Electric pulse breakdown and rock fracture in a coupled environment of increased pressure and temperature

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Abstract: This paper represents the research results of electric breakdown of drilling fluid Versa Pro and rocks, as well as rock fracture caused by pulsed electric discharge in a coupled environment of increased pressure and temperature. It proves that rock destruction including rock boring by means of electric discharge is possible at a depth of down to 3500 m.

1. Introduction
Conventional mechanical methods of rock destruction (drilling) have reached their engineering potential. Nowadays it is necessary to develop new, more efficient, ways and methods of rock destruction. An electric discharge technology of rock fracture discovered and developed in the Tomsk Polytechnic University, Russia, meets most requirements specified to new ways of rock destruction [1]. Physical phenomenon of the technology lies in exceeding the electric strength of liquid dielectrics over the electric strengths of solid dielectrics and rocks when applying an electric pulse voltage for 1 microsecond and less [1,2]. When placing electrodes on a rock surface and applying the high voltage to one of the electrodes, an electric discharge channel penetrates into solid dielectrics. Here it is crucially important that liquid dielectric covers the rock surface, i.e. a rock block should be under the liquid. Breakdown of a solid dielectric (rocks) is a ground for the electric discharge technology. This technology fundamentally differs from other methods of rock fracture by electric field. When a breakdown has occurred, the energy, that has been stored in the pulse voltage generator, releases into a discharge channel in the solid dielectric for a period of 1-10 microseconds. This results in blast-like processes which cause the rock fracture mainly due to tension forces. A working tool that fractures the rock is plasma of a discharge channel; the plasma restores again and again, from pulse to pulse, as pulses come to working electrodes from the high-voltage generator and such an electrode system allows drilling for hundreds meters without replacing the system. The very essence of the technology lies in possibility of getting higher, compared to conventional methods, performance in rock destruction in combination with lower energy consumption.

The electric discharge technology has nowadays found its application in drilling, crushing and cutting off rocks. At present a method of electric discharge boring is of most-in-demand. The increase in drilling depth causes the increase in hydrostatic pressure and temperature on the bottomhole. There are very few references to the cooperative effect of increased pressure and temperature on the breakdown voltage and rock fracture performance at a pulse voltage with a pulse rise time of 1 microsecond and less, available.

Physical and mechanical and electro-physical properties of rocks in the interior of the Earth are significantly determined by a joint effect of increased pressure and temperature occurring at great depths that surely influence the electric discharge rock fracture characteristics. At the electric
discharge rock fracture, one observes reduction of the fracture zone in dielectrics and reduction of rock destruction performance when the hydrostatic pressure increases up to 15 MPa [3,4].

2. Methodology
The research has been aimed at determining the feasibility of electric discharge boring of rocks at depths of down to 3500 m. In order to carry out the research work, there has been developed a test bench allowing to create a pressure of up to 35 MPa, temperature of up to 120°C and to apply the pulse voltage of up to 400 kV to rock sample blocks. We used granite, limestone and sandstones as rock samples and drilling fluid Versa Pro developed by the company Schlumberger as a working medium. A two-electrode system (electrode-electrode arrangement) with an interelectrode gap of 10-30 mm was placed on a rock sample surface and 5 pulses were applied to the rock surface. Before being tested the rock blocks were kept in a drilling fluid for an hour to be impregnated. The depth of rock impregnation with drilling fluid exceeded the depth of penetration of a discharge channel into rock.

3. Results and discussion
An average breakdown strength $E_{br}$ of the rocks mentioned varies as a function of pressure P and temperature T increasing and having their maximum at $P=5-10\text{MPa}$ and $T=35^{\circ}\text{C}$ that is conditioned by the fluid electric strength when the pressure is increasing (Fig.1) [5]. Further increase of P and T causes decrease in $E_{br}$ of the rocks, like of the liquid. Such a decrease is caused by the increase in the temperature as being a factor which, to a large extent, effects a dielectric liquid [6], i.e. under these conditions the electric strength of the rock impregnated with the liquid is mainly determined by the liquid. And the probability of penetration of a discharge channel into the rock is 100% that allows one to conclude that the rock drilling at the depth of down to 3500 m is possible.

![Figure 1](image)

**Figure 1.** The function of rock electric strength and pressure and temperature:
1 – sandstone, 2 – limestone, 3 – granite, 4 – drilling fluid (figures next to dots are temperature values)

The rock destruction occurs in a blast-like way due to the energy released in the discharge channel. The joint increase in both the pressure of up to 35 MPa and the temperature of up to $120^{\circ}\text{C}$ reduces the fracture performance by 5-11 times, particularly, the most significant reduction of the performance occurs in the range of 0.1 – 5.0 MPa and up to $30^{\circ}\text{C}$ that is mainly caused by the pressure increase, (Fig.2). A similar phenomenon is also typical of mechanical rock destruction including mechanical
drilling. For example, the rate of penetration by both diamond and roller drilling technologies is reduced by 12-16 times when drilling the rocks of drillability index VI-IX. The electric discharge technology allows improving the fracture performance and, hence, the rate of penetration by increasing the electrode gap.

![Graph](image)

**Figure 2.** The function of rock destruction performance (1-3) and pressure and temperature: 1- sandstone; 2 - limestone; 3 – granite; figures next to dots are temperature values.

We have carried out test experiments on effecting the coupled environment of increased pressure and temperature on destruction performance and energy consumption as a function of the electrode gap $S = 10-30$ mm.

The table presents figures averaged for 3-5 tests for each gap distance. One can see that the bigger the gap $S$, the higher the destruction performance and the less energy consumption is.

**Table 1.** Fracture characteristics of the granite rock

| S, mm | P, MPa | T, °C | Q, cm³/pulse |
|-------|--------|-------|--------------|
| 10    | 25     | 85    | 0.02         |
| 20    | 25     | 85    | 0.11         |
| 30    | 25     | 84    | 0.31         |

As for deep drilling, here big-diameter boreholes are mainly used; it is possible for the electric discharge boring technology to increase the gap $S$ of up to 30 mm and more.

**4. Conclusion**

The research results prove that rocks are possible to be fractured by the electric discharge technology at a depth of 3500 m and the electric strength of drilling fluid complies with requirements of electric discharge boring technology.

To our mind the technology of electric discharge boring has significant benefits and advantages compared to conventional mechanical methods of drilling. Few advantages are as follows:

1) Rather high destruction performance when having larger gaps $S$;
2) The drill bit does not turn;
3) Significant depth (hundreds – down to thousands meters deep) of drilling without replacing the drill bit;

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