A large number of mercury intrusion curves of sandstones were summarized in Bohai Oilfield. The pore throat parameters of high and ultra-high permeability reservoirs with various permeability differentials were made statistics systematically. Median diameter of the suspended particles can be optimized through major throat radius based on filtration theory. When the median diameter of the suspended particles is smaller than the major throat radius, the particles can put through the pore throat of the rocks. According to the different pore throat structures and dynamic evaluation results, the best matching relation between different types of pore throats and median diameter of the suspended particles is: the maximum value is 2.5m in low-medium permeability reservoirs, 3.0m in medium permeability reservoirs, 3.5m in medium-high permeability reservoirs, 4.0m in high permeability reservoirs and 5.5m in ultra-high permeability reservoirs.

Key words: pore throat parameter; diameter of suspended particle; water quality index; orthogonal experiment; reservoir; median diameter of suspended particle

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Feng Mingsheng, Xu Anzhu, Bie Aifang et al. The establishment and application condition of an abstract model for horizontal wells remaining oil producing. *PGRE*, 2009, 16(6): 95–97

Horizontal wells drilling is an important method of producing remaining oil, but the mechanisms and application conditions are uncertainty due to the complex occurrence of the remaining oil. An abstract model was established for horizontal wells remaining oil producing. Factors influencing horizontal wells remaining oil production, include vertical position and length of horizontal interval, shape and area of remaining oil, reservoir thickness and drawdown, were studied by numerical simulation model. The remaining oil with ratio of length and wideness of 4, 6m of thickness and more than $40\,000\text{m}^2$ of area is suitable to tap the potential by the horizontal wells. When the thickness of the horizontal