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Simulation Experiment Research for Exploding in Fracture

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Abstract

On the basis of low permeability exploiting statement, "Exploding in fracture" is present in this paper and the feasibility and safety of this technology is also analyzed. It is found that the rock damage and fracture by shock wave in "Exploding in Fracture" can be simulated by the experiment of exploding on the surface of the cement sample in deep water. The damage and fracture of the cement sample, and the wave propagation proceed, and the damage and fracture mechanism are described qualitatively. It is found that the micro-fractures and compacted wave have an intimate relationship with the initial damage of the sample. The numerical simulation result is accordant with the experiment result. It also concluded that the qualitative explanation of rock damage and fracture mechanism is right. The compacted damage zone has definite permeability, which has an important means to "Exploding in Fracture" technology.

Key words: Simulation experiment; Exploding in fracture; Damage and fracture

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INTRODUCTION

The exploitation of low permeability reservoir will be faster and faster, because it is an important resource in oil industry of our countryside. The main character of the low permeability reservoir is low permeability and low productivity, so the stimulation is need.

The main technology for low-permeability reservoir stimulation is hydraulic fracturing, high energy gas fracturing and so on. There are some limitations for these technologies. For hydraulic fracturing, the orientation of crack propagation is dominated by Earth stress field, and it can only create a couple of fracture. For energy gas fracturing, it can create many radial fractures, but they are very short. So the effectiveness of both stimulation technologies can not meet the demand for the development of petroleum industry.

1. THE PRESENT OF "EXPLODING IN FRACTURE"

In order to exploit the low-permeability reservoir effectively, the technology of "Exploding in Fracture" is presented by Institute of Mechanics of Chinese Academy of Science. The basic ideal of this technology is as follow:

First, using the hydraulic fracture equipment, the emulsion explosive is taken into the hydraulic fracture by fracturing fluid. Second, the emulsion explosive is denoted and it keeps on deflagration in the hydraulic fracture. During this step, the borehole is protected by well control fluid. Many fractures surrounding the hydraulic fracture are created, and they can greatly enhance the reservoir permeability and the oil recovery.

Not only can this technology greatly enhance the oil recovery for low-permeability reservoir, but also it can change the unexploited reservoir to exploited reservoir.

1.1 Feasibility of "Exploding in Fracture"

The feasibility of "Exploding in Fracture" lies on 4 technology problems hereafter:

(1) Can the explosive be taken into hydraulic fracture?
(2) Can the explosive be fired and keep on deflagration steadily in the hydraulic fracture?

(3) Can the oil-bearing rock be damaged and fractured by explosive exploding?
(4) Can the reservoir be polluted by the unexploded explosive?

Each problem is analyzed, and the conclusion is that all the questions can be solved.

Problem 1: The explosive can be taken into the hydraulic fracture by fracturing fluid. Figure 1 is an in-situ sketch map of "Exploding in Fracture". The right-up side of the sketch map is the in-situ made-up and taken-in of the explosive, and it gives us a general idea about the taken-in approach.

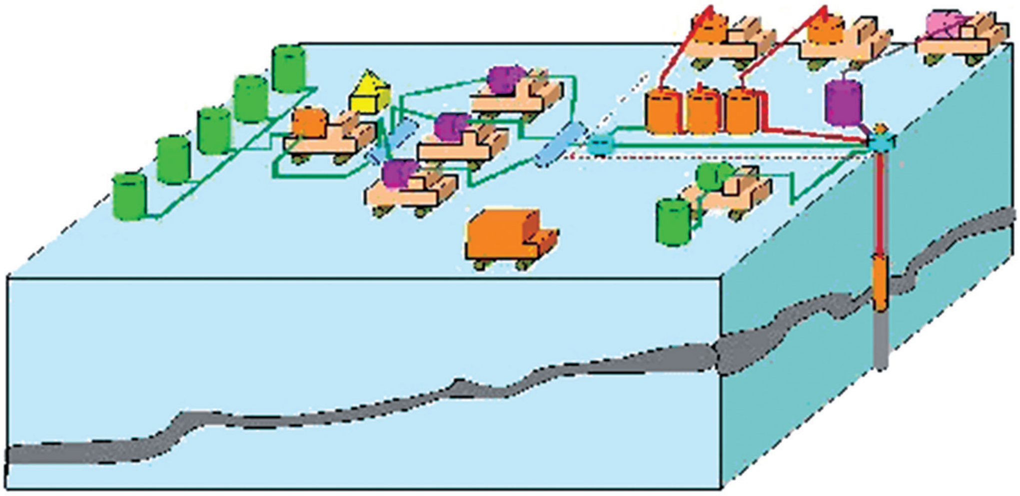

Figure 1
In-Situ Sketch Map of "Exploding in Fracture"

Problem 2: There is a critical dimension for the explosive to keep on deflagration. The critical dimension of the explosive we select is nearly 1mm. The width of the hydraulic fracture is from millimeters to dozens of millimeters, so it is possible to keep the explosive deflagration steadily. Reservoir condition is favor of steady deflagration for the explosive, such as high pressure, and high temperature, and well sealing ability and so on.

Problem 3: Simulation experiment and high energy gas fracturing experience show that the exploding of explosive can effectively damage and fracture rock. The effect of rock damage and fracture by the exploding wave (left photo) and exploding gas (right 2 photos) are showed by Figure 2.

Figure 2
Photos of Rock Damage and Fracture Effect by Exploding

Problem 4: the selected explosive is organic explosive, and it is oil wet, so it can protect the reservoir.

1.2 The Safety of "Exploding in Fracture"

Following the safety regulation during the process of in-situ implement, Operators and equipment is safety. The safety of production fluid is being paid more attention. There are 3 problems about the production fluid.

(1) Can the unexploded explosive be transported to ground?
(2) Can the unexploded explosive be separated from the production fluid?
(3) If the explosive can not be separated, can it be exploding in the oil refining system?

Each problem is analyzed, and the conclusion is that all the questions can be solved.

Problem 1: On the basis of hydraulic fracture experience, the flow back velocity of hydraulic fluid is 10 cm/s. The settling velocity of explosive grain is about

2 mm/s. If the fracture height is 5 meter, the explosive grain which has a 200-meter distance to well bore can be transport to the well bore. The flow back velocity in the well bore is much faster than the settling velocity of explosive grain, so most of the unexploded explosive grain can be transport to the ground.

Problem 2: the concentration ratio of the unexploded explosive grain in the production is less than 1%. The density ratio of explosive grain and production fluid is 1.8-2, and the grain size is on the scale of micrometer, so the unexploded grain can be separated by centrifuge.

Problem 3: the decomposition temperature of the explosive is less than 400 degree, and the explosive concentration is little less than 1%. It can conclusion that the unexploded explosive can but decomposition except exploding in oil refining system.

2. INTRODUCTION OF SIMULATION EXPERIMENT

There are two reasons for the damage and fracture of the oil-bearing rock by the exploding load, which is yield by the exploding of the emulsion explosive in hydraulic fracture. One is the explosion wave, and the other is explosion gas. The action of explosion wave is earlier than explosion gas. So we do some research on rock damage and fracture by explosion wave firstly. By the experiment of exploding on the surface of the cement sample in deep water, the phenomenon of the rock damage and fracture by explosion wave in "Exploding in Fracture" is simulated.

As we know, the oil-bearing core is very expensive and is anisotropy, so it is adverse for us to do basic research. Cement sample in stead of oil-bearing rock core is used in the simulation experiment.

The idea of the stimulation experiment is as follow:

First, the cement sample (Φ300 mm, 300 mm high) is placed in deep water. Second, the emulsion explosive is placed on the surface of the sample. Third, the exploder is fired. Fourth, the sample is extracted from the water. At last, the sample damage and fracture is observed (Figure 3).

In order to observe the inner damage and fracture of the sample, the prefab section was created when the sample is forming (Figure 4).

Figure 3
Simulation Experiment in-Situ

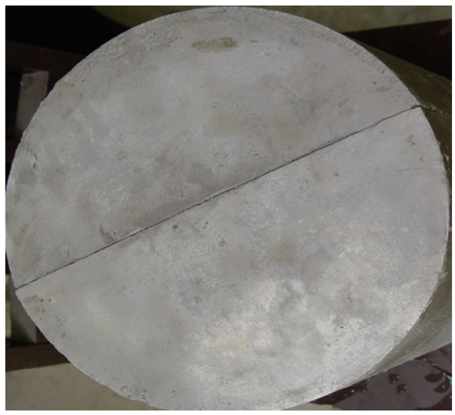

Figure 4
The Sample Photo

3. PHENOMENON OF THE SIMULATION EXPERIMENT

There are four damage zones is found on the sample, compacted fracture zone, compacted damage zone, tensile damage zone and tensile damage zone.

3.1 Compacted Fracture Zone

The condensation fracture area is in the bottom of the compacted pit. In the simulation sample, one sample has one fracture, and the crack length is 30 mm; and to the other three samples, each has three fractures. They have an intersection point at the end point of each fracture. One is paralleling with the direction of the explosive, and the other two have a nearly 60° angel with the direction of explosive (Figure 5 & Figure 6).

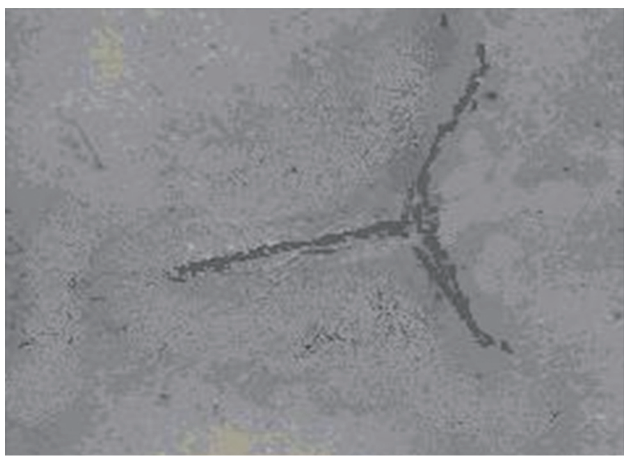

Figure 5
Sample Photo of Three Fractures

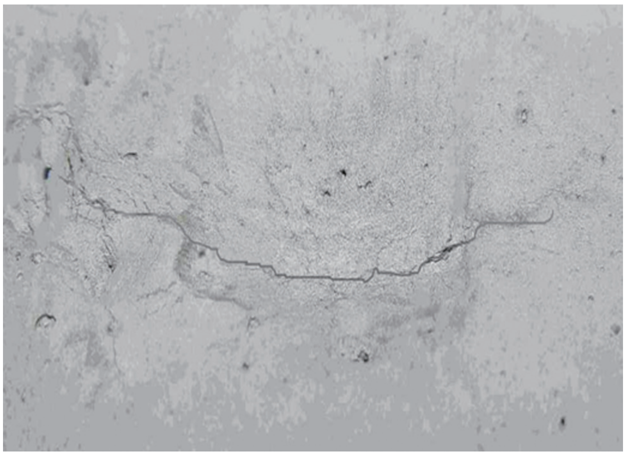

Figure 6
Sample Photo of One Fracture

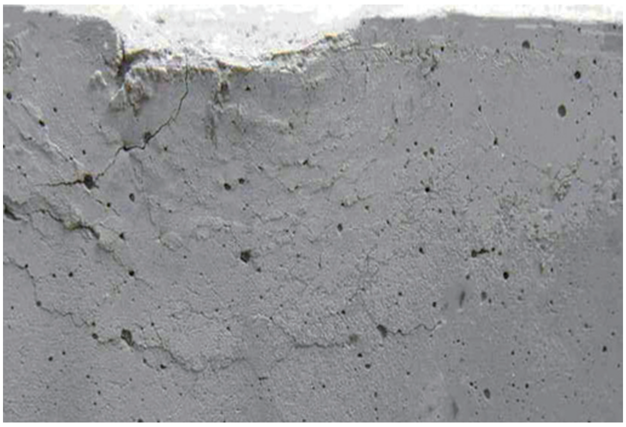

Figure 7
Compacted Damage Zone

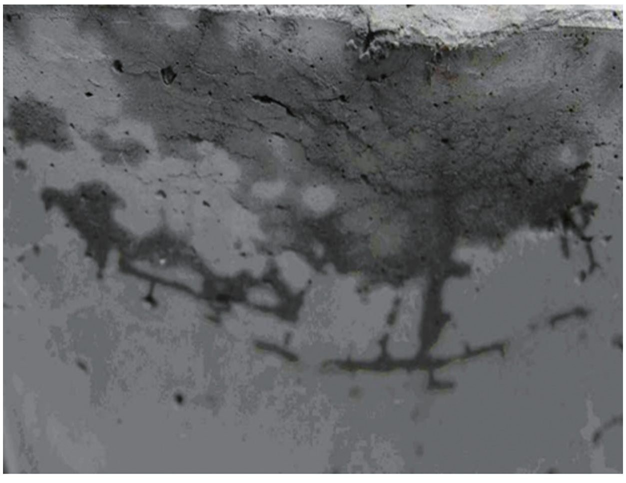

Figure 8
Permeability Experiment

3.2 Compacted Damage Zone

On the top surface of the sample, the compacted pit is observed, and there are many micro-fractures in the pit. On the prefab section, the semi-annular wave is also observed (Figure 7).

It is found that the micro-fractures have an intimate relationship with the initial damage of the sample.

Some water is dropped in the compacted pit. The color of compacted zone becomes thicken, and is close to the saturation color (Figure 8). It is conclusion that the compacted damage zone has definite permeability, which has an important means to "Exploding in Fracture" technology.

In this zone, the sample has sheer damaged, and many sheer micro-fractures are created and they are connected with each other. This is the main reason for the great enhance of the sample permeability.

3.3 Tensile Damage and Fracture Zone

On the top surface, near-annular fractures and some radial fractures are observed, and the near-annular fractures and some radial fractures are connected with each other, and the annulus-radial fracture network is formed.

On the prefab section, the fracture, which looks like "U", is observed. There are nearly 50mm distance between the broadside of fracture and the broadside of the sample and nearly 120mm to 150mm distance between the bottom of fracture and the bottom of the sample.

It is also found that the fractures and damage have an intimate relationship with the initial damage of the sample.

3.4 Prefab Section Analysis

By observing and comparing the damage and fractures on both side of the prefab section and the on the top surface of the sample, it is found that the damage and fractures on both side of the prefab section coincide well and on the top surface of the sample coincide well too, which proved that the prefab section has little influence on the fracture initiation and propagation.

4. QUALITATIVE ANALYSIS OF FRACTURE INITIATION AND PROPAGATION MECHANISM

4.1 On the Top Surface of the Sample

After the exploding of the explosive, exploding wave propagates annularly. On the radial of the sample, it has a pressure which is stronger than the threshold value of dynamic compression strength, and the sample is damaged and fractured by this stress. The wave pressure is decreasing with the wave propagation. When the wave pressure is equal to the threshold value of dynamic compression strength, the fracture propagation stopped, and this position is the boundary of the compact damage and fracture zone.

Due to the pressure on the radial, the cement grain has centrifugal displacement, which causes the hoop tension on the cement grain, and this stress is much greater than the dynamic fracture toughness. The radial fractures initiate and propagate. When the hoop tension is equal to the dynamic fracture toughness, the fracture propagation stopped.

When the wave reached the boundary of the sample, the wave is reflected. The reflected wave is rarefaction wave because of the acoustic reactance of the cement is larger than that of water. The reflected wave superimpose with the exploding wave. If the reflected wave is stronger than the exploding wave, the sample will sustain a radial tension. The annular damage and fractures will initiate and propagate at where the radial tension is larger or equal to the dynamic fracture toughness. When the radial tension is equal to the dynamic fracture toughness, the fracture propagation stopped.

4.2 On the Prefab Section

After the exploding of the explosive, exploding wave propagate downwardly. The exploding wave pressure is stronger than the threshold value of dynamic compression strength, and the sample is damaged and fractured by this stress. The wave pressure is decreasing with the wave propagation. When the wave pressure is equal to the threshold value of dynamic compression strength, the fracture propagation stopped, and this position is the boundary of the compact damage and fracture zone.

Due to the radial of the sample is 150mm and the height of the sample is 300mm, the exploding wave reached the broadside earlier than it reached the bottom of the sample. When the wave reached the broadside and bottom of the sample, the wave is reflected. The reflected wave is rarefaction wave because of the acoustic reactance of the cement is larger than that of water. The reflected wave superimpose with the exploding wave. If the reflected wave is stronger than the exploding wave, the sample will sustain a radial tension. The annular damage and fractures will initiate and propagate at where the radial tension is larger or equal to the dynamic fracture toughness. When the radial tension is equal to the dynamic fracture toughness, the fracture propagation stopped.

When the broadside reflected wave superimpose with the bottom reflected wave, the fracture will change the propagation direction. Due to the sample and the two broadsides reflected waves are symmetrical; the dispositions of the fracture propagation direction change are also symmetrical. When the two crack tip stress field superimpose, the two fractures will counter-propagate and become the interconnected system of fractures.

The “U” fracture is created by the above-mentioned condition.

5. NUMERICAL SIMULATION RESEARCH ON SAMPLE DAMAGE AND FRACTURE MECHANISM

In order to do some further research on the sample damage and fracture mechanism, the stress on different part of the sample is simulated by LS-DYNA software.

On the top surface, the numerical simulation show that the nearer the position to the center of explosive, the stronger of the explosive is. Neither is not the strongest radial tension at the boundary of the surface, nor is at the center. It is an endless belt, and the width of the belt is nearly 20-30 mm, and the radius of biggest annulus is 90-120 mm, which is accordant with the experiment result. It also concluded that the qualitative explanation of annulus-radial fracture network is right.

On the prefab section, the numerical simulation also show that the nearer the position to the center of explosive, the stronger of the explosive is. The strongest extension is a “U” belt, and there is a 50 mm distance from the belt broadside to the sample broadsides, and there is a 120-150 mm distance from the belt bottom to the sample bottom, which is accordant with the experiment result. It also concluded that the qualitative explanation of “U” is right.

CONCLUSION

(1) “Exploding in Fracture” will be one of the most effective technology for formation stimulation. It is proved that it is feasibility and safety.

(2) The rock damage and fracture by shock wave in “Exploding in Fracture” can be simulated by the experiment of exploding on the surface of the cement sample in deep water. The damage and fracture of the cement sample, and the wave propagation proceed, and the damage and fracture mechanism are described qualitatively.

(3) It is found that the micro-fractures and compacted wave have an intimate relationship with the initial damage of the sample.

(4) The compacted damage zone has definite permeability, which has an important means to “Exploding in Fracture” technology.

(5) The numerical simulation result is accordant with the experiment result. It also concluded that the qualitative explanation of rock damage and fracture mechanism is right.

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