Influence of Impulse-Electric Field on Dielectric Properties of Nerve Membranes

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Abstract. An investigational study of the impulse-electric field on an increase in the potential of nerve membranes, increased ion absorption of Na, K, Cl, has been conducted. The aim of this study is not only to observe the performance of the electric field as a source of energy but also to look the effective, efficient and non-thermally disabling, disinfecting the microorganisms. Based on the result of research, qualitatively with object of parasitic nematode, there is tenfold increase possibly in critical nervous membrane from normal potential, in intensity of electrical field of $13.33 - 18.66 \text{ kV/cm}$ in angle, $\theta$ is $44.41^\circ$, and comparative membrane dielectric decreased to 0.2, it led to dielectric rupture, non-active effects, and needs an energy only $0.64 \text{ mJ}$ for twenty triggers, with condition of electrode potential of 6.3 kV.

1. Introduction

Inactivation of parasitic microorganism is very important to consider the adverse effect it produces. The loss of nematode attack, (Meloidogyne species), for example all over the world, has been reported to achieve US$ 80 million/year\textsuperscript{[1]} . To prevent the loss from occurring, the new nematode is needed for better inactivation of parasitic microorganism. There have been many perturbation methods conducted by experts to inactivate the cell membrane in a microorganism, including through chemical, physical and biological methods. Chemically, for example, it was perturbation with ozonization, fumigation, and so on. Physically, it was electromagnetic radiation such as UV-ray, Nitrogen laser-ray\textsuperscript{[2]}, pressure cold plasma\textsuperscript{[3]}–\textsuperscript{[6]}, hot steaming and dry steaming and cooling\textsuperscript{[7]}–\textsuperscript{[9]}. Biologically, it was made for example, by supplying nemathofagus microorganism to eradicate the nematode\textsuperscript{[10]}, \textsuperscript{[11]}. However, of all three conventional methods mentioned above, they have owned both advantage and disadvantage, thus they have rather poor side effects, for example, overheat on medium, destroying molecular structure of the solution, environment, and so on.

One of the solutions to prevent the heat effect of conventional nematode is to inactivate the microorganism by better performance, i.e., impulse-high voltage electric field \textsuperscript{[12]}. Until recently, experts are not sure what is the main cause of bilayer membrane wall break down, and then inactivation of microorganism cell. But there are several theories to support the increases transmembrane potentials by perturbation of electric field able of causing the destruction and reducing the cell immune (\textit{Fang, J., et al., 2006}), including dielectric rupture theory \textsuperscript{[13]}, i.e., increasing intensity of electrical field will cause an increase in cell membrane potential. In certain conditional, if membrane potential exceeds the normal potential, it will be called potential transmembrane, \textit{PTN}. The \textit{PTN} effect is often called electroporation \textsuperscript{[14]}, \textsuperscript{[15]} or transmembrane or break down.
This research aims to explain what is the effect resulted in by electric field on increase in the concentration of ions Na, K, Cl and so on, both inside and outside of cell membrane. The increased potential in ion concentrations is closely related to increased potential in cell membrane consistent with a gradient of Nernst potential, and in what intensity of electrical field that critical potential in the cell membrane can be achieved.

2. Material and Methods

2.1 Material

This study implicated of experimental set-up and equipment is presented in figure 1. Below

![Figure 1. Main of Electrical Experiment Set-up](image)

The data consistent with experiment set-up as in figures 1 as follows. The dimension of sample space is 23 mm length, 10 mm height, 10 mm width and 1 mm thickness made of fiber glass (dielectric strength, 30 MV/m), and relative dielectric constant: \( \varepsilon_{ri} = 3.4; \varepsilon_{rt} = 3; \varepsilon_{rs} = 2; \varepsilon_{air} = 80; \varepsilon_{rk} = 4; \varepsilon_{ro} = 10 \). The source of high-voltage generation is as follows generator YHIG-100 KV, 5KVA with trigger F, \( R_D = 416 \Omega, 140 \text{ kV} \); \( R_e = 9500 \Omega, 140 \text{ kV} \), \( C_s = 6000 \text{ pF}, C_b = 1200 \text{ pF} \), AVO Meter and Oscilloscope and X-Y recorder YEW 3023.

Based on experimental data above, measurement data of electric field impulse effect is gained on nematode reaction as indicated in table 1.

| No | \( V_{in}, \text{kV} \) | \( V_{elek.}, \text{kV} \) | Effect |
|----|-----------------|-----------------|-------|
| 1  | 4,0             | 3,36            | Active |
| 2  | 4,5             | 3,75            | Active |
| 3  | 5,0             | 4,20            | Less active |
| 4  | 5,5             | 4,60            | Less active |
| 5  | 6,0             | 5,00            | Least active |
| 6  | 6,5             | 5,45            | Least active |
| 7  | 7,0             | 5,85            | Not active |
| 8  | 7,5             | 6,30            | Not active/ attenuating |
| 9  | 8,0             | 6,70            | Destroyed |
| 10 | 8,5             | 7,15            | Destroyed |

Photograph result of microscope (x 400 – 1000), gained according to \( V_{elek.} \) voltage control in table 4.1 is as indicated in figure 1 below.
2.2 Methods
If in a medium of the electric field, sample space, there is a microorganism such as a nematode, there will be an increase in potential in the cell membrane. The increase mechanism of potential in nematode membrane can be modeled as indicated in Fig. 3.

From Fig. 3 if electrical field intensity $E$ and flux density $D$ in the sample space due to the potential difference $V$ then there will be an increase in potential in the cell membrane through cuticle layer, muscle in the nematode.
\[ V = 2E_i d_i + 2E_s d_s + 2E_o d_o + 2E_k d_k \] (1)

And,
\[ D = \varepsilon_o \varepsilon_i E_i = \varepsilon_o \varepsilon_l E_l = \varepsilon_o \varepsilon_k E_k = \varepsilon_o \varepsilon_m E_m = \varepsilon_o \varepsilon_r E_r = \varepsilon_o \varepsilon_s E_s \] (2)

In which: \( i \) is isolator, \( l \) is a solution, \( s \) is nerve cell, \( o \) is muscle, \( k \) is cuticle, and \( d \) is spacing. Thus \( V_{Elec} \) relation on \( E_s \) is gained\[16]:

\[ V_{Elec} = 1439.4E_s \] (5)

While, potential of \( V_{Elec} \) or \( U(t) \) is:

\[ U(t) = 0.8387 U_0 \left( e^{-t/T_1} - e^{-t/T_2} \right) \] (3)

Thus,

3. Result and Discussions

Based on equation 5 above, the potential gradient in the nerve cell membrane is highly dependent on the magnitude of \( V_{in} \), \( V_{Elec} \), \( E_s \) angle \( \theta \), and diameter of the nerve membrane cell, \( d_s \). The parameter calculations are made by using Matlab V7R14. According to equation (6), the relation of electrode potential, \( V_{Elec} \) on increase in potential received by the nerve cell membrane of nematode is:

\[ V_{Elec} = 1.9187 \Delta V_{s} \sec \theta \text{ kV} \] (7)

The assumption, that \( \Delta V_s \) is in rupture condition, ranging 1-1.4 volt, and angle \( \theta \) ranging 0˚ – 60˚, then electrode voltage, \( V_{Elec} \) is as indicated in Fig. 4.

![Figure 4](image-url)

**Figure 4.** Relation graph \( V_{Elec} \) vs- \( \Delta s \) and angle \( \theta \)

The relation of input voltage (source), \( V_{in} \) on output voltage \( V_{Elec} \) as in equation (7), is indicated in the figure.
Figure 5. Relation graph of $V_{in}$-vs-$VElec$.

For several conditions of input voltage, $V_{in}$ and electrode voltage (vessel), $VElec$, on direction angle of electric field $E$, see the graph in Fig. 5.

Figure 6. Relation graph of $E_s$, $VElec$, $Vin$-vs-$1/Cos(\theta-60)$.

And several conditions of voltage gradient $\Delta V$, ranging 1-1.4 volt, are indicated in figure 5.
The waveform of impulse voltage, $V_{Elec}$, and $V_{in}$ on time $t$, according to figures 7 and 8, then for angle $\theta = 0^\circ$, it is gained as in Fig. 6.

![Graph](image.png)

**Figure 7.** Relation graph of $E_s$, $V_{Elec}$, $V_{in}$-vs- $Sec\theta^\circ$.

4. Conclusions

In this study, we present of microscope monitoring that in the condition of voltage control in electrode minimum $V_{Elec}$ is 6.3 kV or $v_i$ is 7.5 kV, there is a destructive effect, rupture, in membrane tissue of nematode’s nerve cell. Based on identification according to figures 4.5 and 4.6, so in the condition of control $V_{Elec}$ is 6.3 kV or $v_i$ is 7.5 kV, it occurs in minimum angle of electric field direction $E$ on the nerve cell membrane, $\theta$ is 44.41. There is an increase in the value of relative rupture dielectric, until 5 (five) times from normal condition, in this situation the membrane dielectric breaks out or rupture, thus membrane becomes a conductor.

![Graph](image.png)

**Figure 8.** Impulse voltage of $V_{Elec}$ (kv)-vs-$t$ ($\mu$s).
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