The Microbe Removing Characteristics Caused by Dirty Water Using a Simple Pulsed Power System

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Jin-Young Choi* and Jong-Han Joung***

Abstract - The pulsed power system is widely available for use in pulse generator applications. Generally, the pulse generator is required for very short pulse width and high peak value. We have designed and fabricated our own pulsed type power system and through its use, we investigated microbe removal characteristics. This paper introduces a simple pulsed power system for removing various microbes caused by dirty water. This system includes a 2 times power supply circuit, IR2110 operated by using a fixed voltage regulator 7812 and 7805, and the switching MOSFET (Metal Oxide Semiconductor Field Effect Transistor). We can also control this process by using a PIC one chip microprocessor. As a result, we can obtain good removing characteristics of various microbes by adjusting the charging voltage, the pulse repetition rate and the electrical field inducing time.

Keywords: Microbe Removing Characteristics, PIC Microprocessor, Simple Pulsed Power.

1. Introduction

At present, the pulsed power system is widely used for environments such as removing bad microbes in dirty water.

Nowadays, the effluent from sewage systems and factories include a wide variety of harmful pollutants, such as odor and internal pollution that cause manufactured goods to be inferior [1, 2].

In domestic and foreign countries, researchers have actively done their best to eliminate such a source of pollution. But even now their efforts remain unrewarded [3]. Therefore, we have proposed a simple pulsed power system with several peak voltages and pulse repetition rate.

The existing method for removing bad microbes is usually through the use of chlorine. This process can lead to settlement of sludge in the settling tank of the clarifier by microorganisms that are rich in chlorine [4, 5]. These settled solids (sludge) from primary treatment are becoming the secondary cause of water pollution.

Electro-hydraulic discharge technology (EHD) has been used in many industrial applications. The main advantage of EHD is that it does not require certain explosive chemicals. EHD requires a spark channel formed by an electrical discharge between two submersed electrodes. The energy input into the channel causes expansion of a cavity. This expansion produces a shock wave long enough to destroy various microbes [6~8].

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In this study, an innovative method involving a simple pulsed power system using a PIC one-chip microprocessor is proposed to control the charging voltage and the pulsed repetition rate. In order to investigate the microbe removing characteristics of our simple pulsed power system, we have carried out the microbe removing experiment as a function of the elapsed time from the initial voltage.

2. Experimental Method

Our pulsed power system was designed and fabricated to be suitable for high frequency range and to reduce switching loss and noises.

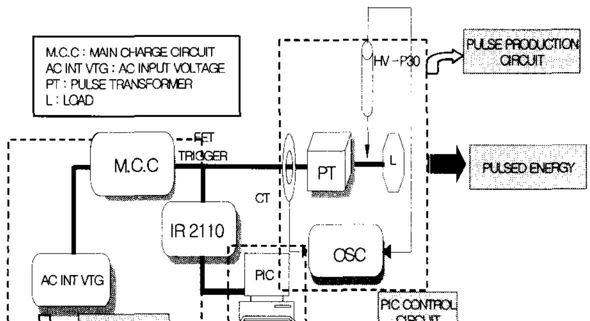

Fig. 1 Schematic diagram of the pulsed power system

Fig. 1 shows a schematic diagram of our pulsed power system. This pulsed power system is composed of input power supply, MOSFET (Metal Oxide Semiconductor

Field Effect Transistor) switching of the PIC control circuit, and pulse generator circuit.

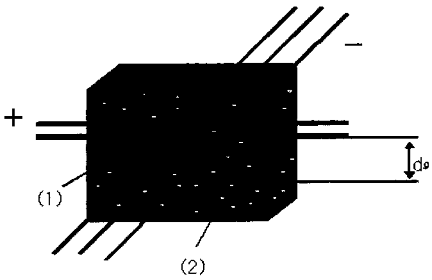

Fig. 2 Figure of electrical discharge for microbe removal

Individually (1) and (2) denote wastewater and microbes, respectively, when the pulsed power is applied between two electrodes causing a strong shock wave. As a result the dielectric bacteria are removed as revealed in Fig. 2.

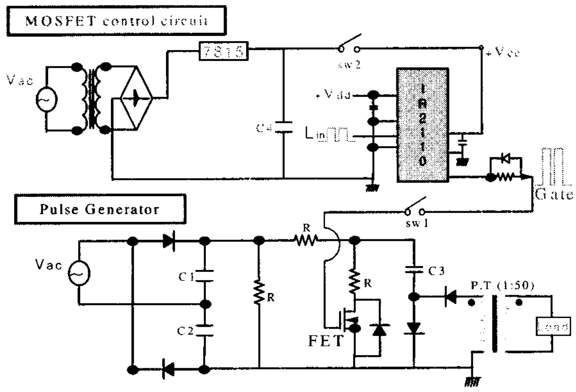

Fig. 3 Schematic of pulse generator and MOSFET control circuit

Our pulse generator system is composed of a 2 times power supply circuit as shown in Fig. 3. IR2110 is operated by using fixed voltage regulators 7812 and 7805. At first, a pulse transformer transfers the energy stored in capacitor C_3, which can charge the maximum voltage of 640[V] from the charging capacitor C_1, C_2 by 2 times the power supply. The output voltage was controlled adjusting the variable transformer [SLIDACS]. When the charging cycle of energy storage capacitor C_3 is completed, the trigger signal of MOSFET (MODEL: SSH9N80A) is applied, then C_3 begins to discharge into the load through the pulse transformer (1: 43). The time control of charging-discharging depends on τ (=RC). The function of the combinational circuit is to generate gate trigger signals to the IR2110 gate. In the PIC one-chip microprocessor, 1 to 1000 pulse signals per second from PIC I/O PORTB are applied to pin9 of IR2110, referred to as real time clock count (RTCC). So it is possible to control the pulse repletion rate easily.

Fig. 4 depicts a control circuit that is composed of a keyboard, LCD (liquid crystal display), PIC one-chip microprocessor (16F877) and the amplification circuit to turn on MOSFET. In this control circuit, the pulse repetition rate is entered via the keyboard, and this input information is transferred to the PIC. The PIC generates signals. However, these signals are too weak to turn on the MOSFET and therefore the current and voltage are amplified with the use of a transistor for high-speed switching.

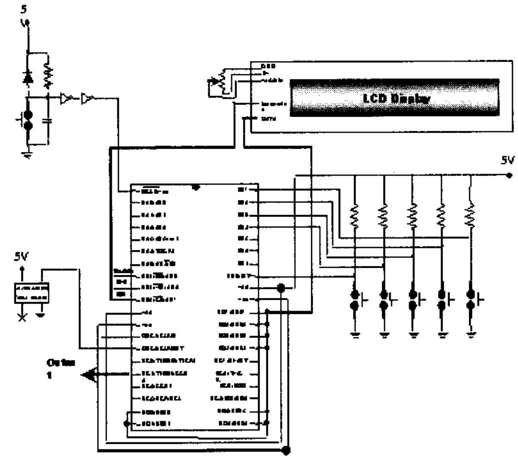

Fig. 4 Schematic diagram of control circuit

The input energy obtained is 0.1 J/pulse in case of C_3=1μF, V_{c3}=450V. Maximum input energy is 50W at 500 pulses per second by the following equation.

$$E_{input}=\frac{1}{2}CV^2=\frac{Q^2}{2C}[J]$$

3. Result and Discussion

3.1 Experimental result

Fig. 5 shows a diagram of the firing voltage waveforms by pulse repetition rate. Fig. 6 depicts a diagram of current and voltage waveforms of arc discharging in 400[pps]. In this case the pulse duration rate is 4μs.

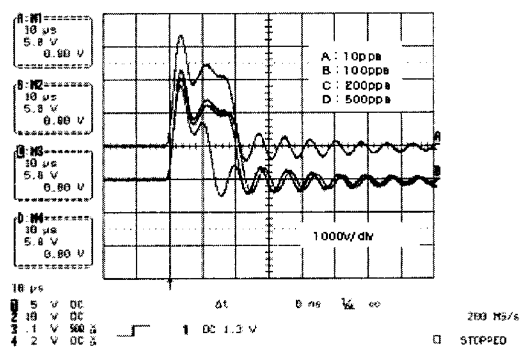

Fig. 5 Example of the firing voltage waveforms by pulse repetition

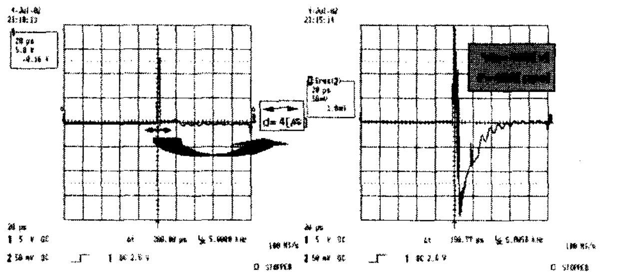

Fig. 6 Example of current and voltage waveforms of arc discharging in 400[pps]

When we increased electric field intensity and elapsed time, pulse duration rate of the microbes was also increased as in the following equation.

$$S = \left(\frac{t}{t_c} \right)^{(E - E_c)/k} \quad [S = \text{destruction rate}]$$

Where, t is disposal time, t_c is critical disposal time, E is electrical field intensity, E_c is critical electrical field intensity, k is constant.

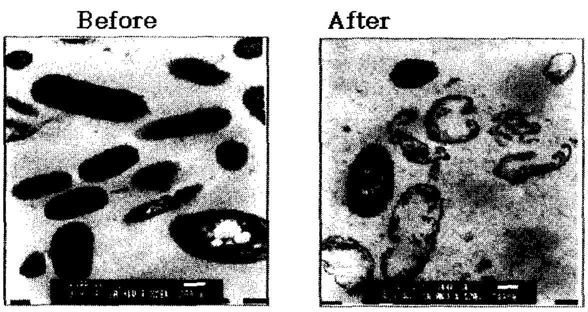

Fig. 7 TEM (InJe University Hospital) micrographs of microbes before and after pulsed energy exposure

Fig. 7 shows the TEM (Transmission Electron Microscopy) micrographs of microbes before and after the applied pulsed power. It demonstrates the optimum condition in which to remove microbes from dirty water.

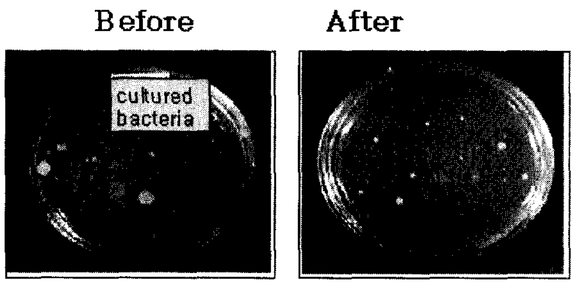

Fig. 8 Incubator of microbes before and after pulsed energy exposing

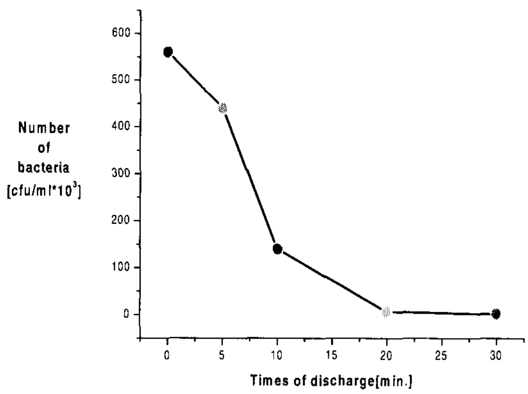

Fig. 9 The number of microbes before and after the applied pulsed power

Fig. 8 illustrates an incubator of microbes before and after the applied power. Fig. 9 shows the number of microbes before and after the applied pulsed power. The initial number of the bacteria is 5.6 x 10^5cfu/ml [cfu/ml : colony forming unit], when we applied the pulsed power to the sample for 5 minutes, 10 minutes, 20 minutes, and 30 minutes with 400 pps. The number of bacteria is changed to 4.4 x 10^5 cfu/ml, 1.4 x 10^5 cfu/ml, 6.4 x 10^3 cfu/ml, and 1.7 x 10^3 cfu/ml, respectively.

3.2 Two mechanisms of microbe removal

The application of pulsed power to microbes in dirty water causes a buildup of electrical charges at the cell membrane [5]. Membrane disruption occurs when the induced membrane potential exceeds the critical value of 1 V in many cellular systems or for example, when it corresponds to an external electric field of about 10 kV/cm [10]. Several theories have been proposed to explain microbial removal by pulsed power. Among them, the majority of research results show electrical breakdown and electroporation or disruption of the cell membranes. These researches indicate that the critical factors are described by two mechanisms as follows.

Two mechanisms have been proposed as the mode of action of pulsed power on microorganisms: electrical breakdown and electroporation.

3.2.1 Electrical breakdown

As shown in Fig. 10, Zimmermann explains what electrical breakdown of cell membrane entails [11]. The membrane can be considered as a capacitor filled with a dielectric (Fig. 10a). The normal resisting potential difference across the membrane is 10V and leads to the build-up of a membrane potential difference due to separation across the membrane. That is proportional to the field strength and radius of the cell. The increase in the membrane potential leads to reduction in the cell membrane thickness. Breakdown of the membrane occurs if the critical breakdown voltage Vc (on the order of 1 V) is reached by a further increase in the external field strength (Fig. 10c). It is assumed that breakdown causes the formation of transmembrane pores (filled with conductive solution), which leads to an immediate discharge at the membrane and thus decomposition of the membrane. Breakdown is reversible if the product pores are small in relation to the total membrane surface. Above critical field strengths and with long exposure times, larger areas of the membrane are subject to breakdown (Fig. 10d). If the size and the number of pores become large in relation to the total membrane surface, reversible breakdown turns into irreversible breakdown, which is associated with mechanical destruction of the cell membrane.

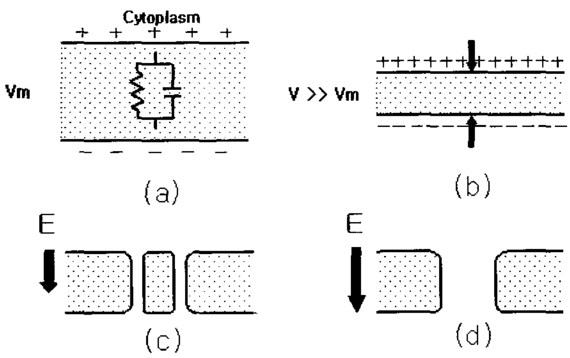

Fig. 10 Schematic diagram of reversible and irreversible breakdown
(a) Cell membrane with potential Vm
(b) Membrane compression
(c) Pore formation with reversible breakdown
(d) Large area of the membrane subjected to irreversible breakdown with large pores

3.2.2 Electroporation

Electroporation is the phenomenon in which a cell exposed to high voltage electric field pulses temporarily destabilizes the lipid bilayer and proteins of cell membranes [10]. The plasma membranes of cells becomes permeable to small molecules after being exposed to an electric field, and permeation then causes swelling and eventual rupture of the cell membrane. The main effect of an electric field on a microorganism cell is to increase membrane permeability due to membrane compression and poration.

4. Conclusion

In this study, we have designed and fabricated a simple pulsed power system with switching MOSFET.

In order to investigate the microbe removing characteristics of our simple pulsed power system, we have carried out the microbe removing experiment as the function of the elapsed time from the initial voltage.

As a result, we have obtained the best condition of 1.7×10^3 cfu/ml at 17kV, repetition rate of 400pps, pulse width of 4μs, and elapsed time of 30minutes.

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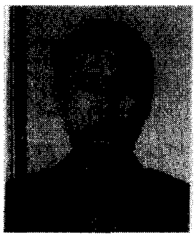

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