International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
***Article Received:** 25 July 2023 **Revised:** 12 September 2023 **Accepted:** 30 September 2023*

Analysis of Experimental Data for Electrical Parameters of Water at a High Voltage Pulse Discharge

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ABSTRACT

In this research paper, we will analyze experimental data pertaining to the electrical parameters of water subjected to high voltage pulse discharge. Such study is crucial for industrial production as it examines the pressure properties and attenuation law of these waves. The pulse discharge in water may generate an extremely high voltage pulse, which was measured at various locations during this study. Through a series of experiments, we discovered that hydrostatic pressure exerted an inhibitory effect on discharge breakdown. This inhibition resulted in an increase in high voltage pulse pressure and a decrease in attenuation, correlating with rising breakdown energy and hydrostatic pressure during the high voltage pulse transfer under different conditions. To further our analysis, we combined the high-frequency discharge characteristics of the pulsed high voltages with the discharge properties of water. Finally, an equation was devised for high voltage pulse attenuation as a function of discharge energy and other electrical properties.

Keywords: high, voltage, electrical, water, discharge, pulse, pressure

INTRODUCTION

Physical Process at its Most Basic. High-voltage pulse discharge breaks down water dielectrics in a short period of time, resulting in a high-temperature, high-pressure plasma channel in the process. Because of the large pressure and temperature differences at the plasma border, the channel rapidly expands outward, converting electrical energy to mechanical energy at a high rate. Water in the vicinity of the plasma channel has a low compressibility, therefore the mechanical energy it contains is primarily discharged as a wave. A shock wave is the name given to the high-energy wave that is created. The maximum pressure of a shock wave is affected by a number of variables, including discharge energy, electrode distance, and hydrostatic pressure. The peak pressure of the shock wave is directly related to the discharge energy because the shock wave acts as a conduit for the discharge energy. The peak pressure recorded at varying distances from the wave source is necessarily different because of the energy attenuation of the shock wave as it travels through water.

Water's damping effect is also controlled by hydrostatic pressure, which has a direct effect on the creation of the first shock wave. Furthermore, the amount of shock wave attenuation during propagation depends on the water dielectric's hydrostatic pressure. The findings show that as conductivity increased, breakdown voltage, breakdown delay time, and energy loss all decreased nonlinearly in magnitude. Pores and two types of tensile cracks predominate in the samples' surface and interior damage, both of which showed a typical two-stage pattern. At the sample's edge, tensile wave reflections are a major source of sample damage. This research provides important insights into the effect of sample damage caused by electrical conductivity, which will help drill tool designers and speed up the application of HVSD drilling technology.

Many researchers are looking into the properties of HVPD-produced WSWs, but only a few have investigated the impact of PH on WSWs. Researchers also conducted experiments to investigate the electrical properties of pulsed discharge in pressured water. There was a correlation between PH and the breakdown voltage of water dielectric and the creation of plasma channels. The bigger the PH, the smaller the bubble maximum radius and the higher the peak frequency were found by Schaefer's research. PH was shown to influence the bubble time and the minimum rarefaction pressure, although the first peak pressures of WSW were unaffected when PH was less than 0.9 MPa. In light of Jeffrey's findings, Lu developed a novel model for calculating thermal radiation power that included bound-bound transitions. According to his estimates, Jeffrey's results were in line with his findings. However, a theoretical investigation of the HVPD in pressured liquid water was used to assess the impact of the law of PH on WSWs. In addition, only PH 0.9 MPa could be compared to experimental data. It's not apparent if PH values > 0.9 MPa have anything to do with the WSW's first maximum pressure. HVPD may be better understood by examining the relationship between pulsed discharge voltage UD and hydrostatic pressure PH, as well as parameters of water shock waves (e.g., maximum pressure PM, wave velocity DW, and energy conversion efficiency). Technology advancements in reservoir fracturing construction might result. As current density and physicochemical characteristics change, the length of time it takes to charge a bilayer varies. This means that shorter on/off periods equivalent to the double layer's charging or discharging intervals should be avoided. Despite the fact that the authors conducted a Faraday-related investigation on the attenuation impact that occurs owing to pulse distortion, they failed to describe the advantages of the non-Faraday diffusion process.

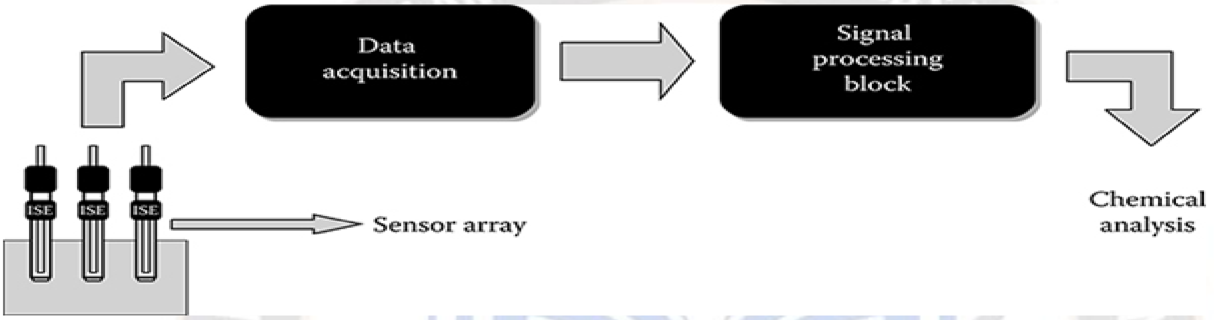

Figure 1 Water pulse discharge

Shaaban compared the losses in pulsed and non-pulsed electrolysis at various frequencies and duty cycles. Negative effects, such as increased corrosion due to current polarity reversal, high electrical energy consumption under pulsed current conditions, and reactive losses caused by inductive reactance, were raised by the study, rather than the positive effects of current-pulsed electrolysis processes. Because of this, the author's pulse experiment did not take into account the difficulty of determining the optimum applied frequency due to the large range of frequencies used. Water electrolysers, unlike electroplating, do not use currents of opposite polarity. In addition, the increased inductive reactance caused by using a higher frequency reduces the reactive loss. concluded that a water electrolysis cell's power efficiency may be improved by using one with a low resonant impedance. Using this information, they reduced the cell voltage needed to attain a set amount of current by using the current versus frequency graph for the electrolysis process. The voltage needed to achieve a certain current level at a specific frequency was calculated using the assumption that the electrolyser would be identical to the electrical equivalent circuit of a battery. In actuality, the comparable circuit may not hold up to this assumption. Shock Wave Pressure Characteristics. At the time of the high-voltage pulse discharge, energy is injected into a plasma channel and rapidly spread around it. Pressure, density, and temperature all rise rapidly as a result of the extrusion of the surrounding water dielectric. Shock waves are created as a result. Breakdown energy, hydrostatic pressure, and shock wave peak pressure are the subject of this investigation (P). One of the sensors, number 1, was chosen as the collecting site for shock wave pressure characteristics since it was closest to the electrodes. The distance between the first sensor and the electrode is this value.

At a known charging voltage and hydrostatic pressure, we were able to accurately gauge the shock wave's peak pressure. Shock-Wave Pressure Characteristics as Affected by Breakdown Energy. When comparing charging voltages, it is important to note that the breakdown energy is related to the charging voltage (P). Shock-wave peak pressure (P) and breakdown energy both rise in tandem as the charging voltage rises. Energy leakage from discharge to breakdown is minimised as the charging voltage is increased. As a result, the peak pressure of the shock wave increases as a result of an increase in plasma energy input. Previous research using HVSD to shatter boulders employed water with low conductivity as the reaction medium, neglecting the impact of conductivity on pressure waves. A broad

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variety of conductivities may be found in drilling fluids, which constitute a complicated compositional combination.

Conductivity can affect high-voltage spark discharge properties such as breakdown voltage, energy loss, and breakdown delay time, however past research has been inconsistent on how conductivity affects pressure wave intensity. Even more so, there are just a few research on the influence of conductivity on HVSD fragmentation and the possible mechanism of rock breaking. High-voltage spark discharges, pressure waves, and rock damage are all being studied in this study to see how electrical conductivity affects the discharge characteristics, pressure wave size, and rock damage. A single pulse of 1444 J in water with varying conductivities was used to break cement mortar, a synthetic counterpart of real rock. Because of the uniformity and controllability of the mortar characteristics, quantitative investigation of the link between conductivity and sample breakage may be performed using mortar rather than raw rock. Reconstructing the mortar sample model before and after damage using X-ray computed tomography allowed us to analyse damage mechanisms.

Objectives of the paper:

- To examine and analyse the experimental data for electrical parameters of water at a high voltage pulse discharge.
- To understand the impact of pulse discharge in water on the production of high voltage pulses.
- To investigate the association between hydrostatic pressure and the breakdown of discharges in the context of high-voltage pulses.
- To evaluate the variations in high voltage pulse pressure and attenuation with increasing breakdown energy and hydrostatic pressure under different conditions.
- To study the high-frequency discharge characteristics of pulsed high voltages in association with the discharge characteristics of water.
- To develop a high voltage pulse attenuation equation as a function of discharge energy and other electrical properties.
- To utilize the results to address issues related to industrial production where high voltage pulse discharges in water play a crucial role.
- To contribute valuable insights to the scientific understanding of the electrical parameters of water under a high voltage pulse discharge.

LITERATURE REVIEW

Jae-Hoon Kim (2021): This research presents a technique for increasing hydrogen production efficiency in a proton exchange membrane-type electrolyser by utilising pulse current (PEMEL). Traditional electrolysis methods with direct current are often regarded as the most straightforward means of producing hydrogen. In order to increase the pace of electrolysis, environmental factors such as temperature and the catalyst employed must be carefully controlled, as described above. As a result, rather of employing environmental factors, we suggest electrolysis using a pulse current that may apply numerous dependent variables at the same time. In the pulsed water electrolysis process, there are several parameters that impact hydrogen generation, and the suggested approach addresses these challenges by deriving factors that affect hydrogen generation while simultaneously adjusting the concentration of hydrogen created by the cell interface. The relationship between the electrolyser load and the frequency characteristics was investigated, and the maximum frequency at which the pulse current could be applied was determined by electrical modelling. The operational properties of PEMEL were also anticipated, and the PEMEL's performance when operated with a certain pulse current was confirmed by experimentation.

D. C. Bian (2018): The pulsed discharge mechanism of hydraulic fracturing is used to increase the permeability of unconventional gas wells, such as coal seams and shale gas wells, by using the engineering background of hydraulic fracturing. Through high-voltage pulsed discharge experiments in pressurised liquid water, we investigated the relationships between water shock wave properties (including maximum pressure, peak wave velocity, and energy conversion efficiency), the discharge voltage, and hydrostatic pressure in order to better understand how water shock waves work. There were a number of observations made, including the following: The following results were obtained: (1) when the discharge voltage was increased from 7 kV to 13 kV, the maximum pressure increased from 12.6 MPa (hydrostatic pressure PH = 12 MPa) to 40 MPa (PH = 6 MPa), wave velocity increased from 1418 m/s (PH = 12 MPa) to 1454 m/s (PH = 6 MPa), and energy conversion efficiency increased from 9 percent to 11 percent; and (2) when hydrostatic pressure was increased from 0 MPa to The fluctuation in electrical parameters that occurs during the pulsed discharge can be used to describe their characteristics.

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PROPOSED METHODOLOGY

We also measured the surface damages by pore size distribution and cumulative area of the pores, applied through transmission technique to detect microcracks inside the sample, and quantified the internal damages by acoustic attenuation coefficient. In order to increase oil and gas production, reservoir fracturing is the most effective approach, since it may significantly increase reservoir permeability. Traditional fracturing methods are ineffective in improving reservoir permeability in unconventional gas reservoirs (e.g., coal gas and shale gas) because of their varying properties. Problems like as low efficiency, a lack of management, damage to the reservoir and subsurface environment, and excessive water use are all too prevalent. As a result, the natural gas mining sector is in desperate need of improved fracturing equipment to accommodate these new methods of extraction. One of the most common applications of high-voltage pulsed discharge (HVPD) is mechanical processing, including lithotripsy and waste water treatment.

Using HVPD to remove oil and gas well clogs and enhance reservoir fracturing has been investigated in recent years. Water shock waves (WSWs) from HVPD are the primary driving force behind the fracturing of gas reservoirs, and various WSWs will fracture coal and rocks differently. As a result, WSW features must be considered in any investigation into this technology. Hydrostatic pressure (PH) can have a significant impact on plasma breakdown, WSW excitation, and transfer processes in oil and gas wells, which can be hundreds or thousands of metres deep. Green hydrogen generation capacity may be limited if the electric energy intake is not taken into account in terms of the peculiarities of the EL load. As a result, a new strategy for boosting hydrogen production is required.

There have been several research on pulsed water electrolysis (PEMEL) since its inception. For the first time, the pulse electrolysis technique was examined theoretically who were working in the electroplating sector. They noticed that even after the electric field had vanished, a short time after a pulsed current had been created, a continuous flow of current continued. Hydrogen production might be affected by pulsed electric field conditions, according to their study. The electrode's surface condition changes when a voltage pulse is applied, according to experiments. Using traditional electrolysis, bubbles develop on the electrode surface, increasing the resistor's overpotential, which is then neutralised by applying a pulse voltage. It is common to refer to this concentration gradient area as a diffusion layer when pulse potentials are applied to a substrate, which rapidly consumes the substrate in the vicinity of the electrode. There was no mention of this link between layer thickness and the current that can be used to control mass transfer in the above research, the pulse on/off period during electroplating can be restricted by the charge/discharge rate of the electric double layer. The discharge procedure is as follows: When the capacitor is fully charged to its rated voltage, the discharge process begins. Due to the impact of conductivity, the maximum charging voltage gradually lowers before breaking down the water dielectric. The voltage drops dramatically as the water dielectric breaks down. The voltage drops as the current increases, and the breakdown channel is filled with electrical energy. The remanent voltage in the capacitor at the time of water dielectric breakdown by arc discharge is known as the breakdown voltage. The breakdown time is the name given to this point in time (the moment of discharge was time 0).

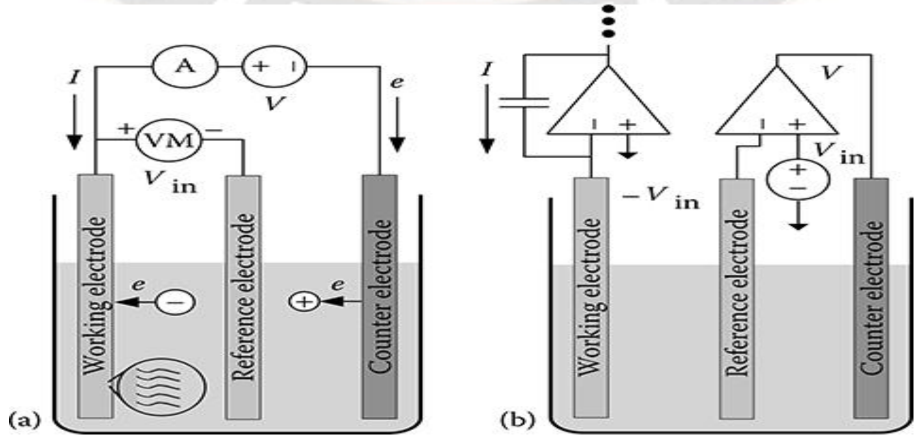

Figure 2 High voltage water pulse discharge

The breakdown voltage of the water dielectric is the most important component in determining the breakdown energy of the water dielectric and directly effects shock wave production in high-voltage pulse discharges. A decrease in breakdown voltage with an increase in hydrostatic pressure was clearly evident when the charging voltage was held constant. As a result of this decrease in breakdown energy, electrical energy consumption increased prior to the water dielectric's discharge breakdown. Breakdown time and resistance increased as a result of the rise in hydrostatic pressure. It took longer to break down when the hydrostatic pressure went up. Because of this, hydrostatic pressure had an inhibitory influence on the disintegration of the discharge. When the hydrostatic pressure was between 0 and 3 MPa, the breakdown voltage attenuation was slow. Hydrostatic pressure has just a tiny impact on the breakdown process. When the hydrostatic pressure reached, the attenuation rapidly increased. Attenuation began to stabilise after this. As a result of this experiment, a large number of bubbles were found on the electrode surface and in the water. Bubbles reduced the breakdown field strength required by the electrode, resulting in a slight loss of energy before the breakdown. The little bubbles in the water were progressively dispersed by hydrostatic pressure when it was between 0 and 3 MPa. Because of the presence of these tiny bubbles, hydrostatic pressure was unable to limit discharge disintegration. A gradual drop in breakdown voltage was seen as hydrostatic pressure was raised. After a particular hydrostatic pressure was reached, the water's initial bubbles dissipated. Due to the loss of hydrostatic pressure's inhibitory influence on channel development, the breakdown voltage dropped dramatically. The electrohydraulic effect is a result of high-voltage spark discharge (HVSD) generating powerful water pulse pressure waves (EHD).

Underwater sound generation, extracorporeal shock wave lithotripsy, well cleaning, and alternative hydraulic fracturing are just a few of the uses for this technology. HVSD and the mechanical power of the drill bit have lately been presented as a new drilling technology that might crush hard rock and boost ROP without creating high temperatures like other new drilling techniques. We tested the effects of discharge voltage, discharge energy, and the number of discharges on rock damage in a series of laboratory tests employing pressure waves to demolish shale, sandstone, and concrete. Drilling systems that are inspired by traditional rotary drilling have been conceptualised by our team. There are many HVSD reactors built into the drill bit's nozzle in this system, and the electricity needed to create the electrohydraulic effect can originate from either a surface power supply or a downhole electrical generator.

The HVSD reactors produce pressure waves that are enhanced by ellipsoidal reflectors that operate on the rock during drilling operations. It is possible to crush the rock down to a few millimetres in depth, however this greatly lowers the surface material's mechanical qualities, making it simpler for the drill bit to crush. These last several years have seen the rise of a hydrogen-centric civilization as a realistic possibility. When it comes to a long-term solution to climate change and the depletion of finite fossil resources like natural gas, coal, and petroleum, hydrogen is one of the most promising options. Hydrogen, despite its eco-friendly attributes and abundance as a universal source of energy, is found in water and organic substances. As a result, a variety of hydrogen production research are taking place. Hydrogen can be classed as grey, blue, or green depending on the process used to make it.

EXPERIMENT RESULT

Green hydrogen is created by directly electrolyzing water with power generated either from a renewable or excess source. Green hydrogen is the most environmentally benign energy source since it only produces hydrogen and oxygen throughout the water electrolysis process. In order to make green hydrogen, water electrolysis is required, and a variety of electrolysers can be used to do this (EL). In particular, PEM water electrolysis provides a long-term option for hydrogen generation because of its small size, rapid reaction, wide range of current, and great operational flexibility. Combined with other renewable energy sources like solar and wind power, it is ideal. Even though there are numerous problems, they haven't been fully investigated because of the lack of demand for PEM electrolysis in the last century. It is thus necessary to design a new research path for green hydrogen generation technologies and a roadmap in light of the obstacles and development level of previous studies The PEMEL method, on the other hand, is still based on electrolysis with direct current.

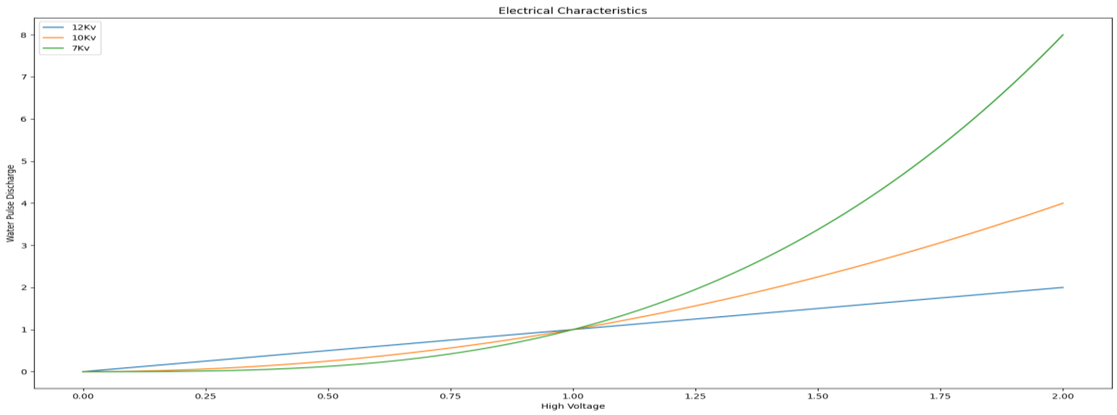

Figure 3 Pulse Discharge

The use of DC current for water electrolysis is constrained by environmental factors such as temperature, catalyst, pressure, etc. The high-voltage pulse power supply's capacitance remained constant. In this experiment, the discharge voltage and hydrostatic pressure were variables. It was necessary to measure the shock wave pressures at each of the six sensor connections. Shockwave pressure features and attenuation were studied in relation to discharge energy, hydrostatic pressure, and distance. All of the water had drained out of the tube. There are seven levels of external hydrostatic pressure. There were six levels of charging voltage classification. Various hydrostatic pressures and voltages were used to conduct a total of eight separate tests (seven levels for hydrostatic pressure and six levels for voltage). Each group of trials was subjected to a total of five discharge tests. This study relied heavily on the measurement of discharge energy and peak shock-wave pressures at each location. A more precise method would yield more accurate results for calculating the breakdown energy of the water dielectric via high-voltage discharge. The real breakdown energy of the water dielectric was determined by the particular breakdown voltage because of the impact of water conductivity, residual capacitance energy, and circuit energy loss. It was thus necessary to utilise a high-precision current test coil and a high-voltage probe during the breakdown process of water dielectric to monitor transient current and voltage. Hence, we could measure the real discharge energy required to degrade the water dielectric material.

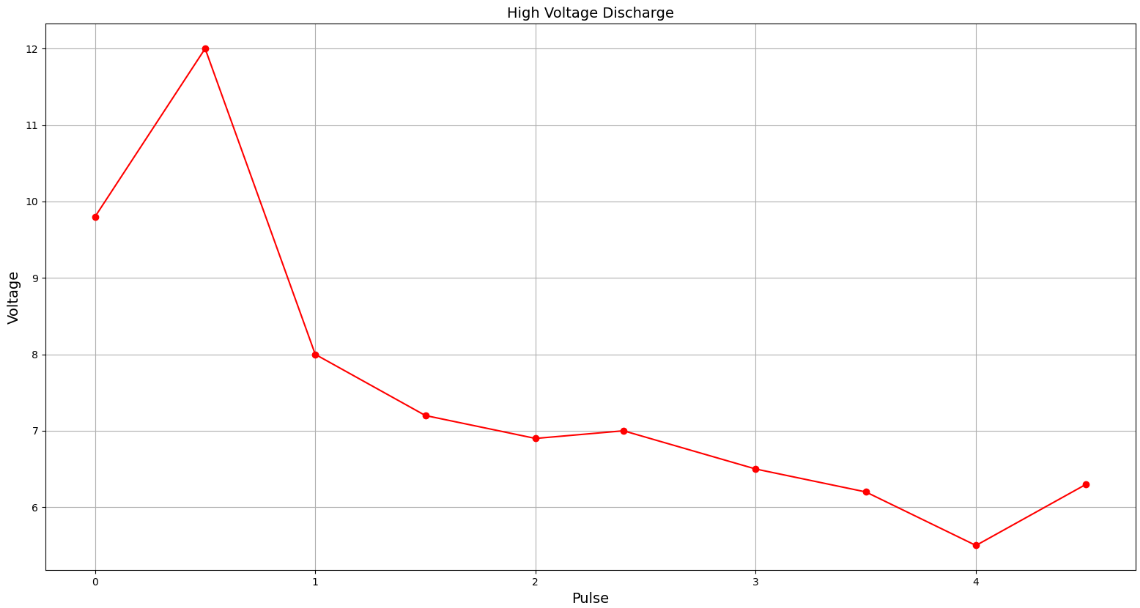

Figure 4 Pulse discharge and voltage level

The sensor recorded the maximum shock-wave pressure at each location. During the high-voltage discharge, the sensor base was built of nylon materials, which successfully insulated it from stray currents at the tube wall, therefore reducing electromagnetic waves and stray currents. To avoid electromagnetic interference with the sensor and the acquisition equipment, a 1 mm thick lead protective cover was utilised. The charge amplifier communicated the shock-wave pressure data to the signal recorder, which then showed them simultaneously on the computer. The whole acquisition system was powered by DC power to avoid the conduction coupling interference of each portion created by the power supply during the high-voltage discharge. The external hydraulic pump supplied the tube's hydrostatic pressure. This apparatus has a high degree of accuracy and exceptional pressure stability. The total weight and bearing pressure of the experimental setup may be as high as this. A substantial quantity of energy was released in a short period of time when the water dielectric was broken by electrode discharge. An accurate assessment of high-voltage pulse discharge characteristics was possible using transient current and transient voltage measurements. An oscilloscope was used to capture data on the transient current and voltage. Petroleum industry research is focused on increasing the rate of penetration (ROP) in unconventional reservoirs, where ROP is inversely related to drilling expenses of 30 to 40 percent of the overall well expenditures. Conventional rotary drilling technologies fail when drilling deep holes because of the hostile environment and improved mechanical characteristics of the rock. A variety of unconventional drilling methods have been presented by academics and engineers over the past several decades, instead than relying on mechanical force to cut through rock.

Result summary

- ✓ Green hydrogen is produced by directly electrolyzing water, being a sustainable energy source as it only creates hydrogen and oxygen.
- ✓ PEM water electrolysis is seen as a prospective method for hydrogen generation due to its small size, rapid response, wide current range, and excellent operational flexibility.
- ✓ There is a need to design new research trajectory for green hydrogen generation technologies considering the challenges and development level of previous studies.
- ✓ The capacitance of the high-voltage pulse power supply remained constant during the experiment, while the discharge voltage and hydrostatic pressure variables were manipulated to measure shockwave pressures at multiple sensor connections.
- ✓ The experiment conducted eight separate tests with different combinations of hydrostatic pressures and voltages.
- ✓ The experiment crucially depended on the measurement of discharge energy and peak shock-wave pressures at each sensor location.
- ✓ The impact of water conductivity, residual capacitance energy, and circuit energy loss on the actual breakdown energy of the water dielectric was observed.
- ✓ Accurate assessment of high-voltage pulse discharge characteristics was made possible using transient current and transient voltage measurements captured on an oscilloscope.

CONCLUSION

Shock wave attenuation decreases with increasing breakdown energy as it travels through the medium of the shock wave transmission process. With rising hydrostatic pressure, the shock-wave attenuation slowed down significantly, which was helpful for steady shock-wave transmission. As the shockwave's propagation distance increased, the stabilising impact of hydrostatic pressure on it grew more and more apparent. On the basis of mass data, an approximate formula for the propagation of shock waves in water with varying hydrostatic pressures was developed and tested. The association between shock-wave transmission attenuation in water and energy, as well as the relationship between hydrostatic pressure and propagation distance, has been established and measured. The discharge breakdown energy of the water dielectric had a direct effect on the peak pressure of the shock-wave resonant wave. Moreover, via simulations and tests, it has been demonstrated that the suggested pulse type can contribute to the enhancement of hydrogen generation by employing the technology described above. Pulses of varying timings and amplitudes are utilised in the simulations and experiments to create the suggested pulse type, which is employed in the simulations and experiments in pulse on/off modes. This was chosen as the preferred pulse type among the others because it produced somewhat more noticeable experimental findings in hydrogen generation than the others. The future design of power sources for power converters will require consideration of hydrogen creation in relation to the shape/patterns of the pulsed energy supplied, such as symmetric pulses and asymmetric pulses, in order to maximise efficiency.

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