EXPERIMENTAL STUDY ON DYNAMIC FRACTURES INDUCED BY WATER FLOODING IN LOW PERMEABILITY RESERVOIRS

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ABSTRACT

The behavior of water flooding in low permeability reservoirs is directly influenced by various fracture systems in the reservoirs including natural fractures, hydraulic fractures and dynamic fractures induced by water flooding. These impacts can lead to some unexpected consequences that highly reduce the oil recovery rate such as higher water cutting rate, low sweep efficiency and off-trend with the orientation of natural fractures.

With lots of intensive work having been done in the past about the impact of natural fractures and hydraulic fractures on oil recovery rate, little work has been done to reveal the mechanism of the dynamic fractures being induced and there exists too few experimental data to support the correlation between the behavior of dynamic induced fractures and the production rate.

In this work, an experimental method is established to simulate dynamic fracture induced by injecting water into core samples. It can be observed that fractures start being induced when water injection pressure is 0.7-3.2MPa higher than the overburden pressure and becomes stable at 1.0-5.0Mpa higher than the overburden pressure. Experimental measurements show that the induced fractures, with length scale mainly within micrometer, tend to grow in a plane pattern, with both fracture width and fracture pressure increase with water injection rate, which can also explain the reason that absolute permeability of core samples under water flooding is significantly enhanced by 5-30 times. On the other hand, the displacement efficiency of the induced fractures is about 9.8-25.5%, which is lower than that of matrix controlled flow ability, which is about 56-63%.

Key words: low permeability reservoirs; water flooding; dynamic fractures; core experiment

INTRODUCTION

The behavior of water flooding in low permeability reservoirs is directly influenced by various fracture systems in the reservoirs including natural fractures, hydraulic fractures and dynamic fractures induced by water flooding. These impacts can lead to some unexpected consequences that highly reduce the oil recovery rate such as higher water cutting rate and low sweep efficiency.

Fan Tianyi in 2015 conceptualized dynamic fractures and based on abundant data of low permeability oilfields, studied their evolution, including cracking, extension and closure. With the gradual extension of dynamic fractures, the injection water forms a narrow range of displacement, which leads to the severe imbalance of water flooding, aggravates the heterogeneity of low permeability reservoirs, and possibility of sudden water influx in the reservoirs.

Guo Farong in 2015 believes that the dynamic fractures in low permeability reservoir and hydraulic fractures of oil well all distribute along the high main stress, while water injection pushes the dynamic fracture to propagate continuously, flooding the main oil wells, and forming a regular pattern of cracks in the plane line.

Wang Youjing in 2015 believes that dynamic fractures refer to the new-generated fracture channels when bottom hole pressure exceeds rock breakdown pressure and propagation pressure. His study shows that the dynamic fractures changed the seepage characteristics of water displacing oil in the low permeability reservoir, aggravated the reservoir heterogeneity, which led to the reduction of profile producing degree and the distribution of remaining oil on both sides of the fractures in continuous or discontinuous belts.

According to site research carried out by Xie Jingbin in 2015 on Chang6 reservior, Ansai oilfield, the opening pressures of dynamic fractures are 20-23 MPa. The dynamic fractures aggravate the reservoir heterogeneity and cause the quick water flooding along the current maximum horizontal major stress direction, which reduces the producing degree horizontally and vertically and influences the reservoir development effects.

Up to now, multiple researches have been carried out on the definition, genetic mechanism, parameter characterization and distribution prediction of natural fractures and hydraulic fractures through various ways. However, past studies on dynamic fractures induced by water flooding tend to focus on analyzing the communication between the production rate and the water injection rate.

RESULTS

1. The establishment of water injection hydraulic fracture laboratory method

Due to poor water absorption ability of low permeability reservoir, relatively high pressure at water injection well; during the actual injection process, the pressure at the bottom of the well is usually higher than the overburden pressure of the rock. The conventional core holder, constrained by the design, can only simulate the situation when the overburden pressure is higher than the porosity pressure, but cannot simulate the situation when the bottom well pressure is higher than the overburden pressure. This laboratory approach constrains the simulation of low permeability oil well high pressure water injection process, leading to a gap in understanding seepage and displacement. The new approach introduced here installed sealing system on both sides of the conventional core holder, which helped to simulate the process when the injection pressure is higher than the overburden pressure. Below in Figure 1 is a diagram of the experimental apparatus. As is shown in Figure 2, the absolute permeability of core samples under water flooding is significantly enhanced by 5-30 times:

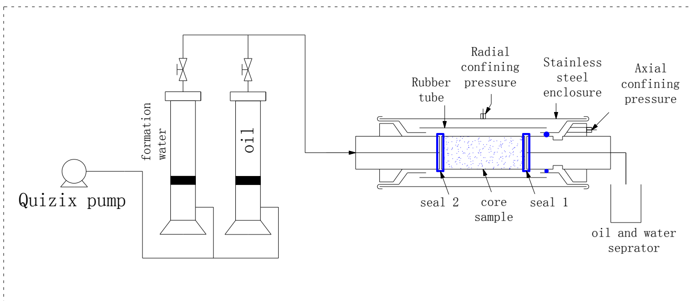

Figure 1: diagram of the experimental apparatus

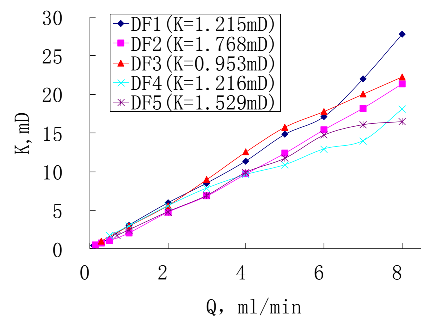

Figure 2: Dynamic fracture permeability vs flow

During the process, both injection pressure and overburden pressure data are collected, as in Figure 3. Meanwhile, the correlation between injection pressure and overburden pressure is shown along the time line, as in Figure 4. The curve mutation point ΔP_A is breakthrough pressure of injection induced dynamic fracture; ΔP_B is steady opening pressure of the dynamic fracture. After the fracture is open steadily, it remains stable.

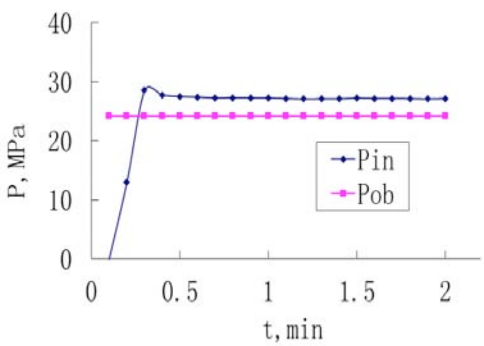

Figure 3: Injection pressure and overburden pressure curve

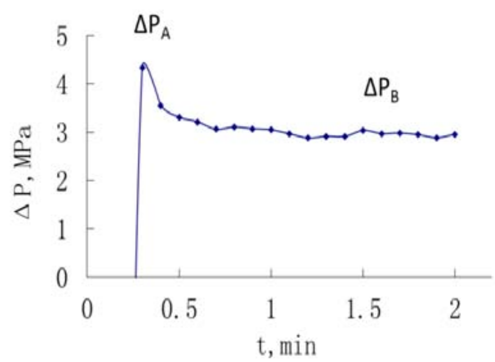

Figure 4: Injection pressure and overburden pressure difference curve along the time line

2. Pressure features of water injection dynamic fractures

Water flooding dynamic fracture stress analysis was carried out in two oilfields in Changqing. For Oil Field A, the oil field breakthrough pressure is 3.5-5MPa, and dynamic fracture open pressure is 2.8-3.4 MPa, as is shown in Figure 3. For Oil field B, the oil field breakthrough pressure is 3-4.5MPa, and dynamic fracture open pressure is 2-3MPa, see Figure 5-6.

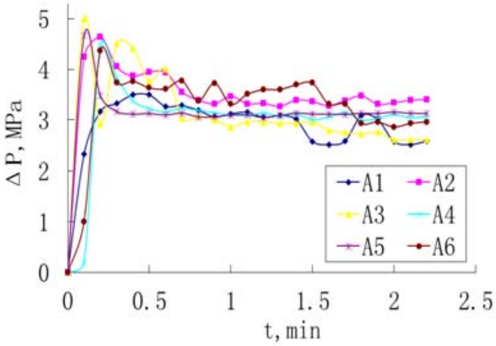

Figure 5: Oil field A-injection pressure and overburden pressure difference curve along the time line

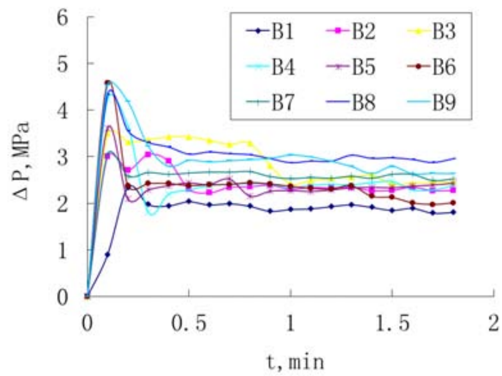

Figure 6: Oil field B-injection pressure and overburden pressure difference curve along the time line

3. Distribution features of dynamic fractures induced by water flooding

Dynamic fractures induced by water flooding cannot be seen by eyes, and can only be observed by microscopic amplification tools. This study conducted CT scanning for fractures, and selected different spots of the scanning plane, as show in figure 5-1 to 5-2, the blue area indicates fracture open surface, and figure 5-3 provided a three-dimensional reconstruction of the characteristics of the fracture surface. The fracture opening surface basically presents the plane distribution characteristics, and the average fracture width is 10-65 microns.

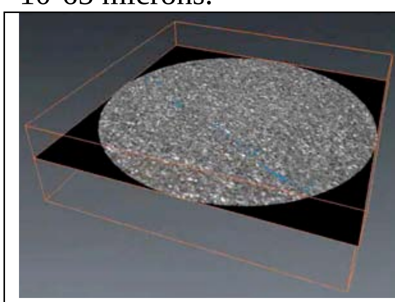

Figure 7-1: features of dynamic fractures induced by water flooding

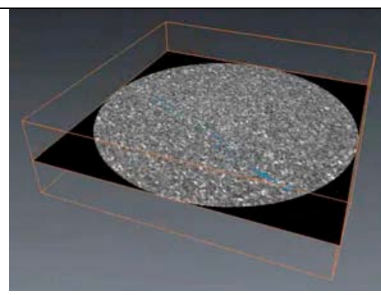

Figure 7-2: features of dynamic fractures induced by water flooding

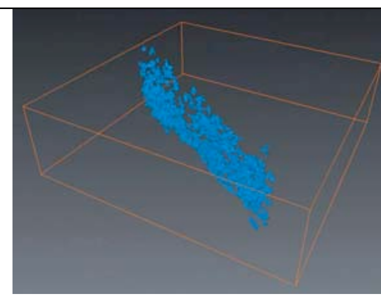

Figure7-3: features of dynamic fractures induced by water flooding

4. Features of dynamic fractures induced by water flooding displacement

Research was carried out on the dynamic fracture recovery degree and water ratio of rocks in an oilfield. After dynamic fractures induced by water flooding was open, the crude oil recovery degree was significantly lower than that of the matrix: the degree of matrix production was 56%, and the degree of dynamic fracture induced by water flooding was 8%-40%, with a wide distribution range, as shown in Figure 8. Comparison of the Daqing Oilfield, Jilin Oilfield, and Changqing oil field on dynamic fractures induced by water flooding is shown in Figure 9, and the core samples parameters are listed in table 1. We can see that matrix recovery rate is between 40%-68%, and dynamic fractures induced by water flooding recovery rate is significantly reduced.

Table 1: core sample parameters

NO.	φ %	Ka $10^{-3}\mu m^2$	NO.	φ %	Ka $10^{-3}\mu m^2$	NO.	φ %	Ka $10^{-3}\mu m^2$	NO.	φ %	Ka $10^{-3}\mu m^2$
1	12.5	0.524	7	14.6	2.58	13	18	1.91	19	13.5	2.66
2	11.6	0.317	8	12	4.3	14	14	1.58	20	16.1	1.69
3	11.4	0.409	9	11.6	0.66	15	9.7	0.266	21	14.3	2.09
4	10.8	0.618	10	12.8	2.65	16	8.4	0.232	22	13.2	1.38
5	11.1	0.559	11	15.3	3.06	17	12.3	0.184	23	13.1	1.63
6	13.3	3.9	12	18.7	5.49	18	15.3	1.14	24	12.6	1.02

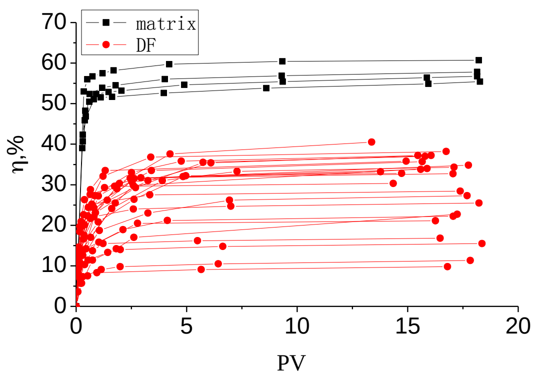

Figure 8: Matrix displacement and dynamic fracture injection multiple fractures and recovery efficiency curve

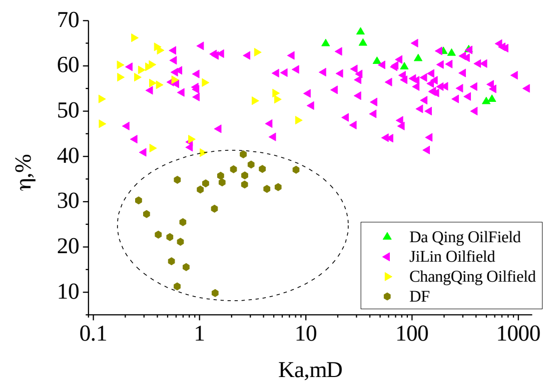

Figure9: Original Matrix displacement and dynamic fracture displacement recovery curve

After high pressure water injection in low permeability reservoir, the injected water flows along the fracture, and the water ratio is increased quickly: the rate of no water recovery rate is 0-15%, and the degree of matrix water recovery rate is between 37%-52%. Figure 10 and Figure 11 demonstrates a comparison between core samples result and oil field result. Figure 11 shows the characteristics of matrix displacement and fracture displacement in the oil field, and also shows the fast rising of water flooding in fractured reservoirs.

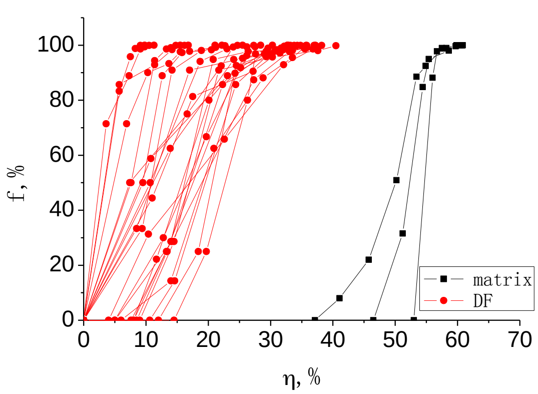

Figure 10: Core samples result- Matrix and dynamic fractures oil recovery(η) and water cut ratio(f)

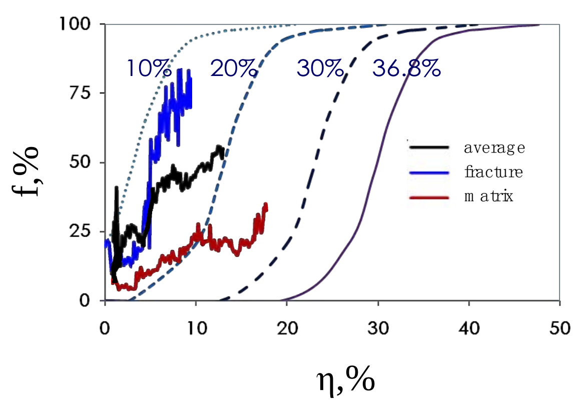

Figure 11: Oil field result-Relation between oil recovery (η) and water cut ratio (f)

CONCLUSION

This study provides data to support the correlation between the behavior of dynamic induced fractures and the production rate, by simulating dynamic fracture induced by injecting water into core samples. The process of water flooding is tracked by recording the variation of the overburden pressure with the water injection pressure and the characteristic of the induced fracture system and the flowing pattern are investigated as well.

Fractures start being induced when water injection pressure is 0.7-3.2MPa higher than the overburden pressure and becomes stable at 1.0-5.0Mpa higher than the overburden pressure. Experimental measurements show that the induced fractures, tend to grow in a plane pattern, while both fracture width and fracture pressure increase with water injection rate, which can also explain the reason that absolute permeability of core samples under water flooding is significantly enhanced by 5-30 times. On the other hand, the displacement efficiency of the induced fractures is about 9.8-25.5%, which is lower than that of matrix controlled flow ability, which is about 56-63%.

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