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Research Article

Experimental Study on Determination of Perforation Damage Parameter of Berea Core

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Abstract: In order the foundation and project number reservoir conditions, an indoor simulation experiment was carried out using the micro-permeameter and Berea cores with different permeability. The thickness and permeability of crushed zone around the perforation tunnels were given under the conditions of different perforating charges (conventional charge YD89-1, large aperture charge YD127-4, deep penetration charge BH54RDX-1) and different permeability (1.0 mD, 10.0 mD, 100.0 mD and 1000.0 mD). The research results show that: micro-cracks will appear in low permeability (less than or equal to 1.0 mD) Berea core, leading to the increase of permeability in crushed zone, which means that under the condition of low permeability, perforation will improve the situation around the holes instead of decreasing the permeability. While the permeability of crushed zone decreases obviously when the core permeability is higher (10.0 to 100.0 mD). Whether the core permeability is low or high, the thickness of crushed zone will increase with the increasing of perforating diameter. The compacted thickness of three types of charges are 10 to 12, 10 to 14, 12 to 16 and 14 to 18 mm corresponding to the permeability of 1.0, 10.0, 100.0 and 1000.0 mD, respectively. The results of this study have an important guiding significance for the optimization of perforating charges and the calculation of skin factors of well completion.

Keywords: Core, determination of compaction parameter, perforation experiment, perforation damage parameter

INTRODUCTION

Perforation is a technique to set up a thoroughfare between reservoir and well using the jet produced from high explosives. Meanwhile, perforation will cause a damage to the reservoir, which affects the production. Lirong and Yuhuan (2001) analyzed the damage mechanism of reservoir during perforating attributed the influencing factors of reservoir damage to the following aspects: perforating compacted effect, perforating parameters, perforating fluid and perforating pressure difference. Since then, scholars have done lots of theoretical study on damage mechanism of perforation completion and the conclusions are broadly similar (Zhang *et al*., 2003; Yuan *et al*., 2006; Sun, 2011; Lu, 2012; Sun *et al*., 2013; Bahrami *et al*., 2011). Liu *et al*. (2006) analyzed the effect on production caused by crushed zone thickness and compaction degree. Li and Sun (2007) carried out a perforating experiment and analyzed the hole depth and permeability change around the holes. Many of other scholars (Li *et al*., 2011; Halleck *et al.*, 1988; Behrmann and Halleck, 1988; Heiland *et al*., 2009; Karacan *et al*., 2001) have also carried out perforation experiments, but these experiments only direct at low permeability cores, as a result, the results have a certain limitation. In this paper, a perforation simulation experiment was carried out to test the invasion depth of perforating charges in different permeability cores, as well as the reservoir damage caused by perforation completion, thus providing a basis for optimizing perforating equipment and improving the efficiency of perforation completion.

MATERIALS AND METHODS

Experimental device: The experimental device is shown in Fig. 1, consisting of 3 parts: an overburden pressure vessel which is used to exert confining pressure on the model, a pressure vessel which is used to keep wellbore pressure and exert pressure on perforating gun, as well as a flow system which is used to exert pore pressure on the model.

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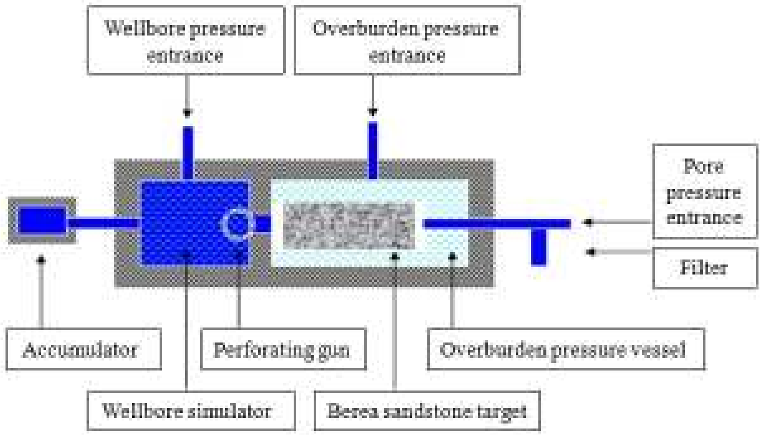

Fig. 1: Schematic drawing of experimental device

The pressure vessels in Fig. 1 can simulate overburden pressure, pore pressure and wellbore pressure. The Berea cores are used to simulate reservoir sandstone, the sodium chloride solution is used to simulate the formation water and the accumulator is used to simulate the buffer which is provided by formation and wellbore. Main experimental equipments and auxiliary equipments: perforating device, simulate core, simulate wellbore, perforating board, cement block and auxiliary device to keep the pressure and control the flow.

Experiment scheme:

- Study the flow condition of perforating cores and test the permeability of different parts of the damaged cores.
- Study the influence of the same perforating equipment on different types of cores (the thickness of crushed zone, the permeability of crushed zone and the generation of micro-cracks) and analyze the damage to each type of cores.
- Study the influence on the same type of core caused by different perforators and analyze the thickness of crushed zone, the permeability of crushed zone and the generation of micro-cracks.

Experimental procedure:

- Put the charge type of YD89-1 into the perforator and then put the perforator into the wellbore simulator. Put the Berea core with a permeability of 1.0 mD into the overburden pressure container and exert pressure on the wellbore and sample through a pressure pump till the scheduled pressure.
- Detonate the perforating gun and take the core out after perforating. Then measure the permeability of different parts of the damaged core with MP401 micro permeability tester and record the data.
- Change the core in step (1) into 10.0 mD, 100.0 mD and 1000.0 mD respectively and repeat steps (1) to (2).

Table 1: Parameters of perforating charges

Charge type	Average depth of perforation (mm)	Average aperture (mm)
YD89-1	505	8.8
YD127-4	657	11.8
BH54RDX	256	20.7

Table 2: Parameters of cores

Permeability (mD)	Length (mm)	Diameter (mm)
1.0±0.5	600±10	180±5
10.0±1	600±10	180±5
100.0±10	600±10	180±5
1000.0±20	600±10	180±5

- Change the charge in step (1) into YD127-4 and BH54RDX respectively and repeat steps (1) to (3);

Experiment parameters: In this experiment, the overburden pressure is 25 MPa, the pore pressure is 15 MPa and the wellbore pressure is 10 MPa. The perforating charges used in the experiment are from Daqing Perforating Charge Plant (Table 1). The cores used in this experiment are Berea cores (Table 2), which are stable and widely used and each type of cores is prepared for three pieces.

RESULTS AND DISCUSSION

Using the experimental system which is designed in this paper, the permeability of different parts of the cores can be measured after perforating and then the compaction degree can be calculated(K/Ki). The measuring results are shown in Table 3.

As is seen from the table, the compaction degree gradually approaches to 1with the increase of depth, namely the permeability of crushed zone gradually recoveries to the original permeability from the center of perforation hole to the deep in the core and the permeability of crushed zone around the whole center changes obviously. In order to ensure the calculation accuracy of perforation completion skin factor, the weighted average method is used to deal with the

Table 3: Measuring results

	YD89-1(K/Ki)				YD127-4 (K/Ki)				BH54RDX-1 (K/Ki)			
R (mm)	1.0 mD	10.0 mD	100.0 mD	1000.0 mD	1.0 mD	10.0 mD	100.0 mD	1000.0 mD	1.0 mD	10.0 mD	100.0 mD	1000. 0 mD
2	2.13	0.32	0.18	0.05	3.13	0.26	0.12	0.03	4.26	0.2	0.08	0.01
4	1.56	0.56	0.46	0.26	2.26	0.5	0.4	0.2	3.01	0.46	0.36	0.16
6	1.12	0.78	0.68	0.48	1.52	0.71	0.6	0.41	2.12	0.67	0.56	0.36
8	1.03	0.91	0.81	0.61	1.16	0.86	0.75	0.58	1.43	0.81	0.7	0.55
10	0.96	1.01	0.93	0.82	0.96	0.96	0.87	0.76	1.2	0.93	0.83	0.7
12	1	0.96	0.96	0.96	1.01	1.01	0.93	0.89	1	0.96	0.9	0.84
14	0.98	0.98	1.03	0.98	0.98	0.98	0.96	0.94	0.95	0.99	0.94	0.9
16	1.03	1.03	1.03	1.03	0.96	1.05	1	0.98	1.01	1.03	0.98	0.96
18	1.05	1.05	1.05	0.97	0.97	1.01	1.01	0.99	1.06	0.99	0.99	1
20	0.97	0.96	0.96	1.02	1.03	0.99	1.01	1	0.99	1.02	1.02	1.02

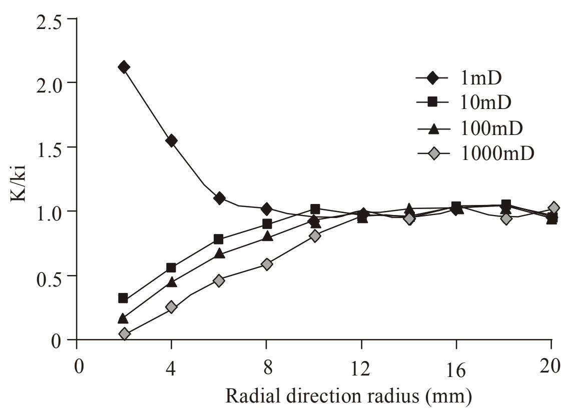

Fig. 2: Impact of different reservoirs on crushed zone (YD89-1)

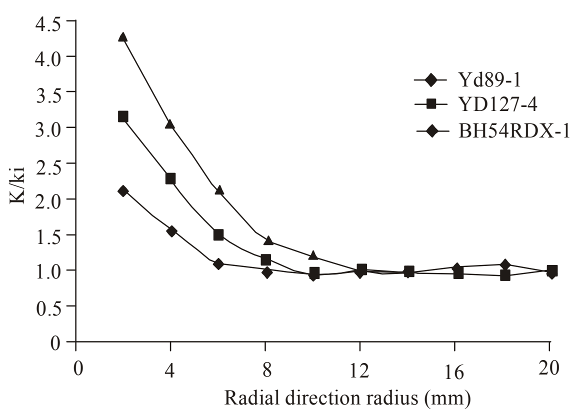

Fig. 3: Impact of different perforators on crushed zone (1 mD)

measured value of the thickness and permeability of crushed zone. The calculation results show that: when the permeability of reservoir is 1.0 mD, the compaction degree of three types of perforating charges are1.17, 1.44 and 1.63 respectively; when the permeability of reservoir is 10.0 mD, the compaction degree are 0.83, 0.84 and 0.85 respectively; when the permeability of reservoir is 100.0 mD, the compaction degree are 0.80, 0.80 and 0.81 respectively; when the permeability of reservoir is 1000.0 mD, the compaction degree are 0.76, 0.77 and 0.78, respectively.

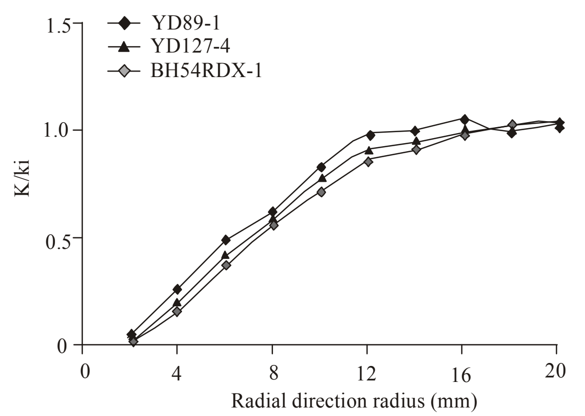

Fig. 4: Impact of different perforators on crushed zone (1000 mD)

The influence of different reservoirs (1.0 and 1000.0 mD) and different perforators (the type of charge is YD89-1) on crushed zone are shown in Fig. 2 to 4.

From Fig. 2 to 4, we can find that:

Cracks will generate in low permeability reservoir (1.0 mD), leading to the increase of permeability in crushed zone and the permeability increases with the hole diameter; the thickness of crushed zone ranges from 10 to 12 mm when using three different types of perforators and the thickness increases with the hole diameter, too.

When perforating in medium and high permeability formation (larger than or equal to 10.0 mD), the permeability of crushed zone decreases obviously. The compacted thickness is 10 to 14 mm, 12 to 16 mm and 14 to 18 mm corresponding to the permeability of 10.0, 100.0 and 1000 mD, respectively. When the reservoir permeability is certain, the compaction thickness will increase with the perforation diameter, while the compaction permeability will slightly decreases. When the perforation diameter is certain, the compaction thickness will increase with reservoir permeability, while the compaction permeability will decrease.

CONCLUSION

- Research results show that cracks will generate in the low permeability cores during perforating, leading to the increase of permeability in crushed zone, that is to say the perforation under low permeability condition improves the situation around the tunnels instead of decreasing the permeability, while the permeability of crushed zone decreases obviously when the core permeability is higher.

- Whether the core permeability is low or high, the thickness of crushed zone will increase with the perforation diameter. When the core permeability is 1.0, 10.0 and 1000.0 mD, respectively, the thickness of crushed zone is corresponding to 10 to 12 mm, 10 to 14 mm and 14 to 18 mm.
- From the center of bullet hole to the deep in the reservoir, the permeability of crushed zone gradually recoveries to the original permeability and the change of permeability near the center of bullet hole is more obvious. Therefore, in order to ensure the calculation accuracy of skin factor, it is necessary to take the weighted average method to deal with the measured data of the thickness and permeability of crushed zone.

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