Experimental Study on Interlayer Interference of Influence Factor

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***Abstract*—In view of offshore conventional heavy oil reservoir, it is characterized by serious interlayer interference, low flooding recovery and difficulty to develop on low permeability layers with the development of large well space and multi-layer commingled. For the purpose of interlayer interference on flooding oilfield development with different standard permeability and permeability ratio, visual physical simulation experiments on dynamic multilayer flooding oil were carried out. The research result show that when the permeability rise, the contribution of high permeability layer significant increase, with the obvious appearance of less oil production of low permeability layer, and the total recovery is significantly decreased. When the permeability ratio rises above 3, the larger contribution of high permeability layer, and the contribution ratio of high and low layers is gradually increased, and the total efficiency is decreased. When the standard permeability is small, which called the permeability value of low layer, the water breakthrough time of high layer is short.**

***Index Terms*—interlayer interference, permeability ratio, standard permeability, flooding efficiency**

I. Introduction

At present, the global oil recoverable reserves found is about 70 billion ton, including large offshore oilfields taking up 41%. There is no exception in China, which oil and gas resource is quite rich, and all kinds of reserves up to 6.1billion ton has been found, mainly concentrating in Bohai Bay. Of all the offshore oil reserves proven up at present, the heavy oil in Bohai bay occupies big proportion, while which has a lower water flooding recovery. The main reason of low recovery efficiency is interlayer interference, which caused by the formation heterogeneous structure and multi-layers commingling injection and production. Therefore, it is of great importance to describe the influence factor of interlayer interference, which could provide suggestion and adjustment for further development, in order to achieve rational efficient development in developing offshore reserves.

II. Experiment

Water flooding process in conventional heavy oil field in offshore due to interlayer interference, there is single onrush of water flooding and features that recovery is low and the low permeability layer is difficult to use [1] [2]. In order to study the conditions under different standard permeability (the low permeability was taken as standard permeability in this paper) and differential permeability, the impact of inter-layer interference on water flooding oil field development [3]-[8], the law reflects the deep changes in inter-layer interference, using sand-filled pipe and joint injection part mining method with the three formation of high, medium and low permeability models. Design experiment models are shown in Table I.

TABLE I. Simulation Plans During Different Flooding Water Permeability Ratio Conditions

Plan	Sand-filled pipes permeability ($10^{-3}\mu m^2$)	Plan	Sand-filled pipes permeability ($10^{-3}\mu m^2$)
1	1000	2	1000
	1400		1300
	1800		2500
3	1000		
	1700		
	3500		
4	850	5	850
	1300		1700
	1700		3500
6	650	7	650
	1300		2300
	2300		3600

A. Experiment Equipments and Processes

This experiment uses sand-filled pipes as the displacement model, which is showed in Fig. 1 and Fig. 2. Three sand-filled pipes were used to modify three layers with different permeability, and before the injection side there was a six-way valve with a piezometer so as to get the injection pressure real-time monitoring.

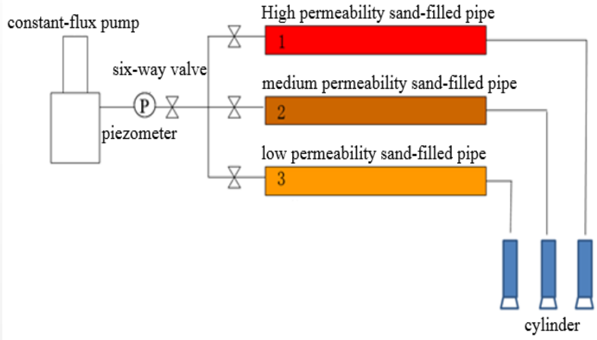

Figure 1. Physical model diagram of experiment.

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Figure 2. Installation diagram of experiment.

B. Experimental Parameters

Sand-filled tubes' length is 350mm with 25mm inner diameter. Oil viscosity is 67mPa.s, and experimental fluid injection is constant flow injection, which single-pipe displacement flow is 1ml/min, and which three pipes joint flow is 3ml/min.

III. Results

A. Single-Pipe Water Flooding Experiment

Taken Plan 5 as an example, Fig. 3 and Fig. 4 show that when the permeability ratio of laboratory experiment is 4.13, it is obvious with analyzing single-pipe experiments that displacement efficiency of three single-pipe water flooding experiments is similar with the same pore volume water injection, which the water cut rises law is close, showing no difference after water produced. Just as permeability increases, single-pipe's absolute recovery period is shortened.

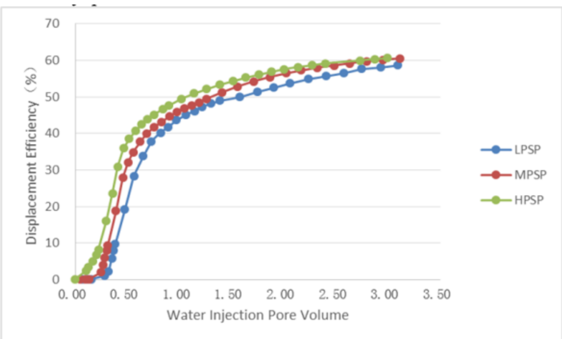

Figure 3. Relationship between each displacement efficiency with water injection pore volume in single-pipe water flooding.

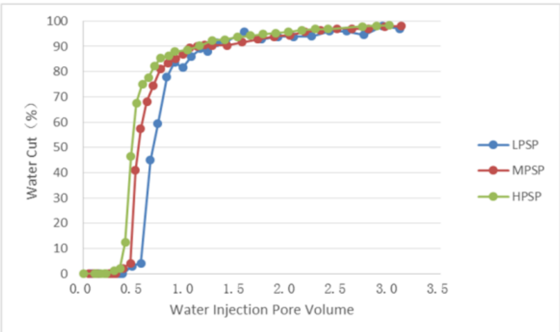

Figure 4. Relationship between each water cut with water injection pore volume in single-pipe water flooding.

B. Three-Pipes Comingling Water Flooding Experiment

From the commingling water flooding experiments phenomenon, during multilayer water commingling injection, the phenomenon of breakthrough along monolayer of high permeability sand-filled pipe (HPSP) is obvious (Fig. 5), which lead to uneven waterline forward and water cut of produced liquid rise rapidly. Water flooding is "nearly pistons' drive in low permeability sand-filled pipe (LPSP) and its displacement is slower (Fig. 6).

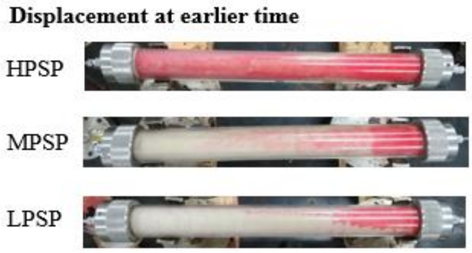

Figure 5. Commingling injection experiment phenomena at earlier time.

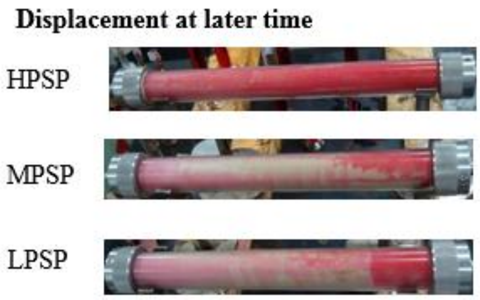

Figure 6. Commingling injection experiment phenomena at later time.

Note from the commingling water injection experimental data (Fig. 7 and Fig. 8), the final oil displacement efficiency of HPSP is significantly higher than in medium permeability sand-filled pipe (MPSP) and LPSP, and the absolute recovery period of single pipe extends with decreasing permeability. Taken injection pressure in view (Fig. 9), the pressure of LPSP is maximal and the pressure of HPSP is minimal during single-pipe displacement experiment. While co-injection pressure is slightly higher than HPSP's pressure during single-pipe displacement and almost coincides with HPSP's pressure during single-pipe displacement in the later flooding part.

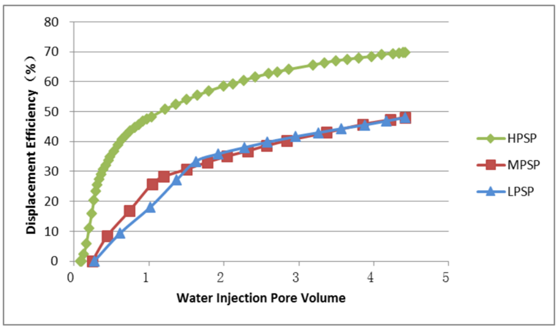

Figure 7. Relationship between each oil displacement efficiency with injection pore volume in commingling displacement.

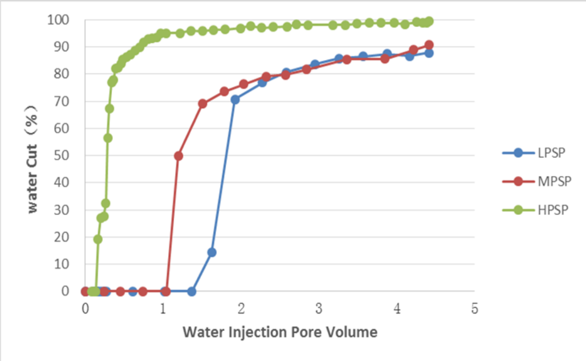

Figure 8. Relationship between each water cut with injection pore volume in commingling displacement

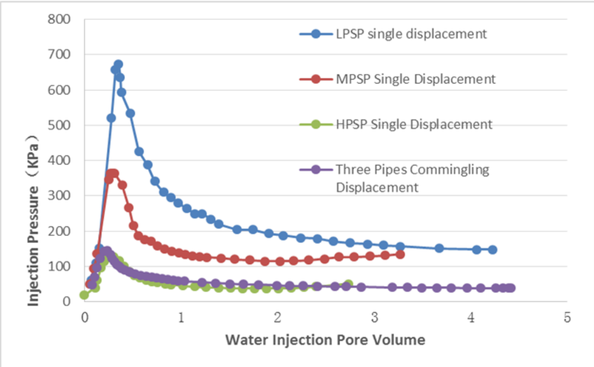

Figure 9. Relationship between injection pressure with injection pore volume in single-pipe and commingling displacement.

IV. Discussion

A. Permeability Ratio

Comparing 3 multiple experiments of 3 sand-filled pipes with different permeability ratios, as it is showed in Table II, conclusions could be gotten as follows: the oil displacement efficiency of LPSP at water break through increase as the permeability ratio rises, while the displacement efficiency decrease when the flooding ends. As the permeability ratio rises, the HPSP's final displacement efficiency and the contribution of single sand-filled pipe increases, but the total displacement efficiency of all is declining obviously. Comparing case 1 and case 3, the difference of their permeability ratio is less than one time, the total displacement efficiency is by nearly 15%.

It is observed that the contribution of single sand-filled pipe is almost a third when the permeability ratio is less than 3, and that the contribution of HPSP is gradually increasing and the contribution ratio of HPSP to LPSP is much larger when the permeability ratio is more than 3, comparing case 1,2,4 with case 3,5,6,7（Table II）. The permeability ratio value of case 7 is 5.72, and the contribution of HPSP to LPSP is more than 5 times. Hence, our results indicate that little oil could be obtained with the permeability ratio rising by the influence of interlayer interference, which is terrible bad for the high-efficient development of oil field.

B. Standard Permeability

It is observed from the water cut curves of the 7 cases that no water produced from case 6 and 7 because of the lower standard permeability during the time of 3 pore volume flooding. The difference of standard permeability of case 1 and 4 is less than $100\times10^{-3}\mu m^2$, with approximate permeability ratio, but the difference of total oil displacement efficiency is a third. Comparing case 3 and case 6, with standard permeability dropped about $300\times10^{-3}\mu m^2$, it is obvious from Fig. 10 and Fig. 11 that the production of LPSP is still in the no water phase stage, even if the water cur of HPSP reaches 98%, which is the limitation water cut. The contributions of HPSP of the two both are 50%, but the difference of contribution of the two LPSP is about one time. In other words, the water breakthrough occurred earlier in the HPSP which the standard permeability is relatively low with rapidly increasing water cut, so much more injected water flow into the HPSP in which high permeability channels formed, which cause much more large liquid produced and little difference of total displacement efficiency. In the case of commingling injection and production, if the production of lower permeability layers wants to achieve higher water cut, the higher permeability layers would keep high water cut production for quite a long time, which is huge waste of injected water. Therefore, the value of standard permeability would directly affect the total displacement efficiency when the oilfield is developed with commingled injection and production, which could be explained like short plate theory that lower permeability layers would do harm to the overall commingling injection and production.

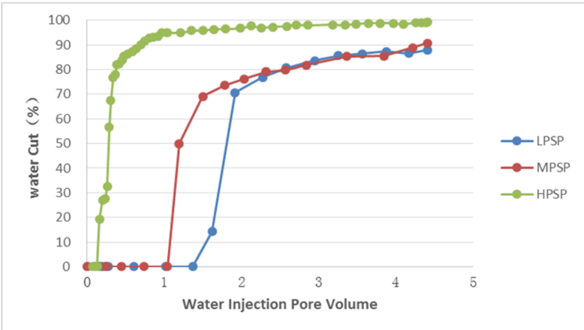

Figure 10. Relationship between each water cut with injection pore volume in commingling displacement at permeability ratio 3.29.

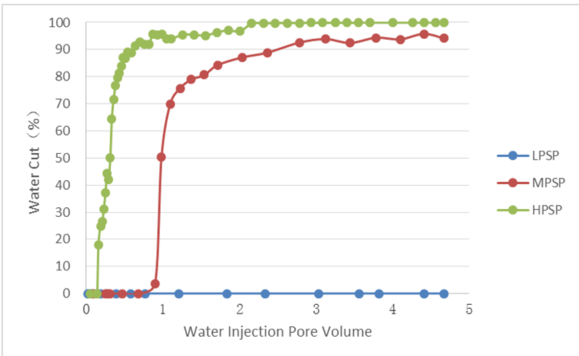

Figure 11. Relationship between each water cut with injection pore volume in commingling displacement at permeability ratio 3.60.

TABLE II. EXPERIMENT RESULTS OF THREE PIPES COMMINGLING INJECTION AT DIFFERENT PERMEABILITY RATIO

Plan	Permeability ratio	Permeability （$10^{-3}\mu m^2$）	Absolute displacement efficiency （%）	Final single pipe displacement efficiency （%）	Contribution of single pipe （%）	Final water cut of single pipe（%）	Total displacement efficiency （%）
1	1.84	973	29.84	76.98	29.83	91.67	79.9
		1288	13.97	83.67	34.99	99.91	
		1797	14.06	82.9	35.18	99.42	
2	2.77	1073	44.53	68.59	29.27	86.6	72.32
		1976	29.28	74.16	34.13	97.58	
		2973	26.34	83.82	36.6	99.87	
3	3.29	973	40.48	50	24.5	68.33	64.62
		1736	23.62	51.15	27.4	80.77	
		3200	27.8	87.61	48.07	99.9	
4	2.13	895	47.32	59.46	30.88	96.88	61.13
		1374	26.94	60.15	32.8	95.74	
		1917	17.12	63.62	36.32	98.32	
5	4.21	858	27.18	41.61	24.66	83.64	50.45
		1708	25.83	41.35	25.5	84.62	
		3611	5.79	65.56	49.84	91.13	
6	3.6	679	-	20.4	13.07	0	48.32
		1534	26.73	52.62	36.52	93.9	
		2449	3.45	67.81	50.4	99.92	
7	5.72	651	-	12.26	10.17	0	44.01
		2329	21.68	52.88	37.4	95	
		3729	9.57	71.28	52.43	99.33	

As the influence of interlayer interference, the high permeability layers absorb more water, while the lower permeability layers absorb less, which cause the driving speed of water flooding front in the higher permeability layers getting faster and faster, thus production of lower permeability layers influenced severely. For the whole flooding area, percolating resistance of higher permeability layer fell sharply as oil viscosity is much larger than water viscosity, causing percolating resistance of the whole flooding area reduction much more than the increment of the percolating resistance of the area on account of oil-water two phase flowing. Thus, most of fluid flood into high permeability layers, while little fluid flowing into lower permeability layers which maintaining high percolating resistance and velocity of waterline advancing getting slower and slower. What is more, when the water produced from the exit end in the experiment, the injection pressure dropped sharply, which further weaken the oil seepage ability of LPSP. The drive pressure is diminishing, which could illustrated as rising of the back pressure in the wellbore because of increasing of fluid density in the wellbore, aggravated the interlayer interference on lower permeability layers. Addition, the decrease of the injection pressure on injection side make much more injected water flow into the higher permeability layers through the preponderance flow path in the formation, which cause difficult use of lower permeability layers and reduction of total final displacement efficiency.

V. CONCLUSION

In multi-layer commingling injection, with the increase of permeability ratio, high permeability layer single contribution rate rise significantly, which constraint low permeability layers seriously, and the total oil displacement efficiency decreases obviously.

When the permeability ratio is less than 3, single pipe contribution is similar in three on commingling displacement experiments; but once the permeability ratio is higher than 3, HPSP's contribution rate is significantly increasing, and the contribution ratio of HPSP to LPSP gradually enlarger.

With same permeability ratio, standard permeability which is the low permeability directly affects the water breakthrough time and total oil displacement efficiency in the high permeability layer.

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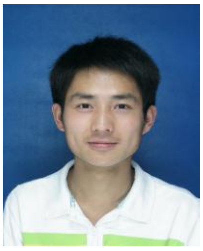

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