Waterless fracturing for shale gas/oil production using plasma blasting

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When extremely high voltage electricity is applied to metal electrodes, electrical energy in an arc discharge is then dissipated through the medium around the electrodes in nanoseconds or microseconds. The sudden temperature in the zone immediately adjoining the electrode increase produces a gas/plasma bubble, which causes an explosive volume increase, which in turn generates a very strong shock and pressure wave to transport energy to wall– this is the phenomenon known as plasma blasting (PB).

We have developed a PB fracking technology that uses a liquid hydrocarbon (LHC) instead of water as the medium for transporting energy and registered as an US patent. The pressure of this shockwave reaches up to 3,500 bar with the 60% energy of hydraulic fracturing, and propagates through the medium of the wellbore and makes a crack in the shale layer. As a result, it is possible to collect shale gas using less than 10% of the LHC used by the existing LHC fracturing method.

We believe that its method is able to save drilling cost because of lower viscosity and density of LHC compared to water, which results in the longer effective fracture length than that of hydraulic fracturing. This technology can minimize energy usage and substantially reduce the amount of potentially dangerous fluids being used; these results in advantages such as reducing costs, more effective production, minimizing the environmental impact, and preventing the depletion of water resources.

1. Introduction

Shale gas has become a prominent new energy resource, which is a natural gas and trapped in shale strata of many places in the world. The conventional fracturing methods for shale gas are based on formation of opening fractures in bedrocks, which involves a relatively low efficiency and high initial capital cost for the facilities. It has been known that initiation of rock fractures is significantly influenced by the rate of loading (Nilson et al. 1985). The conventional hydraulic fracturing method has a low rate of loading and cannot produce a large stimulated reservoir volume (SRV) in an efficient way. It has been a critical task to develop a new fracturing method which is more efficient and environmentally friendly and could create a larger SRV than the conventional methods in producing shale gas (Khan et al. 2012).

The method of fracturing by electric discharge was first applied for a patent under the title “Plasma blasting method” by Kitzinger and Nantel (1992). PB technology applies the high energy electric discharge to generate a plasmatic pore of high pressure and temperature in liquid medium. The plasmatic pore expands quickly to create a shockwave accompanied by intense compressive and tensile stress field. Ai and Ahrens (2006), Ma et al (2008), and Baltazar-Lopez et al (2009) performed analysis and simulation by suing AUTODYN (reference) and LS-DYNA (ref) to examine a few key parameters for the fracture patterns.

This research analysed the fracture patterns in appropriate concrete specimens for PB under isotropic and anisotropic tri-axial compression both in experiments and simulations.

2. Physics and Numerical Models

2.1 Physics of Rock Fracture under Blasting Events

Rock fracture is described by a stress tensor with the material behavior described by its eigenvalues or the principal stress, (σ_1, σ_2, σ_3). The behavior of rock materials may be described by an empirical rule in the 3D Cartersian space of the principal stress. The invariants, I_1, J_2 and J_3, of the principal stress are given as

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3,\; J_2 = \frac{1}{6}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right],\; J_3 = \det(s_{ij})$$ where s_{ij} represents the stress deviator tensor. It satisfies the relationship, $s_{ij} = \sigma_{ij} - I_1\delta_{ij}$, for the Kronecker delta, δ_{ij}. The von Mises stress defined as $\sigma_e = \sqrt{3J_2}$ has been frequently used to predict plastic flow of solid materials in 3D space (Haimson 2006). The rock material undergoes shear failure, when the von Mises stress exceeds its threshold in this stress condition. The principal stresses are either negative or zero, when tension is applied with negative pressure to the rock material. The point where the meridian profile meets the x-axis indicates the maximum pressure that rock can bear the tension applied and is defined by the hydrodynamic tensile limit.

A shockwave generated by a blasting source in a borehole spreads in a concentric direction. Because of this shockwave, rock materials around the borehole undergo momentary high compression in the outward direction of the radius. As the shockwave spreads outwards from the radius of the borehole, the peak pressure tends to decrease, which makes the damage by compression accumulated around the borehole. After compression is initially transmitted to rock due to a shockwave, rock at that point reacts to such momentary high compression and is likely to be deformed outwards from the radius. In this research, we assumed that every fracture in rock specimens occurs due to tensile stress.

3. Experimental setup

Experimental setup consisted of the following three systems according to functions: high voltage discharge circuit; true tri-axial compression system; hydraulic pumping system. Fig. 1 is the schematic diagram of the overall setup.

3.1 High voltage power supply for PB device

A conceptual diagram of the plasma blasting power supply is shown in Fig. 1 (left top). The DC power supply stores electrical energy in the capacitor and boosts it up to the desired voltage. At this time, the air gap switch (left and bottom right) is in an electrically open state until the applied voltage reaches the discharge voltage of the system. When the discharge voltage is reached, the energy stored in the capacitor is instantaneously discharged through the discharge probe, generating a strong pressure/shock wave. Fig. 1 (left and bottom left) is a photograph of a plasma discharge apparatus actually manufactured, which consists of a high-voltage DC power supply, a control panel, and a capacitor bank. Up to 72kV DC power can be supplied, applied voltage and current can be controlled through the control pad, and up to 50kJ of electric energy can be stored in the capacitor bank.

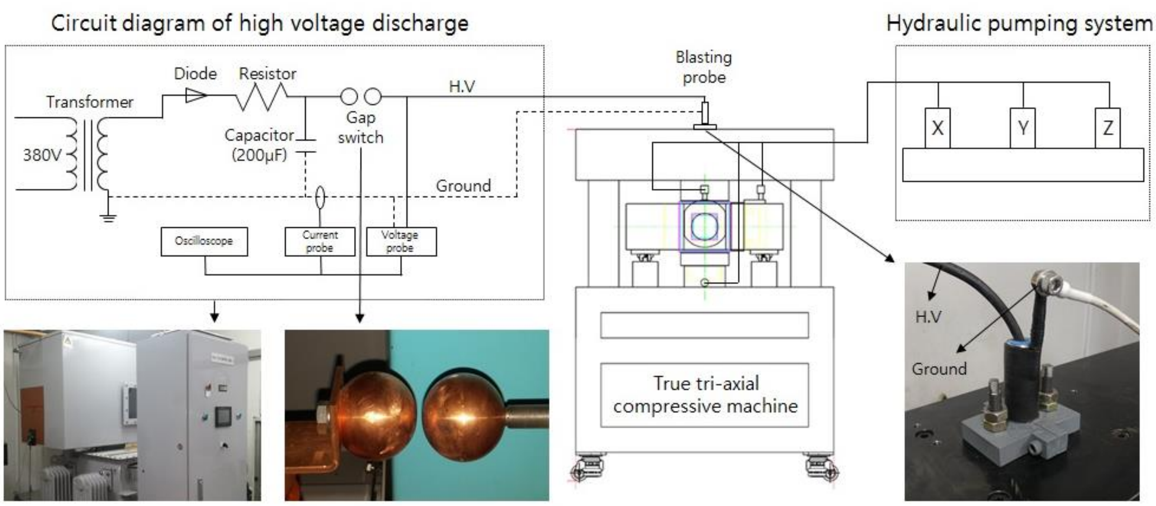

Fig. 1 Schematic diagram of the whole PB technology testing system

3.2 Discharge probe

The discharge probe consists of an anode ①, an insulator ②, and a cathode ③ as shown in Fig. 2 (left). It is important to design a discharge probe having sufficient durability in response to a large shock wave generated in the medium between the electrodes upon discharge. Fig. 2 (right) shows an example of a discharge probe used in actual plasma disruption. Most of the generated shock waves propagate in the radial direction and reduce the destruction of the insulator and the electrode. If necessary, the working fluid in the discharge probe and the inlet for the proppants can be added.

Fig. 2 Plasma discharge probe concept (left) and probe manufactured (right)

4. Summary

We have obtained below results in a laboratory and will show them.

1. A wall of wellbore was kept while plasma blasting
2. Cracks by the plasma blasting showed the similar shape and direction with ones by the hydraulic fracturing
3. When the discharge plasma energy is increased, both main cracks and sub cracks with differences in extensity were observed
4. Multiple blasting experiments showed the extension of cracks, namely possible to have the desired effective fracturing lengths
5. Verified that proppants can be transported into cracks
6. Computer simulation to perform the parametric study for a plasma blasting

References

[1] Khan, R et al. 2012. SPE Inter. Production and Operations Conf. and Exhibition, Doha, Qatar, 14-16 May. SPE-155442-MS.

[2] Nilson, R, H et al. 1985. *Inter. Jour of Rock Mechanics and Mining Sci & Geomechanics* **22** (1): 3-19.

[3] Kitzinger, F. and Nantel, J. 1992. Plasma blasting method. US Patent No. 5,106,164.

[4] Baltazar-Lopez, M. E. et al. 2009. 7th Inter. Energy Conversion Engr Conf, Denver, Colorado, 2-5 August.

[5] Ma, G. W. et al. 1998. *Computers and Geotechnics* **22** (3): 283–303.

[6] Owen, D. R. and Hinton, E. 1980. *Finite elements in plasticity*, first edition. UK: Pineridge Press.