Study on the influence of the electrode model on discharge characteristics in High-voltage Pulsed Deplugging Technology

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Abstract. In the oil-field development, blocking caused by impurities leads to a decline in oil production. The high-voltage pulsed deplugging technology can be applied successfully in oil deplugging. One of the key problems in this technology is the influence of the electrode model on discharge characteristics. In this paper, the electrode structure was studied. Firstly, the influence of the electrode gap on electric field intensity was studied by using ANSYS simulation. Secondly, a high-voltage pulsed discharge experiment system was built and the discharge characteristics were studied under different static pressure when the electrode gap varied. The results show that the larger the electrode gap, the lower the electric strength and the longer the time delay. Short breakdown time delay would make greater energy of impact waves and better blockage relieving effect.

1. Introduction
In the oil-field development, oil layer is polluted by kinds of impurities caused by drilling, fracturing, and so on. The blocking leads to a decline in oil production. Conventional approaches are releasing the chemical agent to relieve clogged wells [1], but the normal chemical technologies bring secondary pollution. How to relieve the blockings is the problem which must be solved in oil extraction. The pulsed high voltage deplugging technology has the advantages, such as environmental protection, high efficiency, and reusability. It is the deplugging technology with broad prospects.

The new pulsed high-voltage discharge technology uses electrohydraulic effect [2, 3] to generate mechanical action. Electrohydraulic effect essentially rapidly transforms electric energy into mechanical energy in impact waves, which will then act on an oil layer. These waves which have extremely strong penetrating power bombard plugging substances and pollutants near the wellbore zone, resulting in the oscillation and crushing of these blockages. Then, cavitation effect and pressure of the oil layer itself are used to suck and push these crushed blockages. Finally, the oil layer plug is removed, and permeability characteristics near the wellbore zone at the oil layer are improved.

In order to apply this technology more effectively on oil exploration, many scholars studied the pulsed high voltage system and discharge characteristics to improve power efficiency and enhance shock wave energy [4-7]. Ref. [4] studied the changing of the properties of the liquid surface. Ref. [5] studied the resistance characteristics of the plasma channel. Ref. [6] investigated the spark discharge parameters for material processing with high power ultrasound. Ref. [7] developed a high-energy arc fracturing device to carry out a series of fracture experiments.
However, the electrode structure, the electrode gap affect the discharge characteristics of the high-voltage pulse, thus they affect whether the technology can be effectively used in the oil block. In this paper, the influence of the electrode model on electric-field intensity was studied by using ANSYS simulation firstly. Because of the complex downhole operating environments, the high static pressure and the crude oil medium have a significant impact on the characteristics of high-voltage pulsed discharge. Thus a high-voltage pulsed discharge experimental system was designed to simulate the downhole working environment with high pressure to study the influence of the electrode model. The experiment will lay a theoretical foundation for the development of the downhole equipment.

2. The influence of the electrode model on electric-field intensity based on ANSYS simulation

The breakdown of matter is related to the strength of the electric filed, and the electrode structure and the gap between the positive and the negative affect the strength. In this paper, column-column model is chosen to study.

Theoretically, the higher the working voltage, the higher the voltage between the discharge electrodes, the easier the breakdown of the medium, and the better the Deplugging effect will be. But the volume of the supply voltage will increase when the voltage increases and insulation requirements for equipment will increase significantly. Considering most well operating environment in China, the dimensions of the underground device was limited. So, the working voltage was chosen in the range of 10-25kV in this paper.

The column-column model shown in Fig.1 was built by using ANSYS simulation, and the model parameters were set as follows: the radius was 2mm and the height was 5mm. Three electrode gaps were chosen as \( d=1.5\text{mm} \), \( d=2\text{mm} \), \( d=3\text{mm} \). A voltage of 20kV was applied between the electrodes of the column-column model.

![Figure 1. The column-column model](image)

When \( d=1.5\text{mm} \), the destribution of the electric-field intensity between the two electrodes was shown in Fig. 2. From the cloud picture, the strongest electric field was concentrated near the electrodes, and the maximum value was 143.52kV/cm.
Adjust the electrode gap and simulate several times. According to the results, the relationship of the electrode gap and the maximum electric-field intensity was got in Fig. 3. From Fig. 3, we can get that the maximum electric-field intensity between the electrodes decreases when the electrode gap increases. When the electrode gap is not sufficient to make discharge breakdown phenomenon occur, the high voltage pulse discharge fails. If the phenomenon occurs, the larger electric-field intensity is needed, thus the larger working voltage is needed. Hence, parameter requirement in the high-voltage pulsed discharge system will also increase. This phenomenon amplifies the requirements for insulation and size of a pulsed high-voltage discharge device.

Figure 2. The distribution of the electric-field intensity between the column-column electrodes when d=1.5mm

Figure 3. The relationship of the electrode gap and the maximum electric-field intensity
3. Design of Experimental System and Results Analysis

3.1. Establishment of Experimental Platform and Parameter Setting

In order to make the technology applied better in the well deplugging, the influence of the electrode model on discharge characteristics was studied when the static pressures were different and the mediums were water or oil-water mixture.

The experiment system was shown in Fig. 4. It was mainly composed of voltage, boost-up circuit, rectifier, capacitor with high specific energy storage, vacuum switch and control circuit, electrode device, a high pressure sealed drum (HPSD) and some measuring equipments. In the figure, the boost-up circuit was composed of voltage regulator and high-tension transformer, and the range of the output voltage was 0-50kV adjustable. A HPSD of low-carbon steel material was designed in order to simulate the downhole working environment with high pressure. The device can be able to withstand the maximum pressure of 40MPa and its tightness is very good. The measuring equipments were composed of high voltage probes P6015A measuring the voltage between the anode and the cathode and PEM Probes measuring the current of the discharge circuit. The voltage and the current were captured by oscilloscope with Model TDS2022. The parameter settings in the experiment were shown in Table.1, where the working voltage was the charging voltage of capacitor.

![Figure 4](image1.png)

**Figure 4.** The experiment system of pulsed high voltagedischarges

![Figure 5](image2.png)

**Figure 5.** The electrode structure

In this experiment, the electrode structure was column-column shown in Fig. 5 in order to withstand the high voltage and make the discharge easier to produce. The electrode device was 300mm high, which center electrode was an anode and the cathode was connected to the housing.
Electrode gap can be adjusted according to the discharge channel. The electrode device was placed in the tank by using plastic rods, and the distance was 280mm from the bottom. The high-voltage line and the ground line of the electrode were introduced by seal pins connected in the tank.

| Parameters                          | Data Range |
|-------------------------------------|------------|
| Supply Voltage (V)                  | 220        |
| Working Voltage (kV)                | 10-25      |
| Capacitor (\(\mu F\))              | 12         |
| Electrode Type                      | Column-Column |
| Distance of Electrode Gap (mm)      | 1.6-1.8    |
| Pressure (MPa)                      | 0-30       |

3.2. Experimental verification and analysis

3.2.1. Experimental verification. Underground operating environment is more complex, in which high static pressure and discharge medium on the high-voltage pulsed discharge characteristics have a key impact. These downhole parameters must be considered for the successful application of high-pressure pulsed deplugging techniques in the downhole. In the experimental verification of the electrode gap, two types of experiments were carried out considering the parameters. Based on the simulation results of ANSYS above, the electrode gap was chosen between 1.6mm-2.0mm and the working voltage was 20kV.

Experiment 1 Discharge medium was water, electrode gap was 1.6mm and the high static pressures were set to 5, 10 and 20 MPa. Under these conditions the experiments were successful and the discharge medium was breakdown. The experimental data were shown in Table 2 and the discharging voltage and discharging current under 20MPa pressure were shown in Fig. 6.

| No. | Electrode gap (mm) | Static pressure (MPa) | Working voltage (kV) | Whether breakdown | Discharge voltage (kV) | Discharge current (kA) | Time delay (us) |
|-----|--------------------|-----------------------|----------------------|------------------|------------------------|------------------------|-----------------|
| 1   | 1.6                | 5                     | 20.0                 | Y                | 18.0                   | 16.8                   | 112.0           |
| 2   | 1.6                | 10                    | 20.0                 | Y                | 20.2                   | 16.8                   | 52              |
| 3   | 1.6                | 20                    | 20.0                 | Y                | 19.8                   | 18.7                   | 52.0            |

Experiment 2 Discharge medium was water, high static pressure was 20 MPa and electrode gaps were set as 1.6mm and 1.8mm. Under these conditions the experiments were successful and the discharge medium was breakdown. The experimental data were shown in Table 3.

| No. | Electrode gap (mm) | Static pressure (MPa) | Working voltage (kV) | Whether breakdown | Discharge voltage (kV) | Discharge current (kA) | Time delay (us) |
|-----|--------------------|-----------------------|----------------------|------------------|------------------------|------------------------|-----------------|
| 1   | 1.6                | 20                    | 20.0                 | Y                | 19.8                   | 18.7                   | 52.0            |
| 2   | 1.8                | 20                    | 20                   | Y                | 19                     | 18.8                   | 73.0            |

From Table 3, we can get: when the discharge medium, the static pressure and the working voltage are unchanged, the larger the electrode gap, the longer the delay. Because the slow capacitor discharge process occurs. The time delay when electrode gap was 1.8mm is longer by 21us compared with that...
at gap of 1.6mm. And the capacitor experienced a slow discharging process. So the breakdown is more random and the phenomenon is more difficult.

![Figure 6](image)

**Figure 6.** The discharging voltage and discharging current under 20MPa

3.2.2. **Field devices pilot experiment.** In order to study the deplugging effect, the cement tube was used for pilot experiment. The cement tube was put into the HPSD and the experiment environment was set as follows: the medium was water and the pressure was 30MPa. The results were shown in Fig. 7. From the figures, the cement tubes were damaged by the shock waves and the damage was obvious.

![Figure 7](image)

**Figure 7.** The damage of cement tube

4. **Conclusion**

In order to study whether high-voltage pulsed discharge technology could effectively remove plugs under downhole operating environment, the ANSYS simulation and experimental verification were respectively adopted on the study of the influence of electrode models on discharge characteristics. The following conclusions could be drawn:

1) The column-column model was chosen to study. The results show that the maximum electric-field intensity between the electrodes decreases when the electrode gap increases. The high-voltage pulsed discharge maybe fails. If the phenomenon occurs, the larger electric-field intensity is needed, parameter requirement in the high-voltage pulsed discharge system will increase. This phenomenon amplifies the requirements for insulation and size of a pulsed high-voltage discharge device.
2) An experimental system of high-voltage pulsed discharge was designed. The discharge characteristic was studied with different static pressures and different electrode gaps. These results indicate that as static pressure, discharge medium and working voltage are unchanged, when electrode gap is larger, the discharge voltage reduced, and the time delay increases. The breakdown is more difficult. Parameter requirement of the whole high-voltage pulsed discharge system is amplified.

3) A cement tube impact experiment was conducted. The tube was broken when the impact waves generated in the discharging medium acting on the tube. Increasing working voltage or decreasing electrode gap are beneficial for improving the strength of impact waves.

In this paper, the results provide a foundation for subsequent development of high-voltage pulsed discharging device. In the next study, other factors will be combined with the developed experimental system.

Acknowledgments
This research is supported by National Key Science & Technology Special Projects of China (2011ZX05021-005) and Youth Science and Technology Innovation Fund of Xi'an Shiyou University (2013QN002).

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