2019 URTeC, Denver

Waterless Fracturing Technology for Shale Gas/Oil Production Using Plasma Blasting Technology

2019. 7.

Green Science Corp. and Handong Global University

Bong Ju Lee

Purpose of this R&D

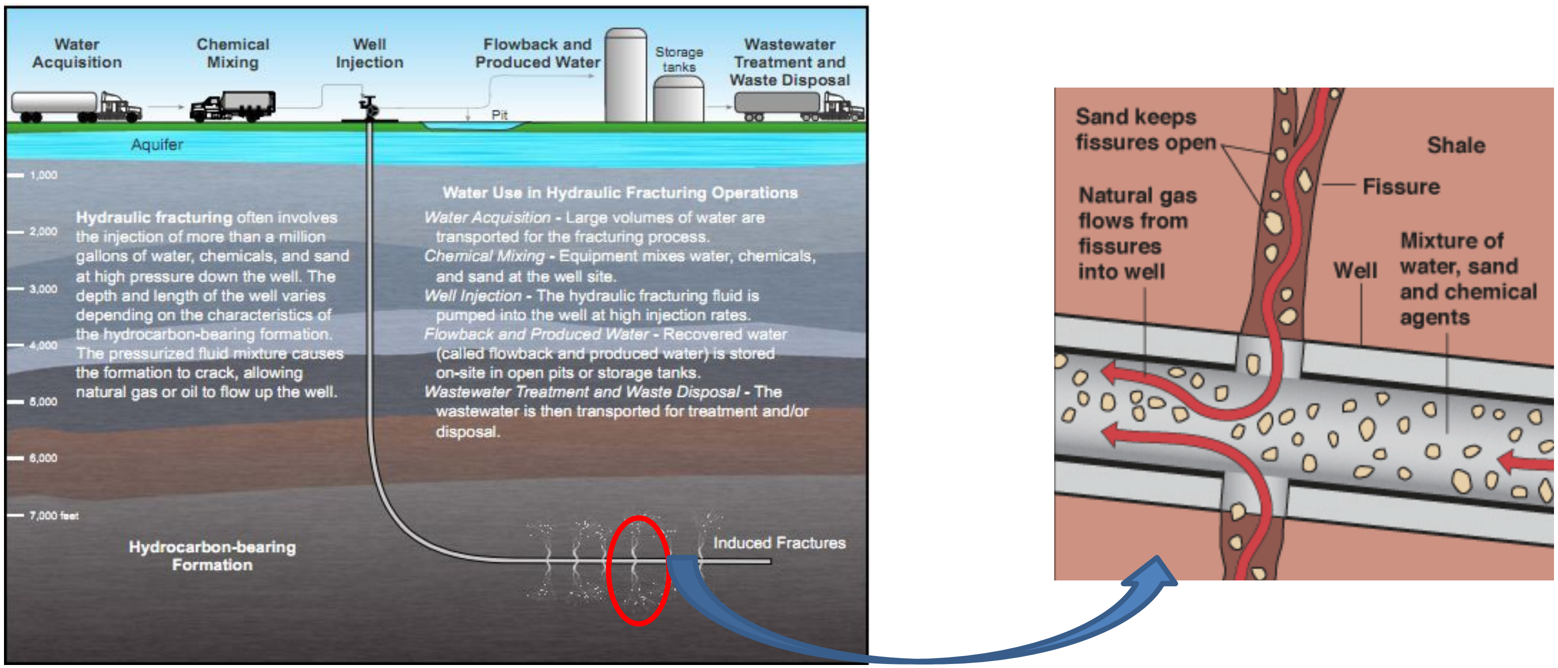
- Developing the feasible waterless fracturing technology to extract oil-gas from unconventional oil-gas field using by the plasma blasting
  - Replace the hydraulic fracturing (Static pressure) with waterless plasma blasting (Dynamic pressure)
  - May revive declining wells by increasing permeability physically

- Plasma blasting technology for waterless fracturing has been developed with a research fund (~USD 3.2 M) from Korean government and Green Science Co. for last 6 years

- Looking for a partner to test this technology at the real shale gas/oil field with the share of cost and know-hows

Hydraulic Fracturing

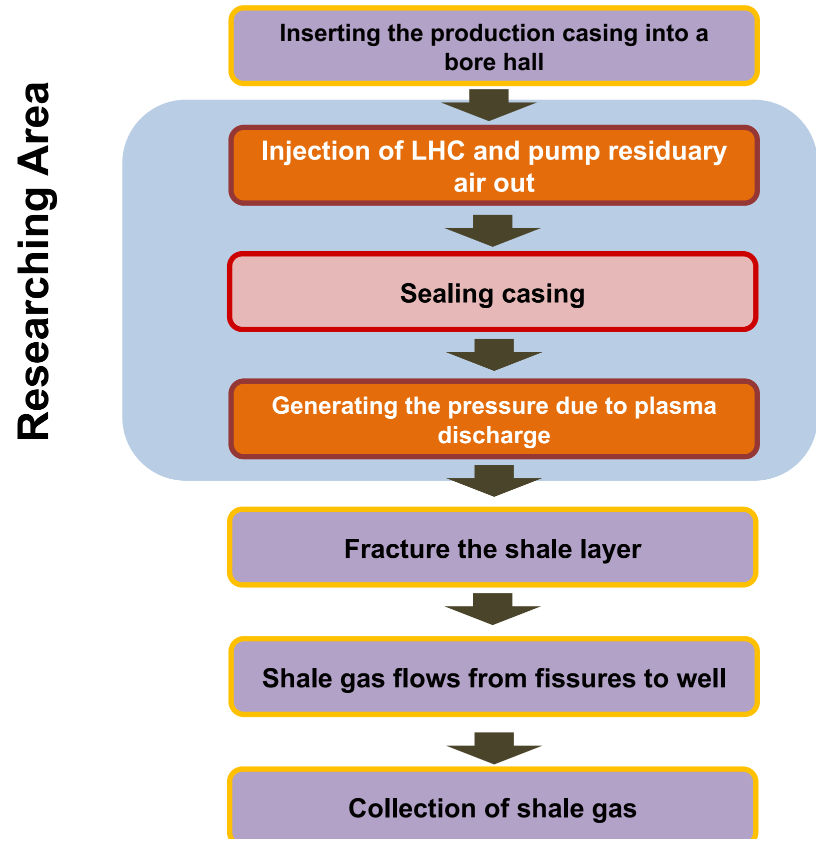
- Fracture the shale strata using highly pressurized (500~1,000 bar by ~10,000 m3/well) water
- Produce oil/gas from almost all of shale fields in North America

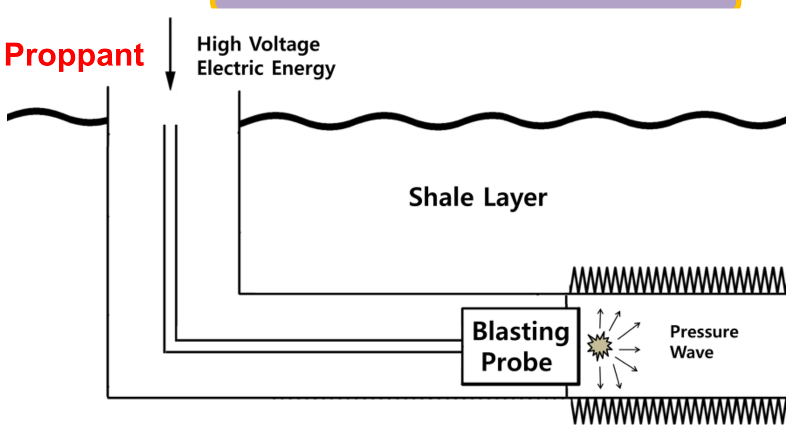


Problems

- Consuming so much of water, 2~100 m^3/Tera joule
- Flowback water along with the shale gas is mixed with chemicals and hazard impurities requires high disposal expense and causes the severe underground pollution.

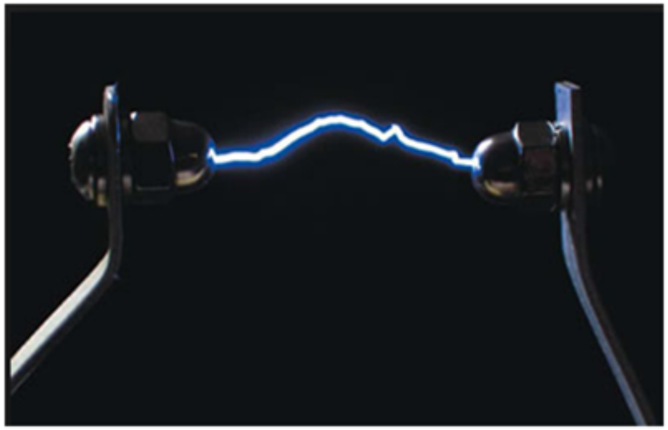
Waterless fracturing technology by a plasma blasting

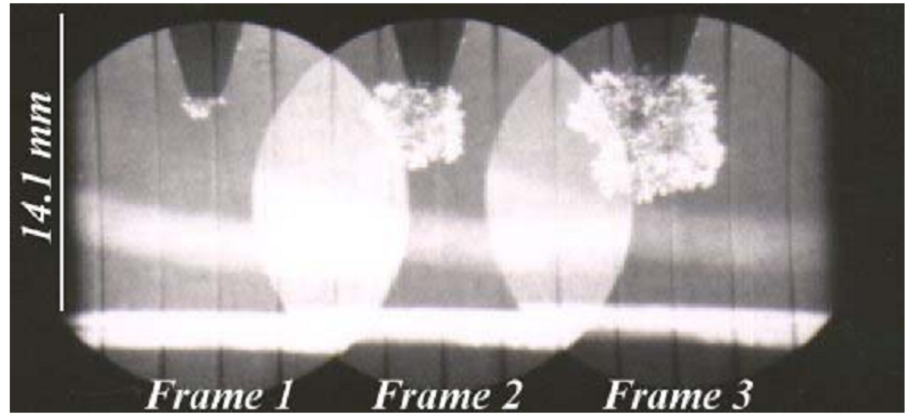




- **Use small amount of Liquid Hydro Carbon (LHC), e.g. LPG, LNG instead of water**
- **Cause no pollution because LHC does not react with underground salt, mud etc.**
- **Much longer effective fracture length because of its lower viscosity and density compared to water.**
- **Applicable to the arid regions, such as western China, Australia etc. and Europe with strong regulation on hydraulic fracturing**
- **Much less energy consumption (~1/4) required and ~100% of LHC is recovered because it is evaporated by geothermal**

Plasma generation for blasting



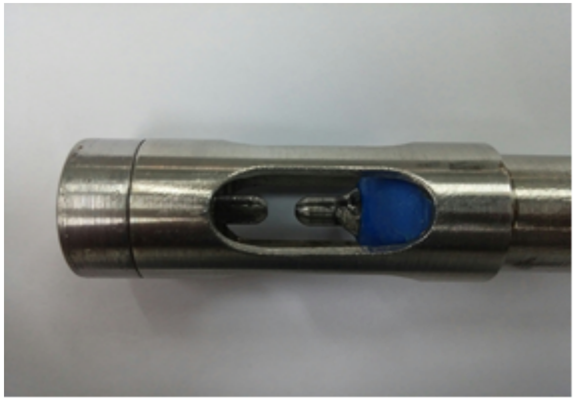


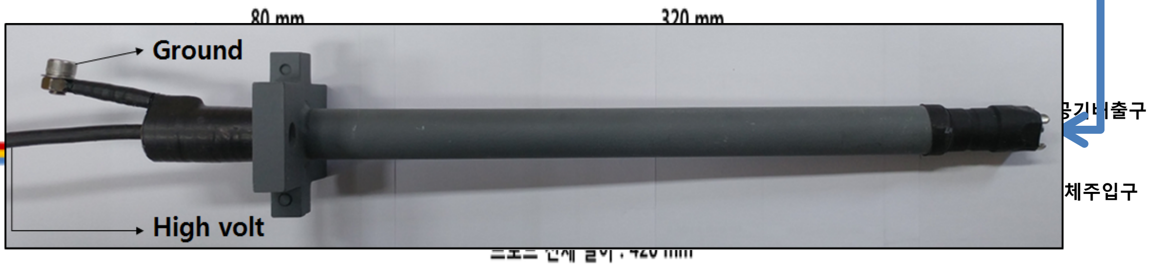
- Plasma is the 4th state of matter and can take energy as much as we supply if conditions are matched generally
- When a voltage between electrodes is above a certain value, charged particles between electrodes are increased rapidly and discharged

  - Plasma is discharged inside the gas bubble and pressure wave is generated due to the rapid increase of temperature and volume expansion

- Able to adjust the size and length etc. of pressure wave according to the shape of electrode and the form of applied voltage

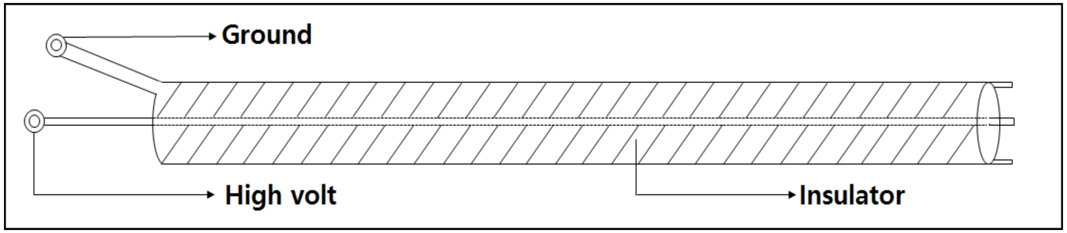
Blasting probe generates the high pressure inside borehole





Supply electricity, LHC and proppant and extract air to prevent from the explosion

[Schematic diagram of blasting probe]



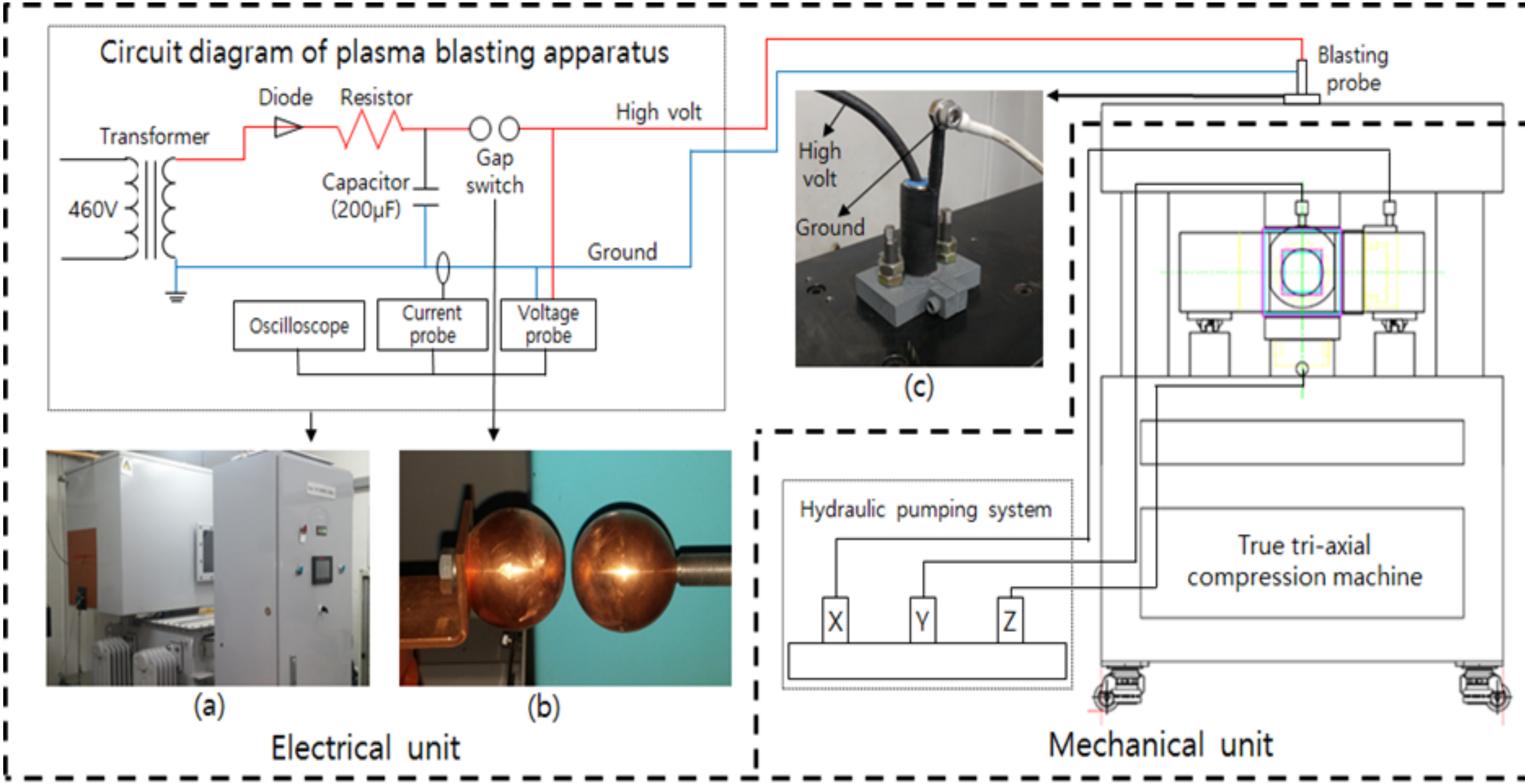
- Essential components

  (①High Voltage electrode ②Insulator ③cathode)

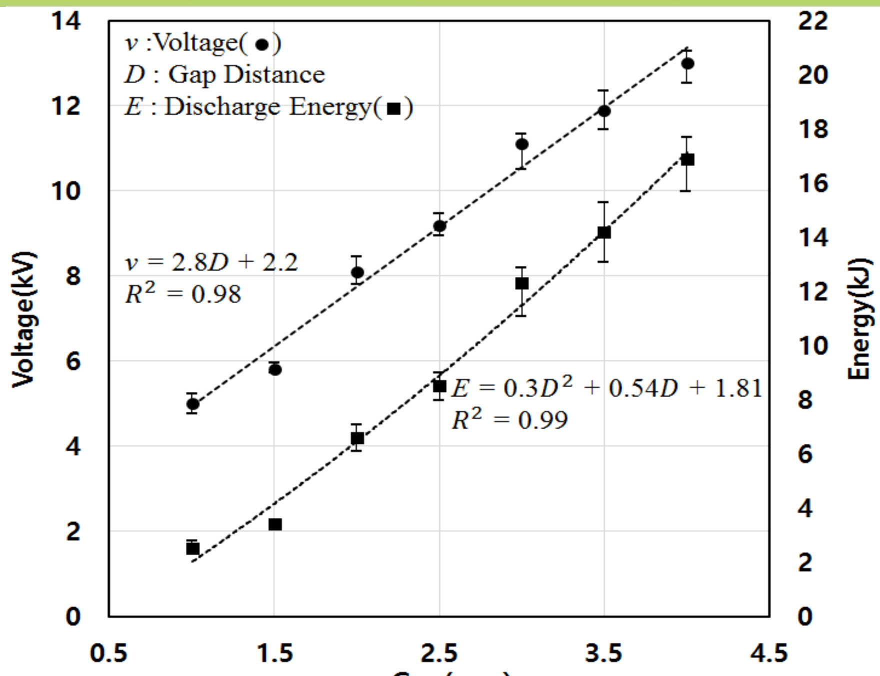
- Proppant/LHC injector to remove air and to fill LHC in wellbore

Schematic diagrams for plasma blasting

(a) the electrical unit, (b) the gap switch and (c) the blasting probe installed in a sample.

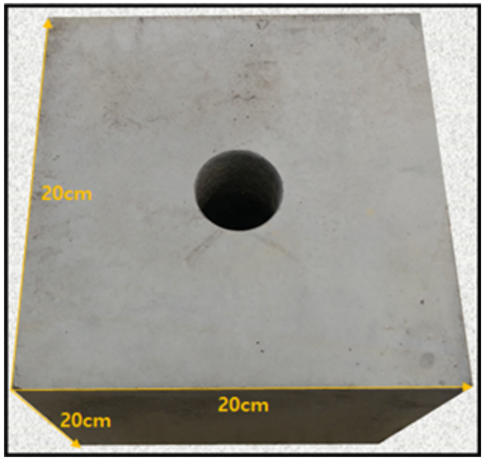


Plasma blasting power supply and samples

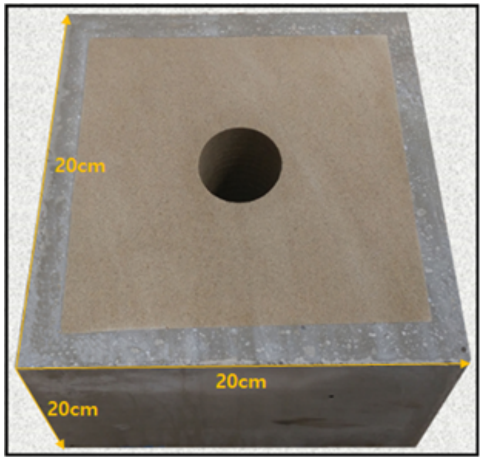


Discharge voltage and energy vs. gap distance

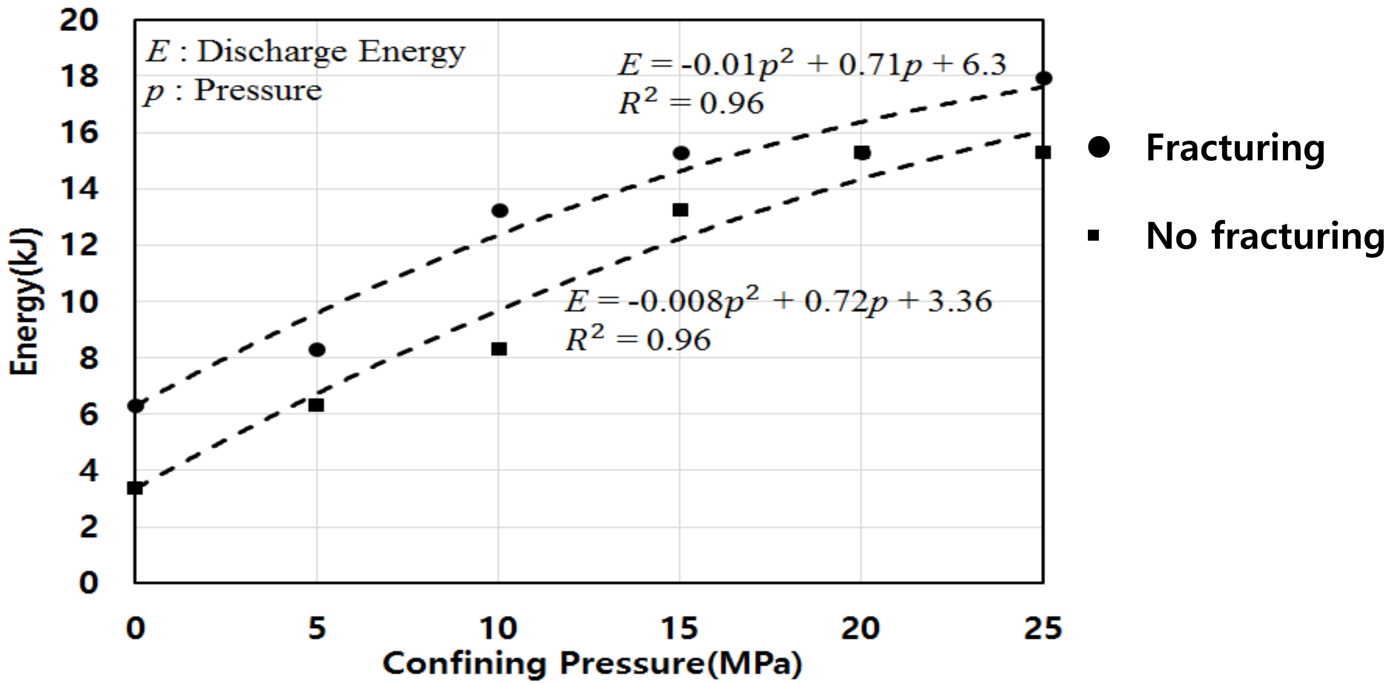
[Plasma blasting power supply]



(a) Cement mortar sample and (b) sandstone sample.



Discharge generates the pressure transferred via shock wave



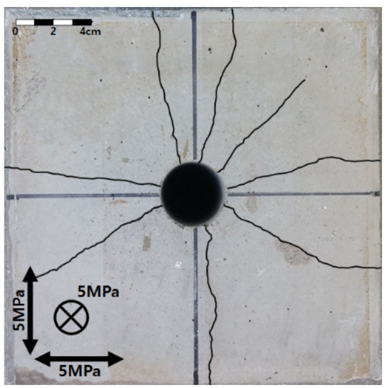
Energies needed to fracture cement mortar samples under hydraulic pressure. The upper line indicates the highest energy criterion and the lower line indicates the lowest energy criterion for fracturing a cement mortar sample by plasma blasting.

- Pressure decreases rapidly as the wave travels long
- Pressure increases as capacitance and discharge voltage increase
- Peak pressure follows against gap distance and to the discharge energy

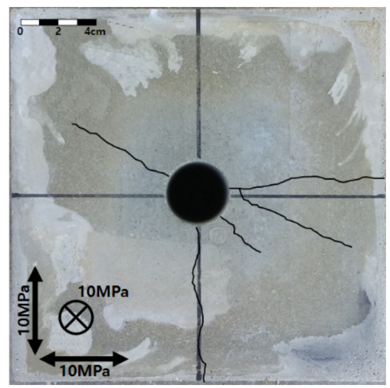
$$P = \frac{9000}{d}(E_B)^{0.35}$$

Patterns of fracture development with similar discharge energy

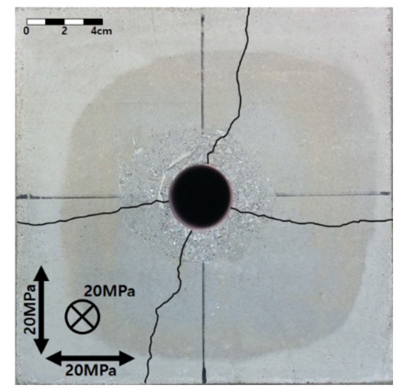
- The gap distance was 3.5 mm for all three samples and the discharge energies were 14.2–14.8 kJ
- Thin solid lines are fractures
- The hydrostatic pressures were



(a) 5 MPa



(b) 10 MPa

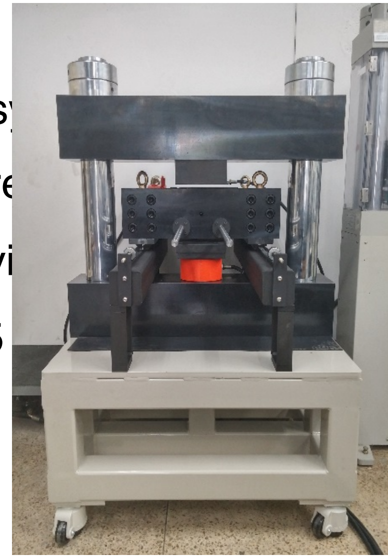


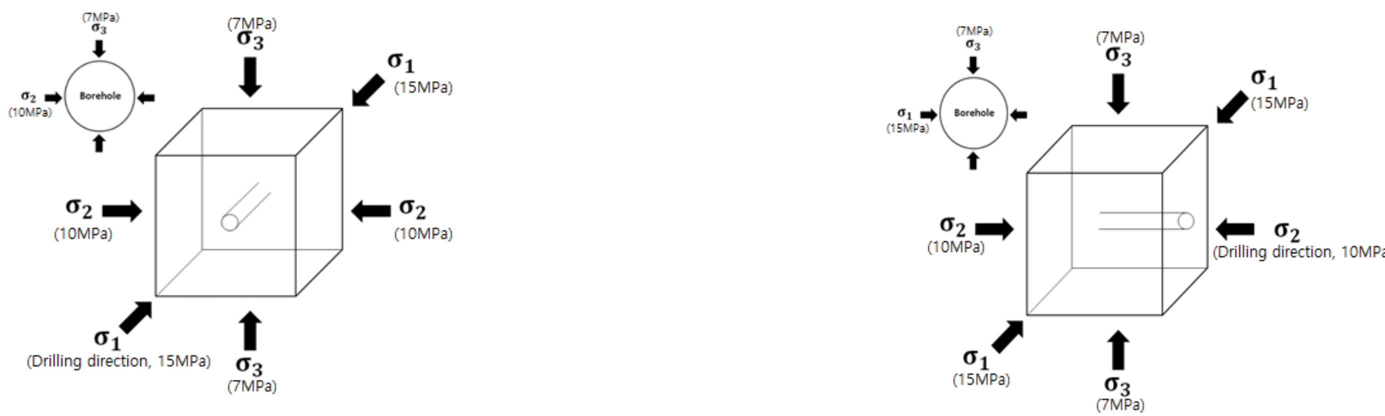
(c) 20 MPa.

A device to mimic the underground environment

True triaxial compressor

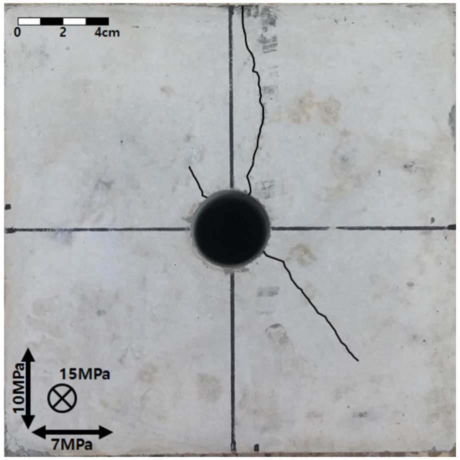
- Independent pressurizing sy   (x, y, z
- Able to actualize the require   stress
  difference to mimic the envi   underg
- Able to pressurize up to 25   mum a



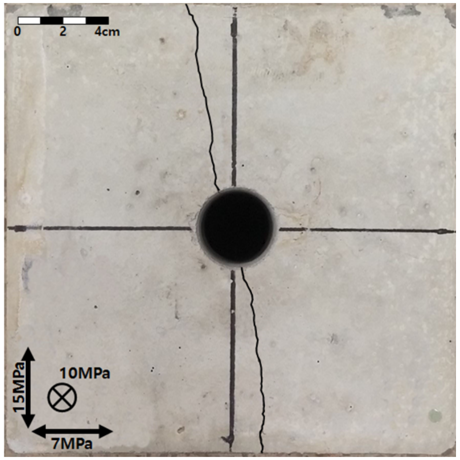


The three principal stresses applied to the samples. (a) If the borehole is drilled along the σ_1 direction, the two stresses on the plane perpendicular to the borehole axis are 10 and 7 MPa, and the differential stress is 3 MPa. (b) If the borehole is drilled along the σ_2 direction, the two stresses are 15 and 7 MPa, and the differential stress is 8 MPa

Characteristics of fracture development, thin solid lines

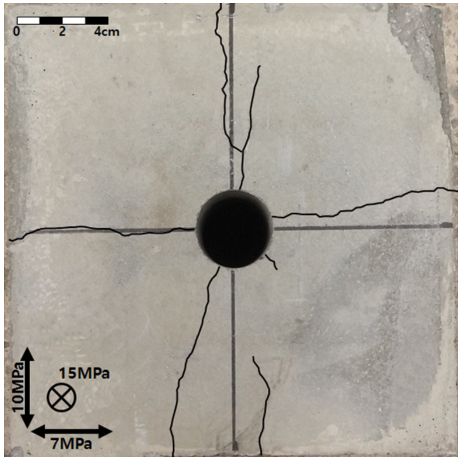


(a)

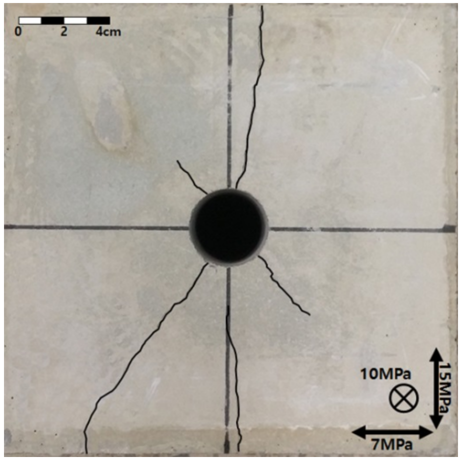


(b)

(a) a differential stress of 3 MPa and a discharge energy of 11.9 kJ, and
(b) a differential stress of 8 MPa and a discharge energy of 13.2 kJ.



(a)

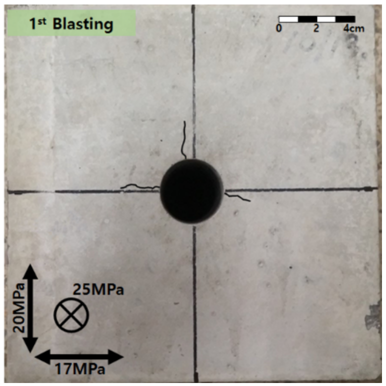


(b)

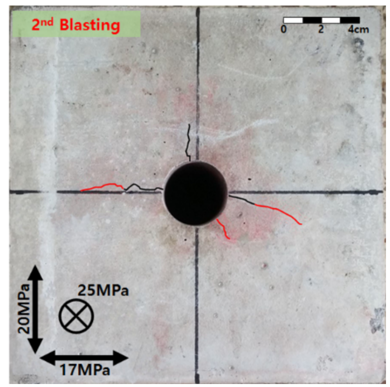
(a) a differential stress of 3 MPa and a discharge energy of 18.5 kJ, and
(b) a differential stress of 8 MPa and a discharge energy of 18.6 kJ.

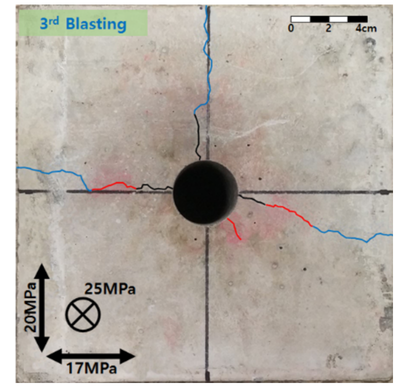
Fracture development by multiple plasma blasts in one sample

❖ The differential stress was 3 MPa and the discharge energy was 10.5 kJ.



(a)





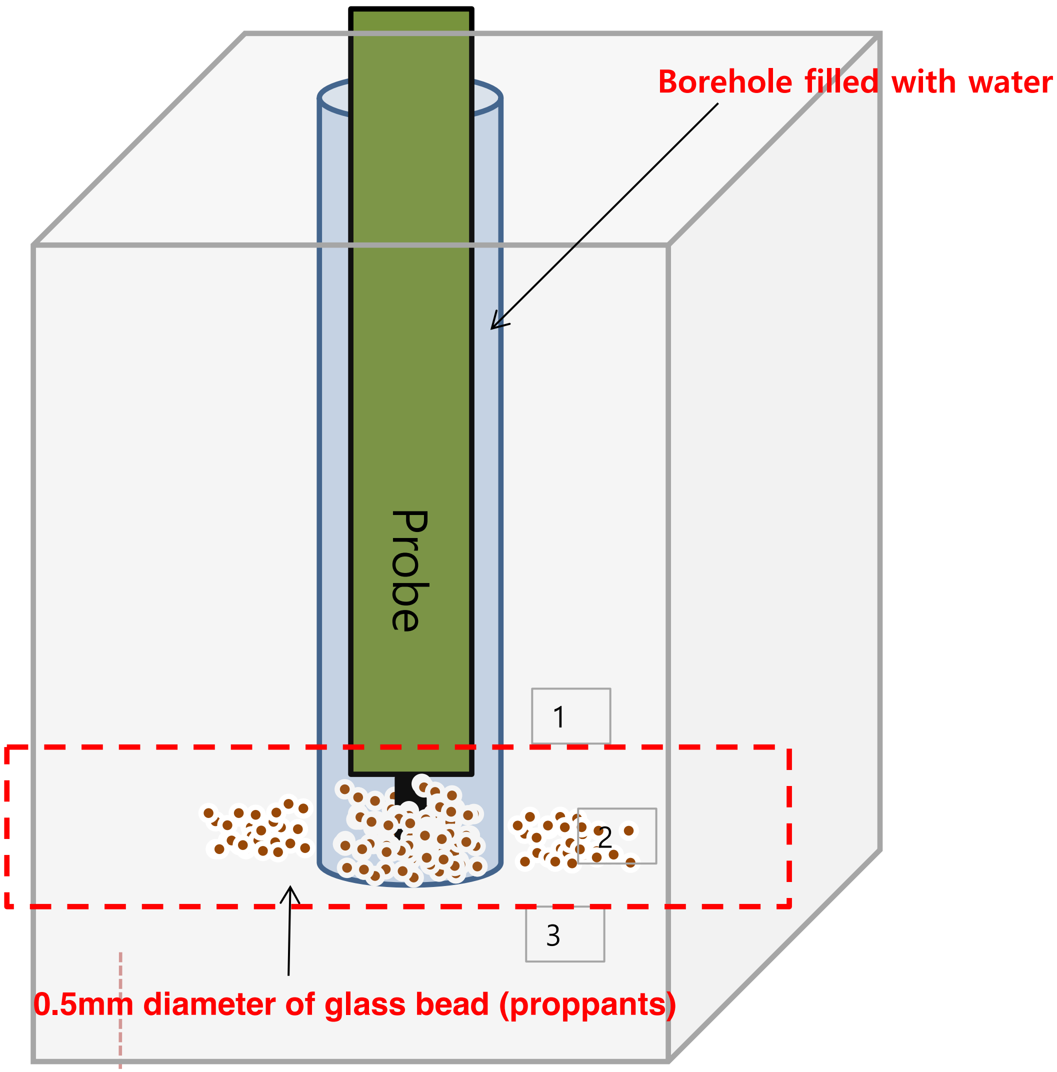
(a) Fracturing from the first blast (black)

(b) Fracturing from the second blast (red)

(c) Fracturing from the third blast (blue)

- Fixing stress condition, done three consecutive blasting
- Observed a form of crack after each blast
- The first-formed-cracks can be lengthened because the most of subsequent blasting energy concentrates on the existing cracks

Plasma blasting experiments with proppants

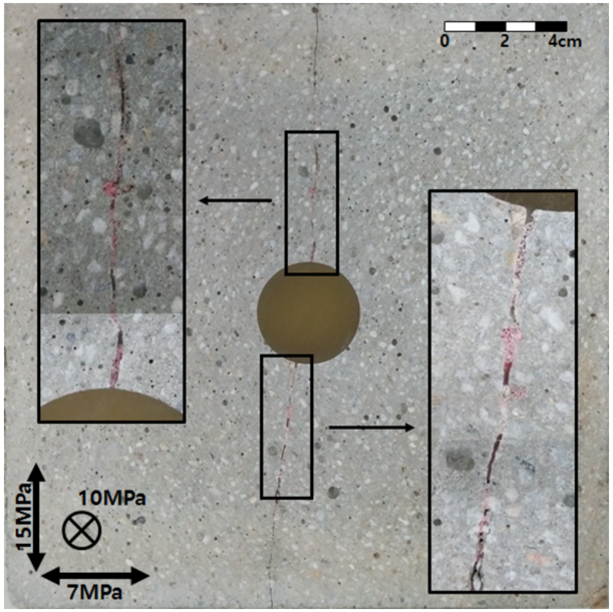


- 20 cmX20 cmX20 cm sized sample, bored 26 mm of borehole at the center of it
- Filled with water after inserting the probe
- Proppants are placed near both electrodes where discharge takes place (precipitated at the floor)

Experiments with differential stress and proppant

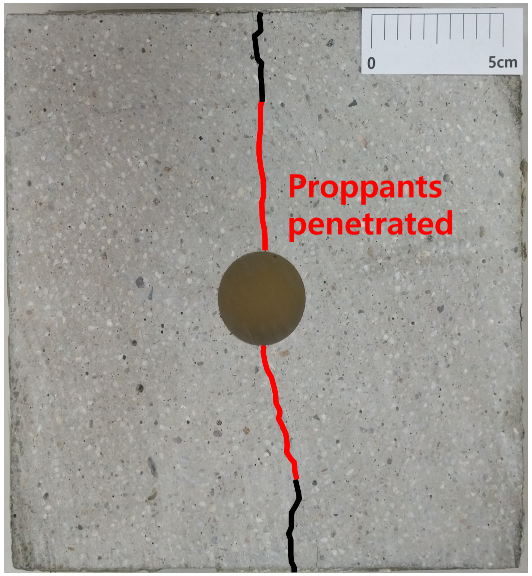
Transportation of proppant

- JB-600 (size of proppants 250μm ~ 425μm)
- Proppants penetrated only the lower part of the borehole where proppant exists
- Penetrated around 5~6 cm of depth



The differential stress was 8 MPa and the discharge energy was 13.1 kJ.

[Upper side]



[Lower side]

Patterns of fracture development in sandstone

Physical and mechanical properties of cement mortar and sandstone samples				
	Density (g/cm^3)	Porosity (%)	Tensile strength (MPa)	Uniaxial compressiv e strength (MPa)
Cement mortar	2.03	1.50	3.26	46.80
Sandstone	2.29	11.94	3.29	46.02

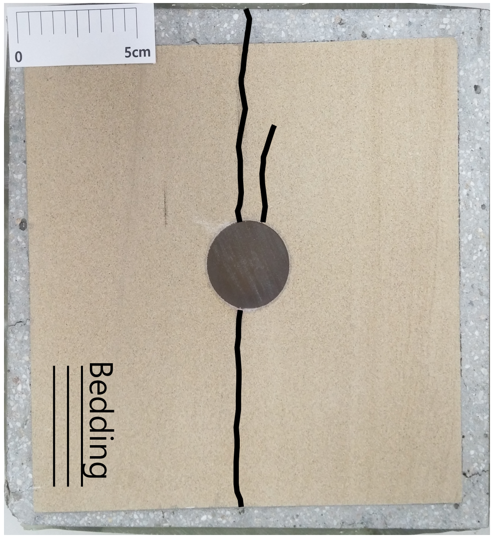
- The differential stress was 8 MPa and the discharge energy was 16.5 kJ.

(a) when σ_1 was parallel to the bedding plane, and
(b) when σ_1 was perpendicular to the bedding plane.

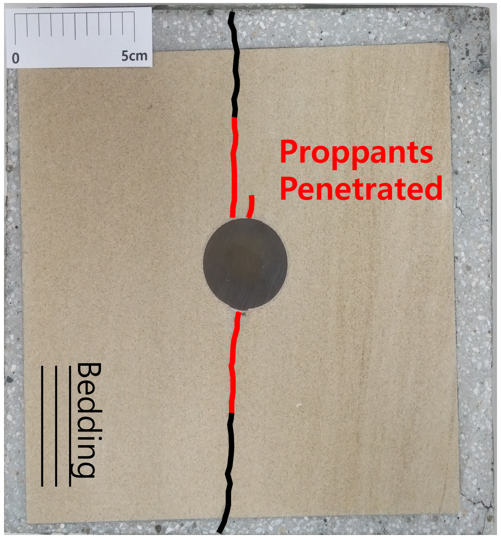
Experiments with differential stress and proppant

Transportation of proppant at natural rock sample (sandstone)

- Sandstone (single axis strength 38.54MPa, tensile strength 4.08MPa)
- Size of proppants : 75μm ~ 600μm
- Bedding direction and crack direction are parallel
- Crack was formed as guided, and proppants penetrated

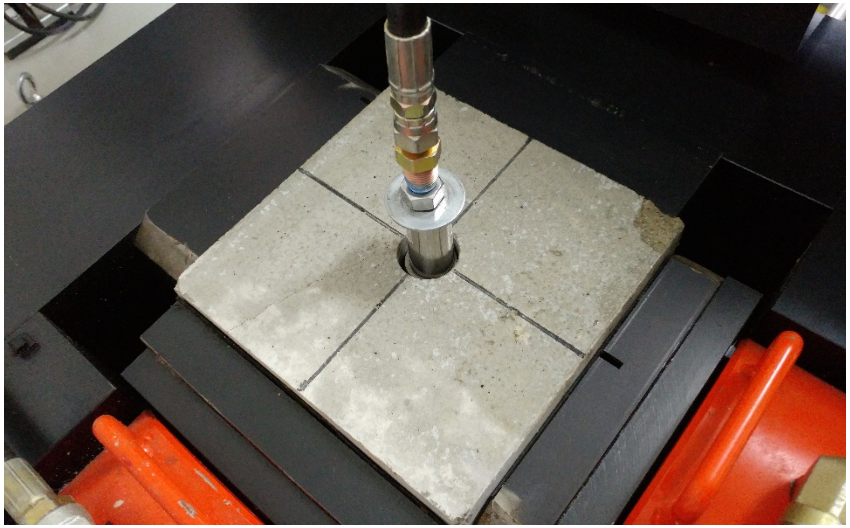


[Upper side]



[Lower side]

Experiments to recover the productivity?



- **Measure the permeability of water (PW) after the plasma blasting**
  - Packer test to measure the volume of liquid, which penetrates inside of a sample once 3 MPa is applied to the liquid
  - Before blasting = $2.21 \times 10^{-10} cm/s$, After blasting = $1.07 \times 10^{-6} cm/s$
  - 10,000 times increase due to the plasma blasting

Patents for waterless fracturing using plasma blasting

특허증
CERTIFICATE OF PATENT

특 허 Patent Number: 제 10-1656716 호

출원번호 Application Number: 제 10-2015-0025305 호
출원일 Filing Date: 2015년 02월 23일
등록일 Registration Date: 2016년 09월 06일

발명의 명칭 Title of the Invention
플라즈마 반응의 충격파를 이용한 프랙처링 장치 및 이를 이용한 셰일가스 추출 방법

특허권자 Patentee
(주)그린사이언스(160111-*******)
강원도 태백시 계산11길 62(장성동)

발명자 Inventor
등록사항란에 기재

위의 발명은 「특허법」에 따라 특허등록원부에 등록되었음을 증명합니다.
This is to certify that, in accordance with the Patent Act, a patent for the invention has been registered at the Korean Intellectual Property Office.

2016년 09월 06일

특허청장
COMMISSIONER,
KOREAN INTELLECTUAL PROPERTY OFFICE
최 동 규

US009890628B2

(12) **United States Patent**
Sin et al.

(10) **Patent No.: US 9,890,628 B2**
(45) **Date of Patent: Feb. 13, 2018**

(54) **FRACTURING DEVICE USING SHOCKWAVE OF PLASMA REACTION AND METHOD FOR EXTRACTING SHALE GAS USING SAME**

(71) Applicant: **GREEN SCIENCE CO. LTD.**, Taebaek-si, Gangwon-do (KR)

(72) Inventors: **Yoong Wook Sin**, Pohang-si (KR); **Chang Woo Ok**, Pohang-si (KR); **Bong Ju Lee**, Pohang-si (KR)

(73) Assignee: **GREEN SCIENCE CO. LTD.**, Taebaek-si, Gangwon-do (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/129,826**

(22) PCT Filed: **Apr. 3, 2015**

(86) PCT No.: **PCT/KR2015/003344**

(52) **U.S. Cl.**
CPC ***E21B 43/263*** (2013.01); ***C09K 8/62*** (2013.01); ***C09K 8/80*** (2013.01); ***E21B 43/003*** (2013.01); ***E21B 43/267*** (2013.01); ***E21B 47/06*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 7/15; E21B 43/26; E21B 43/263; E21B 43/267; E21B 43/247
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

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(Continued)

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KR	10-1998-0702571	A	7/1998

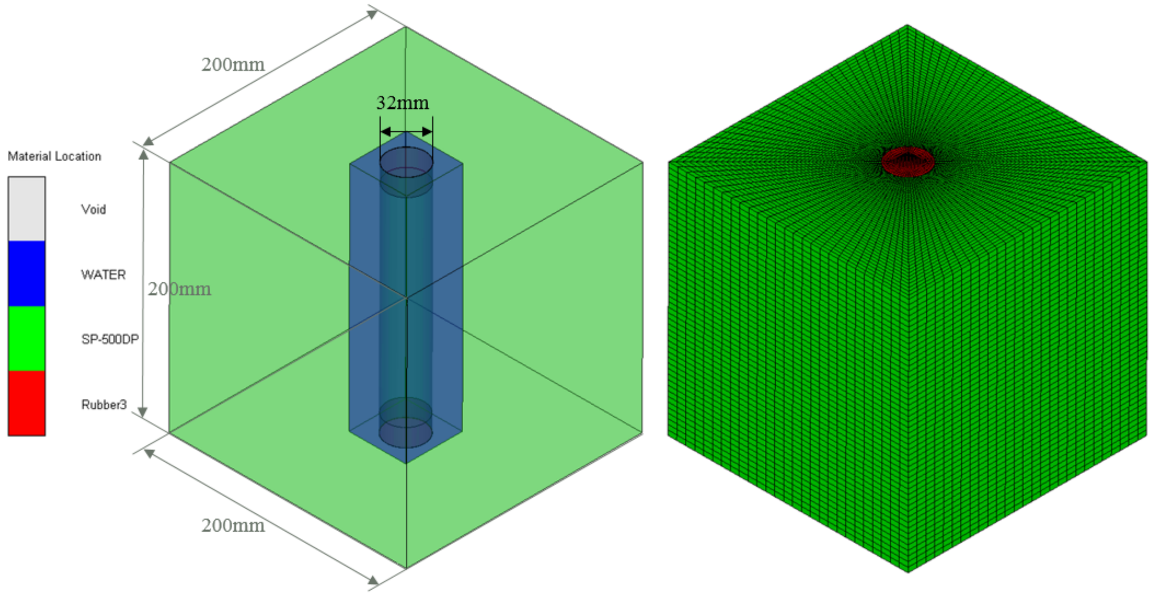
OTHER PUBLICATIONS

- Original Patent of Green Science Corporation’s converging technology of LPG+Plasma blasting (Patent of fracturing equipment using shock wave from plasma reaction and shale gas extracting with it #10-1656716) was registered on Sep. 06, 2016 in Korea
- The same patent was registered in US on Feb. 18, 2018
- Being processed to keep the range of right by submitting continuous complementary patent

Geometry and experimental results are simulated

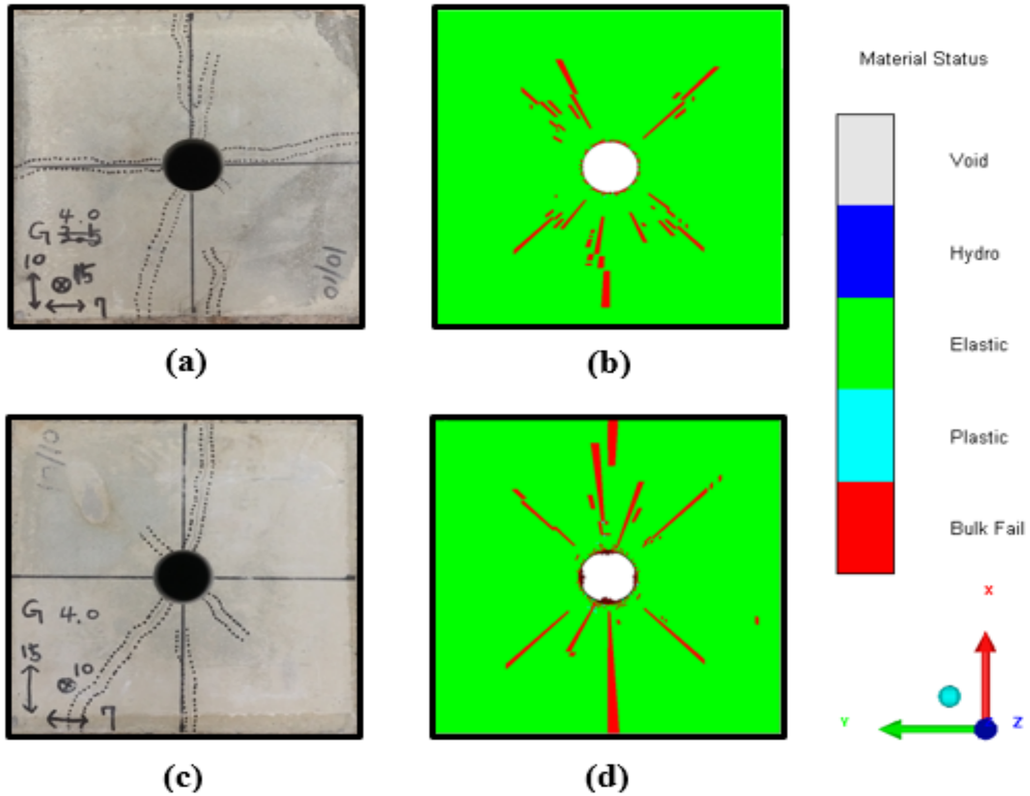
3D Geometry : Lab-Scale geometry

- Analyzed by quartering 20x20x20(cm) cube



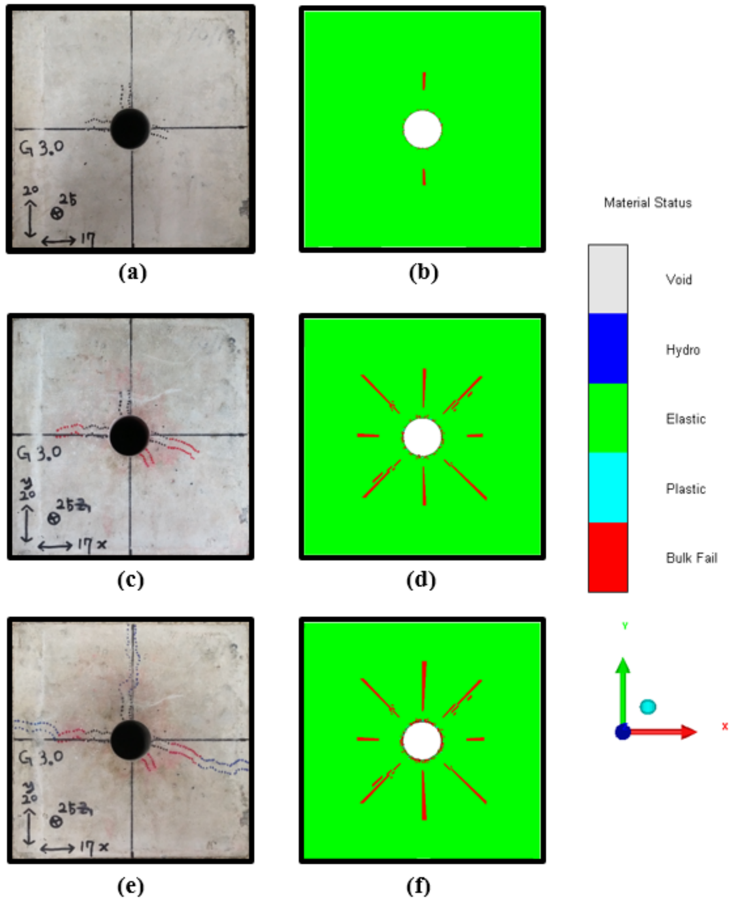
Case Index	Energy Discharged (kJ)	Compression (MPa)				Number of Blasting
		X	Y	Z	Deviatoric Stress	
ISO-1	6.30	0.00	0.00	0.00	0.00	1
ISO-2	6.30	25.0	25.0	25.0	0.00	1
ISO-3	17.9	25.0	25.0	25.0	0.00	1
ANISO-1	17.9	10.0	7.00	15.0	3.00	1
ANISO-2	17.9	15.0	7.00	10.0	8.00	1
ANISO-3	13.2	10.0	7.00	15.0	3.00	1
ANISO-4-1	13.2	17.0	20.0	25.0	3.00	3 (1st blasting)
ANISO-4-2	13.2	17.0	20.0	25.0	3.00	3 (2nd blasting)
ANISO-4-3	13.2	17.0	20.0	25.0	3.00	3 (3rd blasting)

Comparison of results due to anisotropic compression



(a) Experimental result of ANISO-1 (b) Numerical result of ANISO-1
(c) Experimental result of ANISO-2 (d) Numerical result of ANISO-2

Comparison of results due to successive blasting



(a) Experimental result of ANISO-4-1 (b) Numerical result of ANISO-4-1
(c) Experimental result of ANISO-4-2 (d) Numerical result of ANISO-4-2
(e) Experimental result of ANISO-4-3 (f) Numerical result of ANISO-4-3

Summary

- **Waterless plasma blaster is able to do the sophisticate and well controlled fracturing**
  - can be applied to architecture, civil engineering, and mineral exploration
  - most actively studied at NASA for the planet exploration
- **Experimental results of waterless plasma blaster in a laboratory showed the high possibility to be applied to the real shale field**
  - Cracks by the plasma blasting showed the similar shape and direction with ones by the hydraulic fracturing
  - When the discharge plasma energy is increased, both main cracks and sub cracks with differences in extensity were observed
  - Multiple blasting experiments showed the extension of cracks, namely possible to have the desired effective fracturing lengths
  - Proppants can be transported like as the static pressure, i.e., way of hydraulic fracturing even the dynamic pressure is applied
- **The power supply was upgraded to 50 kV and 100 kJ (from 13 kV and 22 kJ) for the real field application**

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2011 - Present : CEO, Green Science Corporation
1996 - 2011 : Principle Researcher
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(NFRI, Korea National Lab.)
1996 - 1997 : Visiting scholar, Princeton University
1991 - 1997 : Assistant/Associate Research Professor,
University of California, Los Angeles/San Diego
1984 - 1991 : Master/Ph.D in Plasma Engineering
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1980 - 1984 : Hanyang University (BE, Nuclear Engineering)

- Have researched in the field of plasma engineering for more than 30 years
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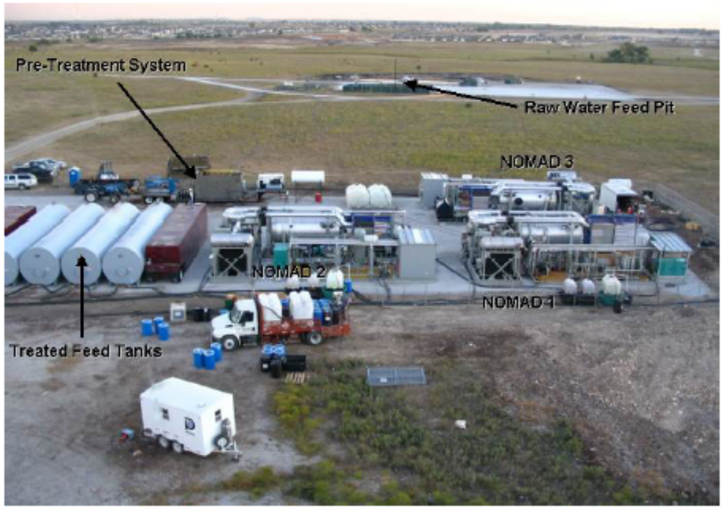
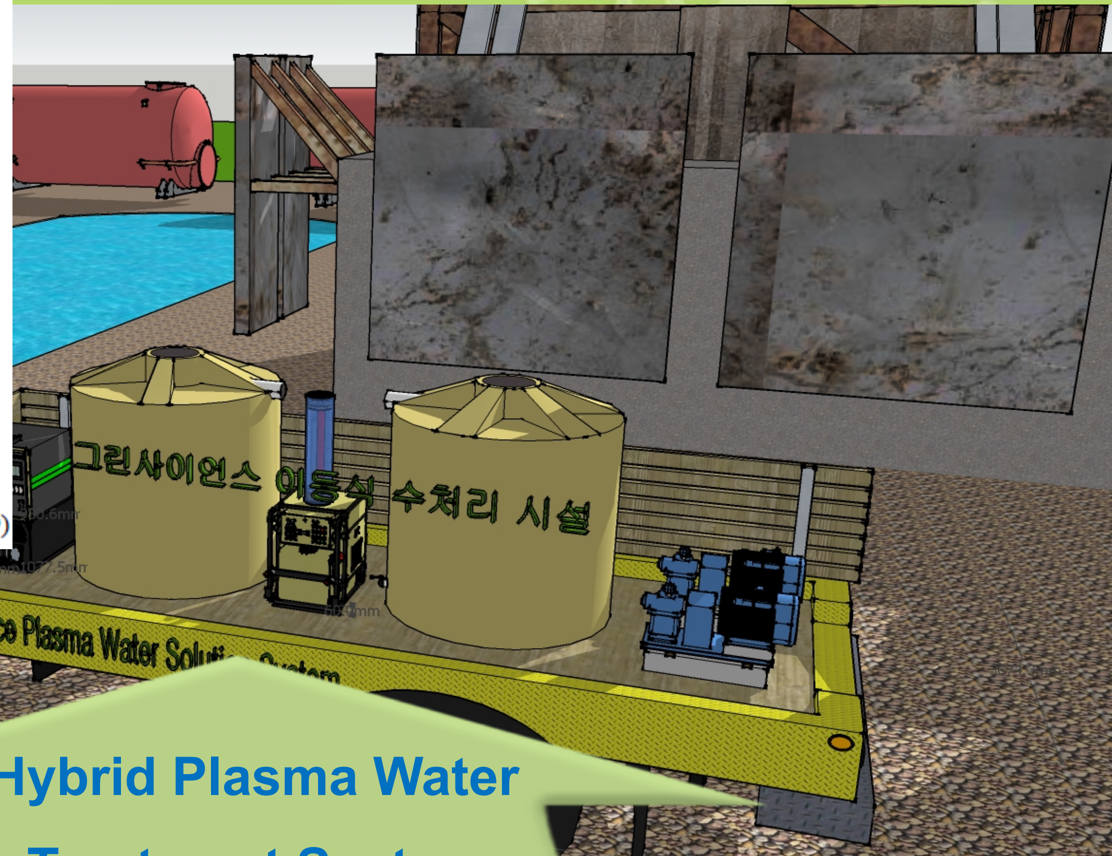
Mobile hybrid system for 1,000 ton/day of flowback water



Fountain Quail NOMAD Facilities (1,000 m^3/d, Source: GTI, 2009)



Hybrid Plasma Water Treatment System

- Reduction of initial construction cost
- Excellent response ability according to the quality of water
- Simple Maintenance
- Capable of processing mass amounts
- Cost reduction