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PORTABLE OZONE GENERATING DEVICE FOR WOUND TREATMENT: DEVICE PROGRAMMING AND FIRST TESTS ON ELIMINATION OF MICROORGANISMS

R.O. Pavlichenko[1], A.V. Klosovskij[1], A.V. Taran[1], G.P. Opaleva[1], M.I. Zolototrubova[1], O.G. Chechelnitsky[1], P.M. Vorontsov[3], Yu.P. Gnidenko[2]
[1]National Science Center "Kharkiv Institute of Physics and Technology", Kharkiv, Ukraine;
[2]V.N. Karazin Kharkiv National University, Kharkiv, Ukraine;
[3]Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv, Ukraine
E-mail: avtaran@ukr.net

Hear we report the final results on developing the portable ozone generating device based on dielectric barrier discharge (DBD) used for antiseptic treatment of wounds at the stage of evacuation and pre-medical care for their further effective treatment. Special attention is paid to device programable operation algorithm and first tests on elimination of various microorganisms are carried out. The developed program based on the PIC18F2550 microcontroller includes a number of simple but precise steps for setting up and implementing the desired functions of the device.

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INTRODUCTION

Problems in wound care are increasingly caused by co-morbidities, as well as by the sharp increase in further resistance to antibiotics [1, 2].

Gaseous ozone-based treatment is the process of administering highly unstable gaseous ozone molecules to treat a wound or a disease. The fundamental process involves the generation and application of gaseous directly to the skin surface to promote wound healing, antibacterial effect, and immunoregulation [3 - 7]. Additionally, because ozone has a long lifetime outside of the plasma region and can be delivered as a gas flow, it can increase the accessibility and application time significantly through simplified systems without the direct application of high-energy CAP plasma that can lead to toxic and harmful effects to the skin tissue [8 - 11].

Directly applying gaseous ozone to the wound surface using a portable system can provide a means to administer the promising ozone therapy while eliminating the complex storage requirements and higher efficacy. It is crucial to develop a simple and swift reliable technique for controlled and localized delivery of ozone gases into the healing region.

The key functionality of DBD-based ozone generation systems is their ability to be powered through simple and low-power electronics, which can aid their portability. Furthermore, many of such ozone-generating setups are highly effective in generating ozone at room temperature with ambient air, which is necessary to develop a portable device.

In this research we report the final results of device development, its programable operation, and first results on microorganism's elimination. The developed device is easy to use and can be powered either from 12 V, in the field, or from the mains in a hospital.

1. DESIGN OF DEVICE

The main view of the portable device in shockproof case used for field conditions is shown in Fig. 1. On the front side of the device a removable cap is maintained, and on the back side there is a digital timer with set buttons (left) and on/off switcher (right).

Fig. 1. The main view of the portable device in shockproof case

The main printed circuits and elements of the portable device have been discussed in detail in [12].

In order to monitor ozone generation modes and device operation several oscillograms are discussed below. In Fig. 2 the oscillogram shows two signals, the upper beam indicates the shape of the control signal from the microprocessor coming to the driver of the key field-effect transistors.

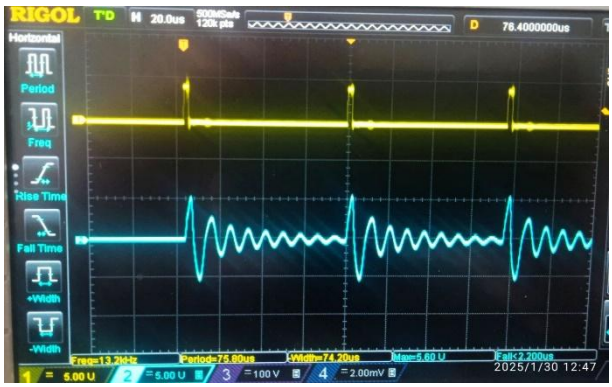

Fig. 2. The control signals of the microprocessor

The duration of the control signals is 3 ms, this determines the steepness of the rise of the leading edge of the output voltage from the high-voltage transformer, which is reflected by the lower blue beam in Fig. 2. After 3 ms of the control signal, the power keys are locked and the LC circuit formed by the inductance of the secondary winding of the transformer and the intrinsic capacity of the ozone reactor freely performs damped oscillations. Short flashes are visible on the yellow beam in three places, on the leading edge of the rise of the high-voltage signal, starting from 2.3 kV and on the negative decline, also from 2.3 kV and on the next half-period of the rise, at the same level. Further oscillations occur below this level. These flashes are streamer barrier discharges indicating ozone-generation process. And the subsequent decaying process does not participate in ozone formation, since the amplitude does not reach the discharge formation voltages. The frequency of control signals (upper beam) is 13.2 kHz. The resonance frequency of the high-voltage signal is about 117 kHz.

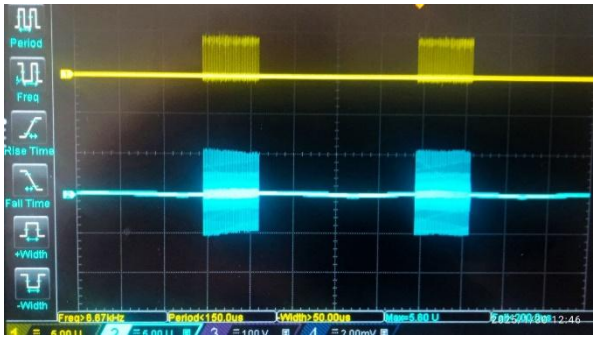

Fig. 3. The control signals of the microprocessor

On the oscillogram in Fig. 3, the upper yellow beam reflects the nature of the key transistor control. It is evident from this that the excitation of high-voltage oscillations is not continuous reflecting 7 ms packets with a frequency of 40 Hz. This mode allows flexible setting of the optimal high voltage for the reactor at a given power consumption, changing the duty cycle of the pulse modulation. All control operations are performed by the microprocessor.

2. DEVICE OPERATION PROGRAMMING

The device operating program provides:

• setting the time of the wound treatment process;

• control of the dynamic indicator that shows the time of the wound treatment process;

• indication of the current time of the device in digital form.

The portable device operation is implemented on the basis of the integrated 8-bit PIC18F2550 controller with RISK-architecture from Microchip Technology Inc. The PIC18F2550 is widely used for the precision and successful development of medical devices. The developed program based on the PIC18F2550 microcontroller includes a number of simple but precise steps for setting up and implementing the desired functions of the device. The controller provides the operating timing, control of the dynamic indicator, device setting buttons.

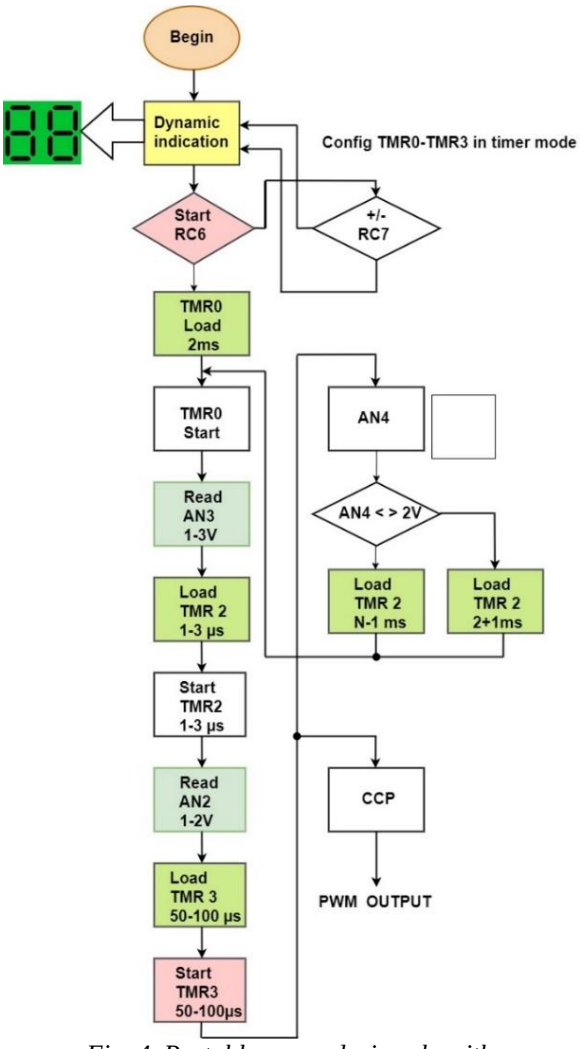

Fig. 4. Portable ozone device algorithm

After turning on the device, when the “START” button is pressed, the control program starts working according to the signal and algorithm in Fig. 4:

1. Initialization of variables and constants;

2. Setting the nodes and pins of the microcontroller:

• setting timer values (TMR0, TMR1, TMR2, TMR3);

• ADC setting (3 channels);

• configuration of the Capture/Compare/PWM (CCP) module, which allows measuring and monitoring various events, as well as generating output signals with pulse-width modulation (PWM);

• pins controlling the setting and START/STOP program buttons;

• pins that ensure the operation of the dynamic indicator.

The RC6 input signal turns on the Start button, and the RC7 signal sets the time value (+/-) of the treatment process, controls the positions of the dynamic indicator, which shows the countdown of the treatment process and sets the period and duty cycle (PWM1 and PWM2), which determines the ratio of the pulse repetition period to the pulse duration (duty cycle).

Three analog ADC channels ensure the operation of the device (reading and writing):

- AN1 regulates the pulse duration (2…18 ms);
- AN2 establishes the pulse duration (5…100 ms);
- AN3 regulates the pulse duration (1…3 ms);

After the wound treatment process is completed, when the "STOP" button is pressed, the program ends.

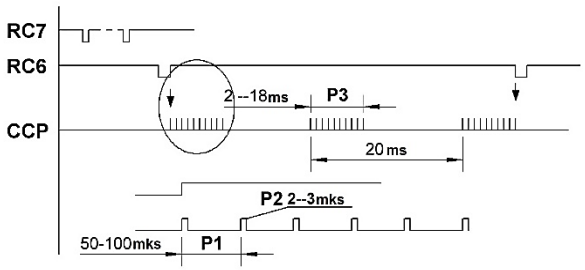

Fig. 5. Input signals

The input signals of the device are presented in Fig. 5 and listed below.

Input signals:

P1(μs) = 0.24×V(n);
P2(μs) = 0.0049×V(n);
P3(μs) = 0.24×V(n);
RC6 – Start button (ON/OF);
RC7 – Button for setting the time indicator value(+/-);
AN2 – Setting the period (50…100 ms), proportional (analog signal (1…2 V));
AN3 – Setting the pulse duration (1…3 ms), proportional (analog signal (1…3 V));
AN1 – analogue duration adjustment P3 (0.5…4 V), respectively (2…18 ms).

The output signals are as following and listed below:

RB0 – charging the battery (pull-up resistor);
RB1 – Start button (pull-up resistor);
RB2 – Time 15 s (level 1);
RB3 – Time 30 s (level 2);
RB4 – Time 45 s (level 3);
RB6 – Time 1 min (level 4);
CCP – pulse width modulation (PWM) mode;
RA2 – Timer indication.

3. TESTS ON ELIMINATION OF MICROORGANIZMS

To carry out experiments on microorganism's elimination under ozone exposure, Endo Agar Base was used which is differential and moderately selective medium for the detection and confirmation of coliforms and other intestinal microorganisms in water, milk, dairy and other food products. The nutrient medium was stirred in 1 liter of distilled water, boiled for 2…3 min until the agar is completely melted, filtered through a cotton-gauze filter, brought to a boil again, cooled to a temperature of 45…50°C and poured into sterile Petri dishes in a layer of 5…6 mm.

Petri dishes with Endo Agar with sealed cultures of Staphylococcus aureus, Shigella sonnei, Escherichia coli, Pseudomonas aeruginosa have been enriched with ozone concentration of 1…5 mg/l for various time (Figs. 6, 7).

Fig. 6. Device used for the experiments

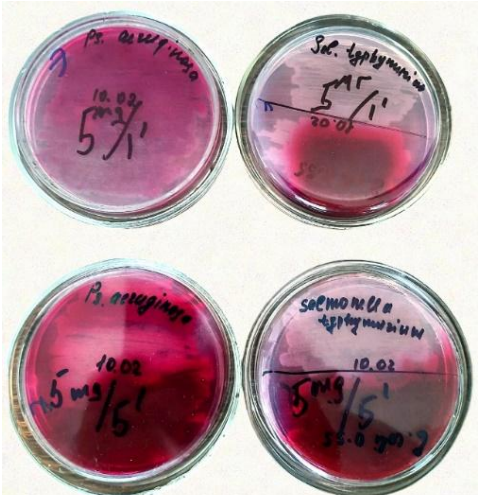

Fig. 7. Petri dishes (ENDO AGAR) with sealed cultures

Afterwards, sowing was carried out in a thermostat at T = 37°C for 48 h. The experiments have shown the decrease of colony forming units (CFU) from 10^7 to 10^2 cfu/ml versus ozone exposition time and concentration-type of sealed cultures. However, the sensitivity of bacteria to ozone varied enormously, depending on many factors. These factors include environmental factors or suspension media, laboratory conditions, the types of organisms, the stages of cellular growth, time period, the ozone concentrations, etc [13].

CONCLUSIONS

The results on developing the portable ozone generating device based on dielectric barrier discharge (DBD) used for antiseptic treatment of wounds at the stage of evacuation and pre-medical care for their further effective treatment. The portable device operation is implemented on the basis of the integrated 8-bit PIC18F2550 controller with RISK-architecture from Microchip Technology Inc. The first experiments on microorgan-

ism's elimination under ozone exposure revealed promising results decreasing surface bacteria contamination.

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REFERENCES

1. Alexander Roth, Akshay Krishnakumar, Rahim Rahimi. Ozone as a Topical Treatment for Infected Dermal Wounds // *Front. Biosci. Elite Ed.* 2023, v. 15(2), p. 9.
2. A. Roth, A. Elkashif, V. Selvamani, R.A. Stucky, M.N. Seleem, B. Ziaie. Wearable and Flexible Ozone Generating System for Treatment of Infected Dermal Wounds // *Frontiers in Bioengineering and Biotechnology*. 2020, v. 8, p. 458.
3. V.A. Bocci. Scientific and medical aspects of ozone therapy. State of the art //*Archives of Medical Research.* 2006, v. 37, p. 425-435.
4. G. Valacchi, Y. Lim, G. Belmonte, C. Miracco, I. Zanardi, V. Bocci. Ozonated sesame oil enhances cutaneous wound healing in SKH1 mice. Wound Repair and Regeneration // *Official Publication of the Wound Healing Society and the European Tissue Repair Society.* 2011, v. 19, p. 107-115.
5. D.B. Peden. The role of oxidative stress and innate immunity in O_3 and endotoxin-induced human allergic airway disease // *Immunological Reviews.* 2011, v. 242, p. 91-105.
6. U.C. Kucuksezer, E. Zekiroglu, P. Kasapoglu, S. Adin-Cinar, E. Aktas-Cetin, G. Deniz. A stimulatory role of ozone exposure on human natural killer cells // *Immunological Investigations.* 2014, v. 43, p. 1-12.
7. V. Travagli, I. Zanardi, G. Valacchi, V. Bocci. Ozone and ozonated oils in skin diseases: a review // *Mediators of Inflammation.* 2010, p. 610418.
8. S.A. Pai, S.A. Gagangras, S.S. Kulkarni, A.S. Majumdar. Potential of ozonated sesame oil to augment wound healing in rats // *Indian Journal of Pharmaceutical Sciences.* 2014, v. 76, p. 87-92.
9. A.M. Elvis, J.S. Ekta. Ozone therapy: A clinical review // *Journal of Natural Science, Biology, and Medicine.* 2011, v. 2, p. 66-70.
10. A.I. Al-Shamma'a, I. Pandithas, J. Lucas. Low-pressure microwave plasma ultraviolet lamp for water purification and ozone applications // *Journal of Physics D: Applied Physics*. 2001, v. 34, p. 2775-2781.
11. B. Eliasson, M. Hirth, U. Kogelschatz. Ozone synthesis from oxygen in dielectric barrier discharges // *Journal of Physics D: Applied Physics.* 1987, v. 20, p. 1421-1437.
12. R.O. Pavlichenko, A.V. Klosovskij, Yu.S. Kulik, I.O. Misiruk, A.V. Taran, P.M. Vorontsov, Yu.P. Gnidenko, Ye.O. Nesterenko. Portable ozone generating device for treatment of infected wounds // *Problems of Atomic Science and Technology. Series "Plasma Physics".* 2024, № 6, p. 96-99.
13. Benjamas Thanomsub, Vipavee Anupunpisit Silchai Chanphetch, Thanomrat Watcharachaipong, Raksawan Poonkhum and Chuda Srisukonth. Effects of ozone treatment on cell growth and ultrastructural changes in bacteria // *J. Gen. Appl. Microbiol.* 2002, v. 48, p. 193-199.

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ПОРТАТИВНИЙ ПРИСТРІЙ, ГЕНЕРУЮЧИЙ ОЗОН ДЛЯ ТЕРАПІЇ РАН: ПРОГРАМУВАННЯ ПРИСТРОЮ ТА ПЕРШІ ВИПРОБУВАННЯ ЗІ ЗНИЩЕННЯ МІКРООРГАНІЗМІВ

Р.О. Павліченко, А.В. Клосовський, А.В. Таран, Г.П. Опалєва, М.І. Золототрубова, О.Г. Чечельницький, П.М. Воронцов, Ю.П. Гніденко

Представляємо остаточні результати розробки портативного озоногенеруючого пристрою на основі діелектричного бар'єрного розряду (ДБР), який використовується для антисептичної обробки ран на етапі евакуації та долікарської допомоги з метою їх подальшого ефективного лікування. Особлива увага приділяється програмованому алгоритму роботи пристрою та проведенню перших випробувань щодо знищення різних мікроорганізмів. Розроблена програма на базі мікроконтролера PIC18F2550 включає ряд простих, але точних кроків для налаштування та реалізації бажаних функцій пристрою.