

Cold Plasma Generator for Medical Use

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ABSTRACT: This article presents a new design for cold atmospheric plasma generator for medical use in sterilization of medical equipment and to improve the healing of wounds. Improving the design of the generator is made possible through the use of ferrite core tube and two additional gas-discharge electrodes.

KEY WORDS: Cold atmospheric plasma generator, pin-to-hole discharge

I. INTRODUCTION

In the human organism, nitric oxide (NO) has many important biological functions that lead to its regulatory role in the cardiovascular, respiratory, digestive, and nervous systems, and it plays key roles in healing infections, inflammation, and fighting tumor growth. The main source of exogenous nitric oxide is plasma biomedical technology. The technology of plasma therapy uses a stream of exogenous nitric oxide (plasma chemical genesis) that normalizes the microcirculation, activates antioxidant protection, and has an antibacterial effect. Combined, these activities substantially reduce infection and inflammation and also stimulate tissue regeneration.¹ Cold plasma kills bacteria better than antibiotics.^{1,2} During the cold plasma treatment of wounds, a wide range of environmentally friendly particle (NO , O_3 , OH^- , O^{2-} , H_2O_2 , UV-radiation) are created that destroy biologically dangerous pollutants—pathogens and chemical toxicants. Cold plasma has been clinically proven as an effective means of inactivation of microorganisms, so it is used to disinfect wounds and sterilize medical instruments.

The advantages of using plasma flow in medicine include the following:

- the ability to stop bleeding, including the large area, inequality or difficult to access wound surface;
- bactericidal action;
- low penetration when exposed to biological tissues;
- the lack of any hard ionizing radiation;
- safety equipment, subject to the generally accepted safety measures, and proper methodical use;
- ease of use, relatively low equipment cost, and reliability of the method.

The applications of cold plasma in the medical field include the following: dis-

infection and treatment of wounds, treat skin tumors in dermatology, sterilization of medical equipment, therapy of oncological tumors, and partial use in ophthalmology, gynecology, pulmonology, otolaryngology, dentistry, gastroenterology (see application reviews^{1,2} and particularly³ and references cited therein).

II. FORMULATION OF THE PROBLEM

The main method of generating cold plasma for medical use is creating a bandwidth stream of helium, argon, or air (in this case we speak of cold atmospheric plasma [CAP]) through a dielectric tube that contains electrodes with a potential difference of 5 to 35 kV (and sometimes more). The end of the tube contains a diaphragm with a small hole passing through the plasma that forms a thin plasma needle or plasma jet.⁴ This plasma flow is directed to the object, and this type of plasma device is called “pin-to-hole” (PTH). Another type of plasma device is known as a “dielectric barrier discharge” (DBD).² This type of plasma apparatus has an active electrode with a dielectric layer. A gas discharge is created on this dielectric layer when the electrode is near a living tissue. To date, many devices have been made commercially available for plasma treatment: Plazon,² Hand-PlaSter,⁴ MicroPlaSter[®],⁵ Relyon[®] Plasma Generator PG31,⁶ and many others. They operate on the principles described above. The objective of the present research is to improve the existing getting CAP generator that works on type of category “pin-to-hole” gas discharge.

III. THE PHYSICAL PRINCIPLES OF PLASMA GENERATION USING GAS DISCHARGE

The easiest way to obtain plasma is through a gas discharge.⁷ The gas discharge is triggered electrically by a certain pair of electrodes to which high voltage is applied. Depending on the magnitude of the voltage and power, different types of gas discharge can be created: a spark, glow, corona, arc, and others. To generate the cold plasma, a discharge is generated using a DC pulse (or high frequency) DBD. The plasma is called cold when necessary to maintain the existence of plasma ionization created by the electrons, which are much lighter and much more mobile than ions. Because electrons have a low mass, they cannot “heat up” the heavy molecules, and the average plasma temperature is approximately equal to room temperature. This plasma is very weakly ionized (i.e., degree of ionization <1%) and can be obtained by relatively low power source voltage (i.e., power up to 100W). Cold plasma is fully described in classical physics, and quantum effects do not play a significant role. Plasma particles interact with each other according to the simplest laws, i.e., by electrostatic Coulomb forces. Another feature of “cold” plasma is that it does not create a thermal effect on the environment (as in biological tissue in clinical applications). The physical mechanism of plasma in air at atmospheric pressure ($p \approx 101$ kPa) follows.⁷

Let $n(\epsilon)d\epsilon$ be the number of electrons in 1 cm^3 with energies of ϵ up to $\epsilon + d\epsilon$ (the physical meaning of the function $n(\epsilon)$ is a function of the distribution of electron

energies, normalized by the density of electrons). Let $\sigma_i(\epsilon)$ be an effective cross section of ionization of atoms in the main state, the electrons with energy $\epsilon = \frac{m_e v^2}{2}$ (as plasma is weakly ionized, the relativistic effects may be neglected). The rate of ionization or the number of acts that create electrons in a 1 cm³ volume during 1 second is

$$\left(\frac{dn_e}{dt}\right)_i = \int_0^\infty N_e v \sigma_i(\epsilon) n(\epsilon) d\epsilon = v_i n_e, \quad (1)$$

where N_e is the average number of electrons in 1 cm³. The value v_i is known as the frequency of ionization. Integration of the energy in the formula (1) is actually not from zero, as the ionization potential for each gas is a default value, since $\sigma_i = 0$ when $\epsilon \leq I_i$ (see Table 4.3 in P Raizer Yu).⁷ The frequency of ionization is proportional to the density of gas and determined energy spectrum of electrons:

$$v_i = N_e \frac{\int_{I_i}^\infty \sigma_i(\epsilon) n(\epsilon) d\epsilon}{\int_{I_i}^\infty n(\epsilon) d\epsilon} = N_e \langle v \sigma_i \rangle,$$

where angular brackets indicate the average over the spectrum. A complete and detailed description of electron interactions not only with atoms and ions but also with the field requires knowledge of the electron distribution function. In physics, cold weakly ionized plasma at atmospheric pressure is determined by the Maxwell distribution:

$$\varphi(v) dv = N_e \cdot 4\pi \left(\frac{m_e}{2\pi kT}\right)^{\frac{3}{2}} e^{-\frac{m_e v^2}{2kT}} v^2 dv,$$

where $k = 1.381 \cdot 10^{-23}$ J/K (Boltzmann constant), $m_e = 9.109 \cdot 10^{-28}$ g is the mass of the electron and T is the thermodynamic temperature. Knowing the distribution function may in principle be used compute any value relating to the electron gas. By Maxwell's distribution function of the electron energy distribution is defined as:

$$n(\epsilon) = \frac{\varphi(v)}{m_e v}, \quad \varphi(v) = n(\epsilon) \sqrt{2m_e \epsilon}.$$

The possibility of leakage of electric current to form the arc discharge provides the emission of electrons. However, the release of an electron from a solid body (electrode) must expend energy, the minimum value of which is called the work function. It depends not only on the state of the surface, its cleanliness and roughness but also on single crystals. It is the default value for each metal (see Table 4.7 in P Raizer Yu).⁷ When the cathode (an electrode from which electrons go) temperature is low, a field electron emission phenomenon occurs. Its current density is determined by the Fowler-Nordheim equation:

$$j = 6.2 \cdot 10^{-6} \frac{E^2 \sqrt{\frac{\varepsilon_F}{\phi}}}{\varepsilon_F + \phi} e^{-\frac{6.85 \cdot 10^7 \phi^{\frac{3}{2}} \xi}{E}}, \left[\frac{A}{cm^2} \right],$$

where E is electric intensity, ε_F is limiting Fermi energy, ϕ is the electron work function, and ξ is the correction factor (see p. 68 in P Raizer Yu).⁷ In order to discharge, the field intensity of $E \approx 10^6$ V/cm discharge current value in the air must reach 10–50 mA. This type of discharge makes cold plasma generators work. Thus, the degree of electrons that ionize gas is actually $n(\epsilon \geq I_i)$.

IV. THE DESIGN PRINCIPLES OF THE COLD PLASMA GENERATOR

The construction of known medical plasma PTH-type devices contain common elements. First, pulses of high voltage are fed to the electrodes, which are protected in dielectric cylindrical casing. One of the electrodes is a ring, and the second is in the form of the probe along the central longitudinal axis of the cylinder. The cylinder is pumped full at low pressure with inert gas or air. The gas is ionized when it passes between the electrodes, and the resulting plasma is pushed outside.^{2,5} One option for improving the design is to combine increasing voltage and electrodes in one case (Fig. 1). This design is essentially a pulse transformer with a ferrite core in the form of a tube, through which air enters. The use of air as a “source” plasma is due to its availability and its beneficial clinical result.^{1,4,5} The system will operate with maximum efficiency provided that the wind-up transformer is set in resonance. The following elements are identified in the figure:

1. Protective dielectric housing;
2. Input stream of air;
3. Tubular ferrite core;
4. Holder of the central electrode (pin);
5. Central electrode (pin);
6. Secondary winding (many turns of thin wire);
7. Isolation between primary and secondary windings;
8. Primary winding (one layer of thick wire turns);
9. Electrical contact between the secondary winding and the center electrode;
10. Two bit ring electrodes;
11. Gas discharge area (hole);
12. Out of the plasma jet;
13. Supply input electric current.

The main advantage of this design over the previous model is that it uses high voltage directly to the same place and form. Other structures are present to supply high-voltage wires separately obtained using a high-voltage transformer to the point of discharge. In the known constructions, the circular electrode (Fig. 1, number 10) is executed as a puck with appearances inward, in the amount of 6 (Fig. 2). Another modification of the cold plasma generator is an increase of places of gas discharge formation, which is the source of plasma. In an ideal model, the area of gas discharge must form a ring that occupies all of the space between electrodes. This can be realized by bit electrode design, which is shown in Fig. 2. Two electrodes in the form of rings with internal projections are rotated

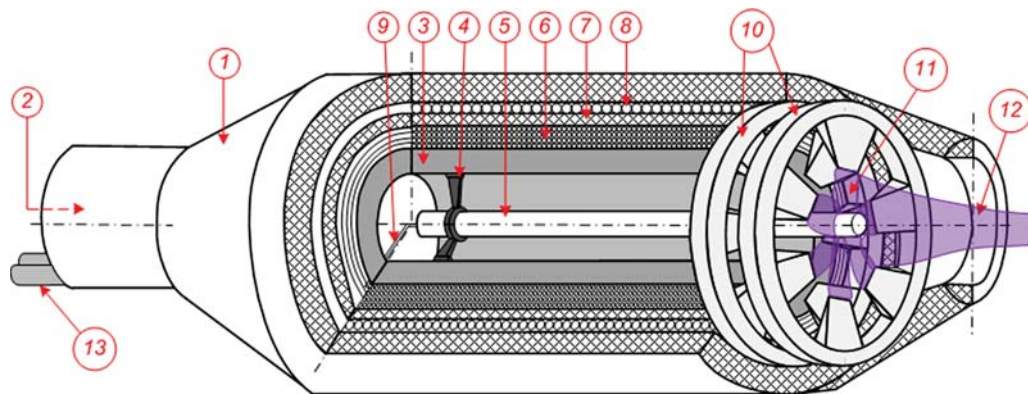


FIG. 1: Construction of cold plasma generator for medical use

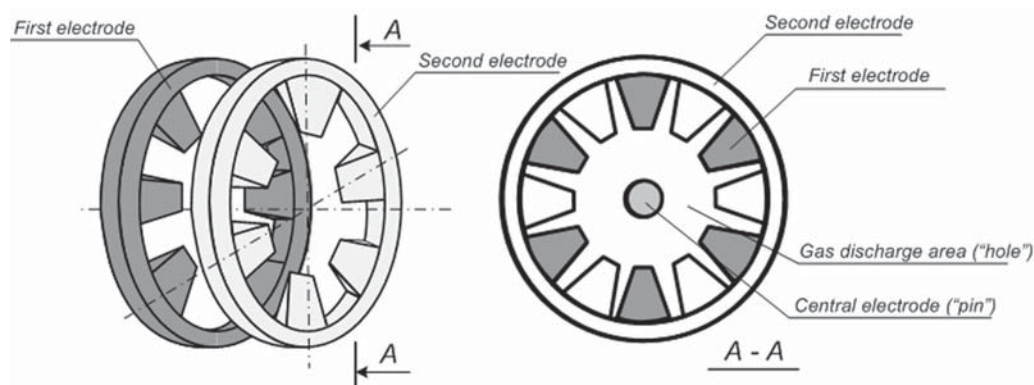


FIG. 2: Electrodes construction of cold plasma generator for medical use

by 30° relative to each other. This creates a gas discharge evenly around the central electrode. One of the electrodes may make a motion (rotation) and thus can control the discharge area. The degree of ionization in this case may be controlled by the power of the discharge current. Except for that, in a construction, it is possible to add an additional electromagnets, the field of which will push plasma outside and form the plasma jet.

V. CONCLUSION

In this article, we have provided a short review of the application of cold plasma in medicine. The physical principles of generation of cold plasma have been briefly presented, and the construction of an improved generator of cold plasma for medical use has been offered. In future research, we will create an operating pre-production model of this device and we will provide a theoretical estimation of the power of such a generator.

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