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The Characteristics of the Dominant Flow Channel Using Ma20 Block in the Liaohe Oilfield as an Example

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Abstract

The existence of the dominant flow channel caused the oil field recovery efficiency low, the rising cost of production and the development benefit drop, which brought great pressure to oilfield development, so the study of the characteristics of the dominant flow channel is increasingly urgent. According to the geologic features and the production process of long-term water injection development in the Ma20 block of the Liaohe oilfield, reservoir heterogeneity is the root cause of forming the dominant flow channel. The characteristics of the dominant flow channel in the process of water injection were analyzed. By analyzing the performance characteristics of the dominant flow channel in the dynamic production data, electrical, static and so forth, the dominant flow channel was determined to guide water injection development of oilfield and provide the basis for the research of other dominant flow channel of high water-cut stage reservoir.

Key words: The dominant flow channel; Development benefit; Geologic features; Heterogeneity; Development of water injection

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INTRODUCTION

With continuing development of oilfield water injection, oil field has entered into the high water-cut stage. The injected water flows along with high permeability and high-watered flow channel. The flows enlarge the original size, making inefficient or invalid water injection cycle. Therefore, the dominant flow channel was formed. In the process of water injection development, early water breakthrough of the production well, high moisture content and low recovery degree all are the evidence of the formation of the dominant flow channel. These channels will increase the cost of development and drop the product efficiency. So the research of the characters of the dominant flow channel is imperative.

In order to recognize the dominant flow channel exactly, the scholars has made plenty of researches. Liu Yuetian and Sun Baoli made use of the Big Channel Identification Expert System, describing the dominant flow channel[1]. Meng Fanshun took advantage of Fisher Princple to derive a discrimination function, which can identify the dominant flow channel[2]. With this function, the recognization of the dominant flow channel on the computer has come true. Wang Lushan utilized water flooding characteristic curve for discerning the dominant flow channel[3]. They classify advantage channel interporosity flow degree by fuzzy clustering analysis. Feng Qihong and Shi Shubin came up with the idea of identifying and making quantitative description of large pores on the basis of taking a full consideration of oilfield static data and dynamic data combining the methods of percolation theory and math[4]. Liaohe oilfield has exploited for 40 years. The reservoirs were developed unequally. The dominant flow channel has a wide distribution range. Based on the results of previous studies, this paper analyzes the cause of the dominant flow channel and takes advantage of the dynamic production data, electrical characteristics and geological characteristics to confirm the dominant flow channel.

1. THE GEOLOGICAL FEATURES OF THE STUDY AREA

Ma20 fault block area of Xinglongtai oilfield is located in the central of Xinglongtai fractured anticlinal structural belt of in the Western sag of Liaohe faulted basin. The structure acreage is 11.3 km^2. Oil-bearing formation is the Xinglongtai oil layer, the paleogene Shahejie group. This formation has abundant reserves making it the main oil-bearing series of this area. Es_2VI to Es_2XII are the target stratums. The average of total thickness is 215.35 m. The main reservoir lithology is feldspar coarse grained sandstone, pebbly sandstone, sandy conglomerate and argillaceous cementation. The average porosity is 19.4%. The effective permeability is 272×10^{-3}-695×10^{-3} μm^2.

The study area developed the subfacies of the fan delta front and prodelta, including underwater distributary channel, the edge of underwater distributary channel, river mouth dam, distributary interchannel thin sand layer, far bar, predelta mud and other microfacies types.

2. THE FORMATION AND CHARACTERISTICS OF THE DOMINANT FLOW CHANNEL

The formation of the dominant flow channel is influenced by both inside and outside factors[5]. The inside factor is mainly the heterogeneity of reservoir. The outside factor is the long-time water injection development or the roughly development. Reservoir heterogeneity is the decisive factor.

The dominant flow channel is an extremely reflection of the inner contradictions, so its formation is in the control of the reservoir heterogeneity. The reservoir heterogeneity is the reflection of heterogeneity of rock material and pore space. Reservoir heterogeneity is the root cause of the formation of the dominant flow channels. Because of the existence of the reservoir heterogeneity, the water flow is along with high permeability layers during the water-flooding development. After the long-time water-flooding exploit, due to the water flow scouring action, the porosity and permeability of high permeability layers become higher and higher. As a result, the dominant flow channel was formed.

Under the long-term influence of high strength injection-production rate, the formation can form the dominant seepage channel easily. External cause is mainly manifested in hydrodynamic scour and fluid friction. A large number of indoor study shows, when water flow rate is very low, the reservoir hasn't sand production, but when the flow velocity increases gradually, the reservoir began to have sand and sand production rate increases rapidly. It made reservoir permeability become large. In the middle part of the flow channel, sand production rate is the fastest and a high-speed flow banding namely dominant flow channel will be formed.

In general, the dominant flow can be easily formed channel in the formation with larger thickness and permeability, especially in the distributary channel microfacies with higher pore throat radius. After the formation of different scale dominant flow channel, the development of dynamic data and log response showed a significant change.

2.1 Geological Characteristics of the Dominant Flow Channel

2.1.1 The Permeability and the Average Pore Throat Radius

According to SY/T 6285-1997 "The oil and gas reservoir evaluation method", sandstone oil reservoir is divided based on the surface pore radius median (R50). The reservoir whose value of R50 is between 15-25 μm is defined as the big channel reservoir. The reservoir whose value of R50 is more than 25 μm is defined as the extra big channel. R50 is consistent with average pore throat radius and also applies to the average pore throat radius.

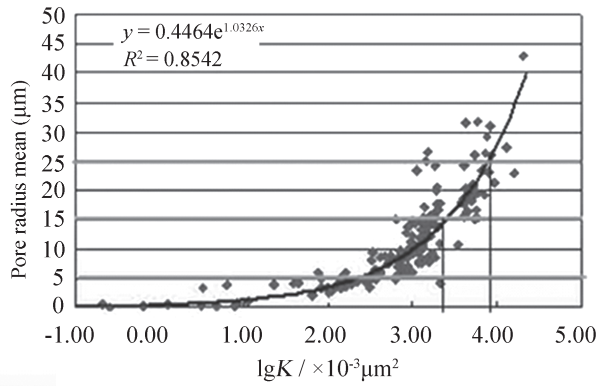

Figure 1
The Cross-Plot of Pore Throat Radius and Permeability in Ma20 Block

Seen from the permeability and pore throat radius diagram, the reservoir whose permeability is greater than $6,000\times10^{-3}$ μm^2 corresponds to the extra big channel; The reservoir whose permeability is $6,000\times10^{-3}$ μm^2 corresponds to the big channel; The reservoir whose permeability is between 200×10^{-3} μm^2 and $2,000\times10^{-3}$ μm^2 corresponds to the conventional channel; when the reservoir permeability is less than 200×10^{-3} μm^2, reservoir corresponding channel value is small and water is more difficult to apply to this range.

2.1.2 The Thickness and Permeability Differential

According to pressure core data in recent years, under the present the condition of well pattern and injection-production pressure system, the formation of the dominant flow channel is closely related to the reservoir permeability and permeability differential. With the increase of permeability, oil displacement efficiency was improved and the possibility of the dominant flow channel increased greatly.

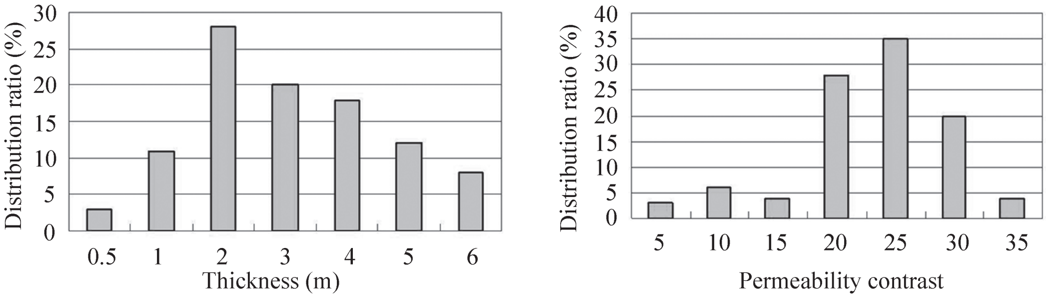

Figure 2
Big Channel Sand Layer Thickness and Permeability Differential Statistical Figure

Statistics show that the dominant flow channel are mainly distributed in sand layer whose thickness is greater than 2 m, which states that the thickness of sand layer must reach a certain thickness to form the dominant flow channel. Most of the permeability differential is above 5. The differential permeability of the samples is between 5 and 10 accounting for about 10% of the total. The remaining 90% have the dominant flow channel well layers over the poor level in more than 10. The more serious reservoir heterogeneity is, the more easily the dominant flow channel is formed.

2.1.3 The Permeability Variation

Seen from the physical property change of the core well, washing time increases, the proportion of low permeability samples becomes smaller and smaller. In other words, the proportion of high permeability samples becomes larger and larger. Since 2012, the samples whose permeability is between 1,000×10^{-3} μm^2 and 10,000×10^{-3} μm^2 have accounted for more than 50% in the coring.

All wells in study area were divided into two groups according to time. Compare the permeability variation of the well layer in the similar location at different times. As shown in Table 1, after the washing for a long period of time, maximum permeability is within the 30,000×10^{-3} μm^2 and permeability change is small, which indicates permeability will not continue to increase. Thus, permeability variation can also be seen as the characteristics of the dominant flow channel.

2.2 The Variation Characteristics of Dynamic Production Data

2.2.1 Great Difference of Water Absorption or Fast-Varying Water Absorption in the Water Injection Profile

The thickness of some strong water accepting layers accounts for a small percentage of total thickness, while the injection volume of these layers has a high proportion of total injection volume. For example, in Figure 4, the thickness of the 16^{th} layer is lower, but the injection volume is much larger than other layers, where the dominant flow channel may develop.

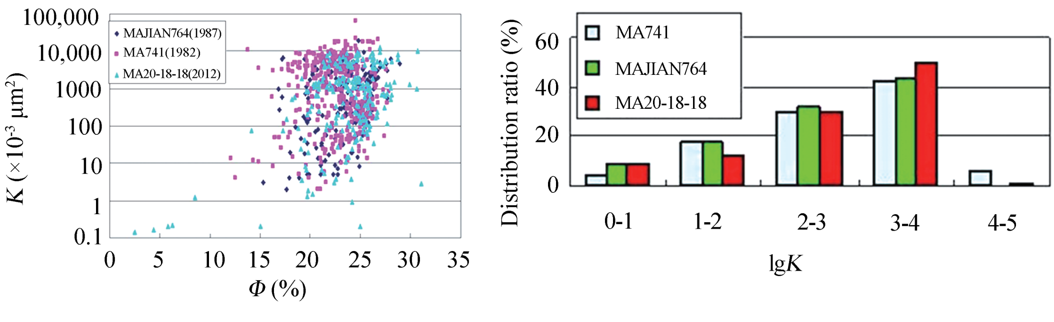

Figure 3
Permeability Variation Characteristics in Different Washing Period

Table 1
Permeability Variation of Well Layer During Different Periods in the Study Area

Item	Numerical value				
Permeability (×10^{-3} μm^2)	< 100	100-500	500-1,000	1,000-2,000	> 2,000
The degree of change (times)	-	1.2-2.5	1.6-3.1	1.7-3.5	1.3-2.5

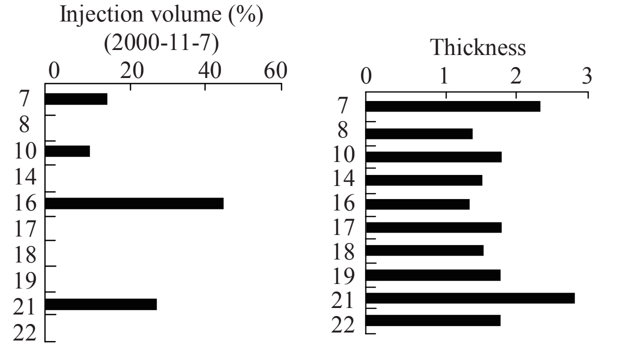

Figure 4
Vertical Analysis Diagram of Injection Percentage in the Well of Which Water Injection Profile Is Abnormal

The water injection profile with high water absorption and the well layers with fast-varying water absorption over time, reflect large pore characteristics. The well layers with great difference of water absorption or fast-varying water absorption have the existence of dominant flow channel. For example, in the 54th layer of Ma20-18-18 well, the relative water absorption is 63%, much higher than other layers. In the 35th layer of Ma20-18-18 well, the relative water of the water injection profile changed rapidly in November and December, 2004. These two layers may have the existence of dominant flow channel.

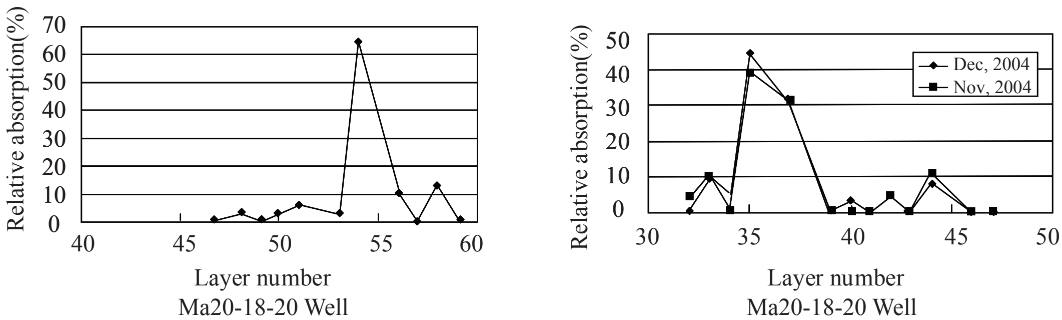

Figure 5
The Layers With High Water Absorption Display or Fast-Varying Water Absorption Over Time

2.2.2 High Moisture Content

Another expression of the formation of inefficient circulation band is moisture content. The sudden change of moisture content is always followed by abnormal condition underground, which is one of the key dynamic factors of the formation of inefficient circulation band. According to the single well production data, the dominant flow channel always exists in the wells where monthly water yield suddenly increases while monthly oil production declines.

2.2.3 Injected Water Breakthrough in the Individual Direction of Well Group as Tracer Shown

As the existence of plane heterogeneity, in injection-production well group, the injected water mainly presses onward high permeability zone, which is scoured more frequently by water, and easy to form the dominant flow channel.

2.2.4 The Bottom-Hole Pressure Changes in the Oil and Water Wells

The bottom-hole pressure changes in water injection well reflect the connected relationship between water injection wells and production wells. After inefficient circulation band formed, in the pipe flow condition of fluid flow, the seepage resistance is small, and the bottom-hole pressure of oil well is gradually close to the bottom-hole pressure of water well. If there is no leakage or damage of casing and channeling water absorption, then the dominant flow channel can be identified based on the abnormal changes of water injection volume or injection pressure. If there is no inefficient circulation band, water injection volume is proportional to the injection pressure. It is shown that there is no inefficient circulation band, if water injection pressure stays the same while water injection volume is increasing or if water injection volume stays the same while water injection pressure is reducing.

2.2.5 The Great Difference Value Between Original Water Saturation and Current Water Saturation in Carbon Oxygen Test

According to the test data of carbon oxygen, the permeability as well as the difference value between original water saturation and current water saturation in dry layer sample is small. Among weak, medium and strong water flooded layer, the difference of permeability is little while the difference value of water saturation gradually increases (as shown in Figure 7), which is easy to form the dominant flow channel.

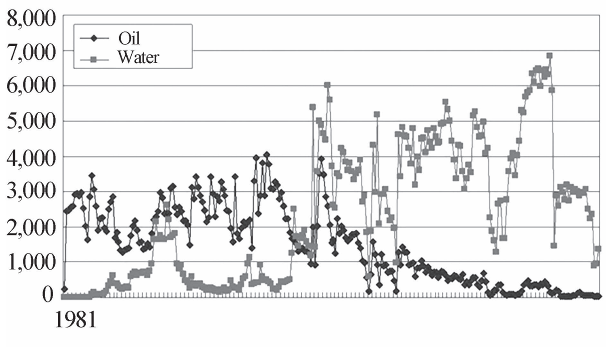

Figure 6
Ma20-18-18 Well (Monthly Water Yield Suddenly Increased and Monthly Oil Production Declined in 1992)

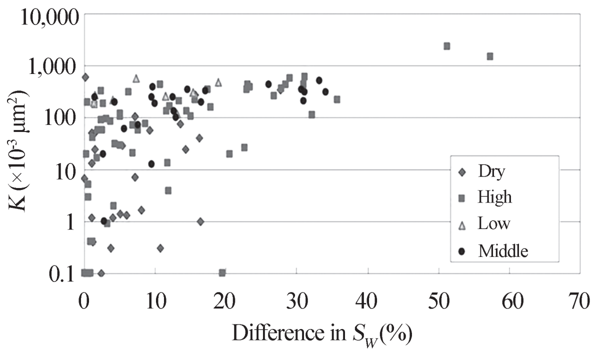

Figure 7
The Crossplot of Water Saturation and Permeability in Different Water Flooded Layer

2.3 Electrical Characteristics of the Dominant Flow Channel

After reservoir modification of long-term water injection, the following phenomenon can be appeared: The great increase of water saturation, oil saturation reduction, the increase of permeability and porosity, the reduction of shale content and lower cementation strength of rock matrix as well as the change of reservoir wettability. As a result, the value in well logs changes, such as: (a) The reducing extent of the microelectrode curve; (b) The increasing range of SP curve; (c) The declined resistivity value on R045 curve[6]. In the study area, the above characteristics are very obvious. The increase or decrease is relative to the before and after the water flood. These changes in logging curves can be qualitative judgment of the formation and existence of the dominant flow channel.

As the columnar section of coring well in the study area (Figure 8) shown, the range of SP curve increases, while the extent and magnitude difference of the microelectrode curve reduces. Through studying reservoir properties, the layers of the curve which had the above changes, were the layers where dominant flow channels developed. Therefore, we can come to the conclusion that, when the range of SP curve increased as well as the extent and magnitude difference of the microelectrode curve reduced, there may be the existence of dominant flow channel in this layer.

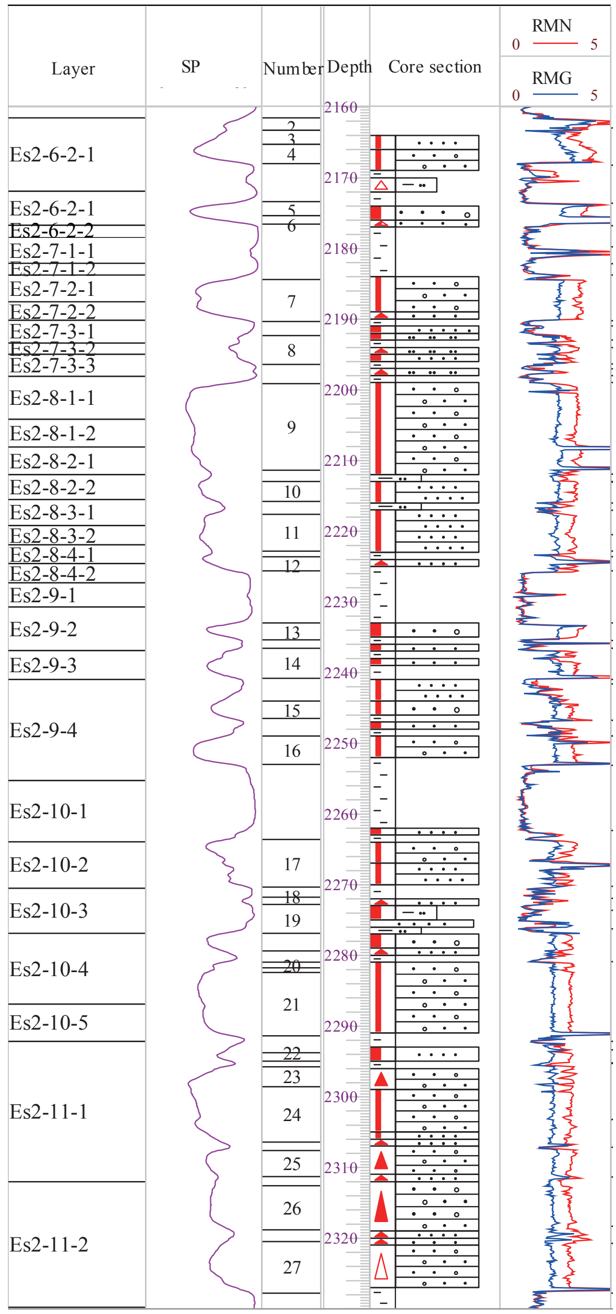

Figure 8
The Columnar Section of Coring Well at Ma 20 Block

CONCLUSION

(a) Reservoir heterogeneity is root cause of the formation of the dominant flow channel. Long-term and large-scale water injection is the immediate cause. The more serious the reservoir heterogeneity is, the more easily the dominant flow channel is formed.

(b) On the static state, the dominant flow channels are mainly developed in subaqueous distributary channel. When the reservoir permeability is more than 200× 10^{-3} μm^2, the dominant flow channels are easy to be formed. The layers whose thickness in single sand layer is more than 2 m, and permeability contrast is higher than 10, are easy to form the dominant flow channel.

(c) There are many dynamic features of the dominant flow channel, mainly including the very different water injection profile or quick change of injection, sudden change of moisture content, injection water breakthrough, bottom hole pressure change, and the large difference value between original water saturation and current water saturation.

(d) There are many electrical features of the dominant flow channel, mainly including the increasing range of SP curve, the reducing extent of the microelectrode curve, and the declined resistivity value on R045 curve. These changes in logging curve can qualitatively judge the formation and existence of the dominant flow channel.

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