Chapter 32
Characteristics and Control Factor of Preferential Water Drive Channel in Meandering River Sandstone

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32.1 Introduction

In the process of waterflooding development of sandstone oil fields, the injected water will sweep preferentially along the intervals with high porosity and high permeability for heterogeneity in sands inside, which causes swept degree of injected water unevenness and influences the effect of oil field development. For high porosity and high permeability interval in sand, many scholars proposed several concepts such as high permeability channel, dominant flow channel, large pore path and made a lot of work on characteristics [1, 2], identification method [3–6], plugging measures [7, 8] of large pore path, and control of dominant flow channel on remaining oil [9]. Taking M-I-1 single sand layer in the Kumkol South Oil Field as an example, this article put forward concept of preferential water drive channel, which is more intuitive to reveal the static and dynamic characteristics that the sand has high porosity and high permeability interval first and then has long-term brushing of injected water, providing a basis for further potential tapping of meandering river sand bodies.

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32.2 Geologic and Development Conditions of the Study Area

Located in the southern depression, South Turgay basin, Kazakhstan, Kumkol South Oil Field is an anticline sandstone reservoir with edge water, where the main oil-bearing formation M-I belongs to meandering river deposit. Vertically, M-I formation can be divided into M-I-1 and M-I-2 single layers, in which five microfacies including point bar, abandoned channel, final channel, overbank sand, and alluvial flat develop. The main reservoirs are point bar sand and overbank sand, and abandoned channel or final channel is the boundary of point bar sand. The reservoir lithology are siltstone, fine sandstone, and fine–medium sandstone, with average porosity 28.5% (range, 24–30%), and average permeability 1324.3 × 10^{-3} μm^2 (range, 170–2690 × 10^{-3} μm^2), which are medium–high porosity and medium–high permeability reservoir. The M-I reservoir has been started water injection development since 1991. By far, the oil field has entered high water cut and high recovery degree stage with a geological reserve recovery degree of 56.2% and total water cut of 96.3%, being seriously waterflooded.

The initial production of new oil wells differs widely, with the daily oil production ranging from 0.8 to 16.6 t, and total water cut of 0–99%, which shows that the reservoir has certain remaining oil potential, but the water drive spread is ununiform.

32.3 Static Geological Characteristics of Preferential Water Drive Channel

32.3.1 Sedimentary Characteristics

A sedimentary characteristic of preferential water drive channel includes internal architecture and heterogeneity of single sand body. For sandstone architecture, the research ideas and methods have become mature [10–14]. Previous studies show that reservoirs with a thickness of over 3 m, porosity of over 20%, and permeability of over 100 × 10^{-3} μm^2 can form large pore path [15]. In layer M-I-1, log interpretation shows the average thickness of single point bar sand is 3.4 m (746 single sands) and the average thickness of single overbank sand is 1.5 m (148 single sands). Point bar sands, positive in rhythm, are mainly fine sandstone and fine–medium sandstone, with lateral accretion shale beddings inside. The lateral accretion shale beddings divide the point bar sand into the bottom part with good connection and the top part with weak

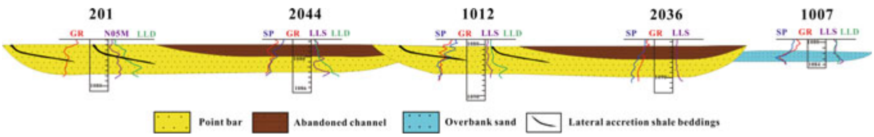


Fig. 32.1. Architecture characteristics of meandering river single sands

Table 32.1. Heterogeneity parameters of meandering river single sands

Single sand	Porosity (%)	Permeability parameters				Rhythm
		Average permeability (10^{-3} μm^2)	Permeability contrast	Abrupt injection coefficient	Variation coefficient	
Point bar	26	1324.3	215.7	3.18	0.88	Positive
Overbank sand	24	128.2	26.5	2.27	0.55	Uniform

connection or no connection. Overbank sands, uniform in rhythm, are characterized by thin sands as internal architecture, which are developed when rivers overflew the bank and distribute at the side of the point bar, with poor lateral continuity (Fig. 32.1).

The point bar sands have an average porosity of 26% and an average permeability of 745.9×10^{-3} μm^2, while overbank sands have an average porosity of 24% and average permeability of 318.6×10^{-3} μm^2. The point bar single sand has higher permeability parameter values and stronger heterogeneity than the overbank sand (Table 32.1). Therefore, the bottom part of point bar sand has the geological conditions to develop as preferential water drive channel.

32.3.2 Waterflooding Characteristics

High porosity and high permeability intervals in sand are generally strongly waterflooded [16], sandstone architecture control waterflooded characteristics [17, 18]. Because point bar sands are semi-connected, their bottom part is widely connected and is seriously waterflooded and forms apparent preferential channels, while their top part is mainly non-weak waterflooded intervals due to the blocking of lateral accretion shale beddings. Overbank sands made up of thin silt-fine sand are poor in physical property and connectivity and fast in lateral change, so they have low sweeping degree of injected water and weak waterflooded degree (Fig. 32.2). Therefore, the bottom part of point bar sand is preferential water drive channel.

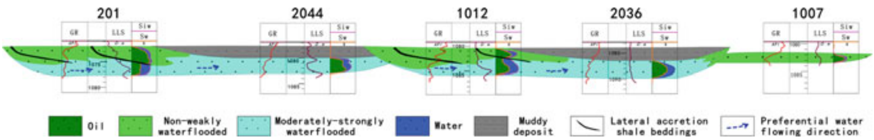


Fig. 32.2. Waterflooding characteristics of point bar sand

32.4 Dynamic Development Characteristics of Preferential Water Drive Channel

When the injected water flows in the meandering river sand body, it rapidly breaks through preferential water drive channel at the bottom of point bar sand and causes swept degree of single sand unevenness in vertical direction, with obvious changed dynamic production characteristics in single well. In a water injector, there are strong water-intake intervals in injection water profiles, having characteristics that injection rate increases but injection pressure is constant or even decreases; in oil producer, there are strong production intervals in production profiles, having characteristics that well will have high fluid production and low water cut or high fluid production and high water cut.

In water injector 304, layer M-I-1 belongs to point bar sand deposition with a thickness of 6 m, average porosity of 32.7%, and average permeability of 1745.2×10^{-3}μm^2, having the geological conditions to be developed as preferential water drive channel. This well was perforated at 1090.3–1093-m interval to inject water. In 2011, water injection profile was tested in the perforation interval, which shows this perforation interval contains two water-intake intervals, among them relative water absorption of 1090.3–1091.5-m interval is about 14%, while that of 1092–1093-m interval, developed at the bottom part of sand, is as high as 86%. Therefore, 1092–1093-m interval is strong water-intake interval and is preferential water drive channel.

In water injector 24, 300 and oil producer 244, layer M-I-1 belongs to point bar sand deposition with high porosity and high permeability and has the geological conditions to develop as preferential water drive channel. Water injector 24 was started water injection in February 1994 after perforation. From May 1994 to February 2002, the injection pressure had been on the decline on the whole, having an average value of 10.9 MPa and average injection rate of 205 t/d with little change. From February 2002, injection pressure decreased than earlier period to an average of 8.3 MPa, while average injection rate increased to 1240.4 t/d. Meanwhile, well 300 (160 m northwest of well 24) began to inject water and well 244 (300 m northwest of well 300) began to produce. When well 300 began to inject water, the average injection pressure was 8.3 MPa and the average injection rate was 366 t/d. Compared with well 24 during initial water injection stage, the injection pressure was smaller, while the injection rate was bigger. From February 2009, injection pressure in well 24 and well 300 has been stable, while injection rate has increased obviously, and injection rate curve above the injection pressure curve (Fig. 32.3a, b) shows preferential water drive channel has been formed in these two wells in the layer M-I-1. Well 244 was perforated to produce in June 2000. In the first three years, the average fluid production and water cut were 215.6 t/d and 22.4%, respectively, which confirmed the well with high fluid production and low water cut. After July 2005, as water injection went on in well 24 and well 300, fluid production and water cut of well 244 soared up to an average of 489.1 t/d and 96.2%, respectively, with high fluid production and high water cut, which shows preferential water drive channel has been formed in this well in the layer M-I-1 (Fig. 32.3c).

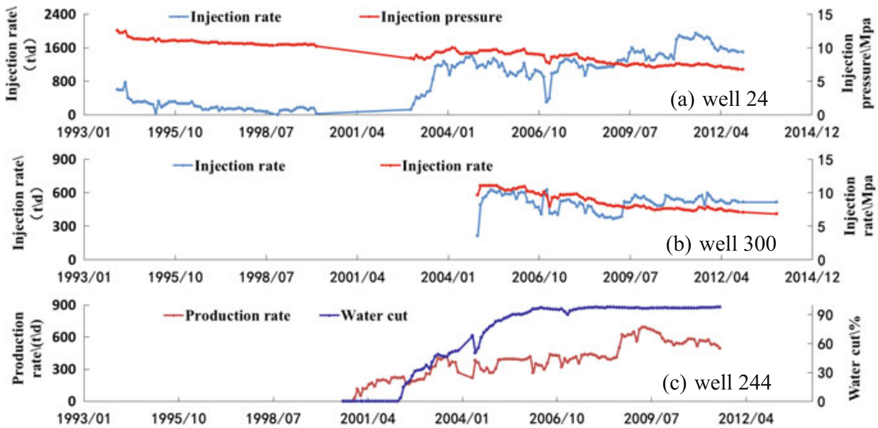


Fig. 32.3. Production characteristics of water injector well 24 (see Fig. 32.5 *A*–*A*′ for the location of the well group)

32.5 Controls of Sandstone Architecture on Preferential Water Drive Channel

Numerical simulation results of well group show that in vertical direction, for semi-connected architecture characteristics of point bar sand, the injected water flows prior into the preferential water drive channel at the bottom of point bar sand, with high oil displacement efficiency; in contrast, because of blocking of the lateral accretion beddings, the top part of the point bar sands is difficult to be swept by injected water, poor in sweeping efficiency, and rich in remaining oil, which shows that the top part of point bar sand is the main potential interval in different water cut stages (Fig. 32.4). Sandstone architecture control formation of preferential water drive channel.

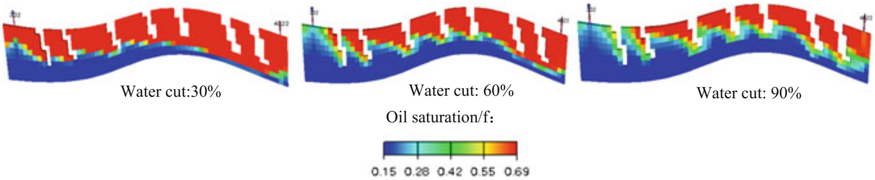
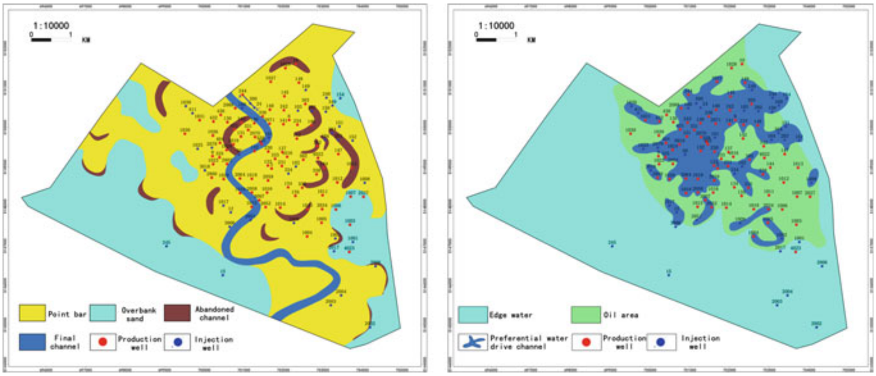


Fig. 32.4. Remaining oil distribution in point bar sands at different water cut periods

Using static geological and dynamic development data, we analyzed and identified preferential water drive channel in 39 water injection wells and 78 production wells. The result shows that in the plane, because of wide distribution area and better physical property, the injected water flows preferentially into the point bar sand, most oil-bearing areas of point bar sand have been swept by injected water, and preferential water drive channels were developed in nearly half of the well areas, while in other areas, because of lateral blocking of abandoned channels and final channels, injected water cannot effectively sweep in point bar sand and preferential water drive channels were not developed. Overbank distributes at the side of the point bar near the alluvial flat, with poor lateral continuity and physical property, so waterflooding degree is low and preferential water drive channels were not developed (Fig. 32.5). If suffered long-term waterflooding development, preferential water drive channels will be developed in much more point bar sands, which will seriously influence the water injection development effect.

Statistical analysis of numerical simulation results shows that average recovery degree, average remaining oil saturation, and average remaining oil reserves abundance in point bar sands are 58.9, 29.7%, and 296 kt/km^2, respectively, while in overbank sand these values are 53.6, 33.8%, and 103 kt/km^2, respectively. Moreover, in M-I-1 single sand layer in this oil field, the distribution area of point bar sand is much more wider than that of overbank sand. Therefore, the point bar sands are the main targets for future development.



(a) Planar structure of single sands (b) Planar distribution of preferential water drive channel

Fig. 32.5. Planar map of single sand structure and distribution of preferential water drive channel in layer M-I-1

32.6 Conclusions

(1) In meandering river sandstone, the thickness of point bar sand is greater and its physical property is better than that of overbank sand. The point bar sand is a semi-connected body because of lateral accretion shale beddings developing inside, so the injected water sweeps preferentially along the bottom part of the sand, and the bottom part is preferential water drive channel, which is strong water-intake (or strong liquid production) interval in injection water (production) profiles. Overbank sand is thin sand with low heterogeneity and therefore is non-weakly waterflooded and is not preferential water drive channel. Sandstone architecture control formation of preferential water drive channel.

(2) In meandering river sands, point bar sand is the main potential target in plane because of wide distribution area and larger remaining oil reserves abundance, and the top part of point bar sand is the main potential interval in vertical direction due to blocking of the lateral accretion beddings.

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