International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:2, 2014

Impact Porous Dielectric Silica Gel for Operating Voltage and Power Discharge Reactor

E. Gnapowski, S. Gnapowski

***Abstract*—**This study examined the effect of porous dielectric silica gel the discharge ignition voltage and input power in a plasma reactor. For the experiment was used a plasma reactor with two mesh electrodes made of stainless steel with a mesh size of 0.1x0.1mm. The study analyzed and compared with parameters such as power, ignition and operation voltage of the reactor for two dielectrics a porous and glass. During experiment were observed several new phenomena conducted for porous dielectric. The first phenomenon was the reduction the ignition voltage discharge to volume around few hundred volts. Second it was increase input power six times more compared with power those obtained for the glass dielectric. Thirdly difference it is ΔV between ignition voltage V_i and operating voltage reactor V_m for porous dielectric it was 11%, while ΔV for the glass dielectric it was 60%. Also change the discharge characteristics from DBD for glass dielectric to the streamer resistance discharge for the porous dielectric.

***Keywords*—**Input power, mesh electrodes, onset voltage, porous dielectric.

I. Introduction

DIELECTRIC barrier discharge (DBD) forms between two electrodes (one electrode can be rotating electrode) [1]-[3] separated by a dielectric barrier. A classical DBD system contains metallic electrodes and a solid dielectric which is impermeable to gas, generally of glass or some other type of insulating material. The type of discharge is influenced by many factors such as the dielectric constant, its thickness, gap distance, frequency, type of gas used, the pressure etc. Changing these parameters you can change the characteristics of the discharges characteristic [4]-[8]. Obtained discharge at atmospheric pressure makes it easier to apply, inter alia for cleaning and sterilization of surface structure [9], [10]. This research used electrodes of different geometry and a dielectric type enabling gas to flow over the surface of the electrodes and through the dielectric [11]-[14]. This unique configuration reduces ignition voltage and increases discharge power. The use of a porous dielectric allows an increase in power discharge at a much lower supply voltage compared to a DBD utilizing solid glass dielectric [15]-[17].

II. Materials and Methods

The investigation was conducted utilizing the plasma reactor presented in Fig. 1. Fig. 2 shows a schematic of the measurement system, which consisted of an autotransformer, a high voltage transformer of 230/10000 V and 50 Hz, a gas flow meter (Bronkhorst F-201CV-1K0-AAD-44-V), and an ozone analyzer (BMT 961TC). To measure voltage and current an oscilloscope (Techtronix TDS 2024B, 200 MHz, 2 GS/s) equipped with a high voltage probe (Tektronix P6015A, HP1137A and current probe Tektronix P2220 1x/10x) was used. The reactor consisted of two mesh electrodes separated by a porous dielectric which allowed gas flow through the electrodes and dielectric surface. The reactor was operable in two configurations: first, as shown in Fig. 3, with a porous dielectric allowing gas flow perpendicular to the mesh electrode, discharge gap and high-voltage mesh electrode; second, as shown in Fig. 4, with an impermeable dielectric, enabling use of one gas-permeable electrode. Geometrical parameters of the reactor and conditions for each experiment are presented in Table I. As porous dielectric, this research used silica gel balls with diameters of 1.6 and 2.6 mm. The porous dielectric silica gel balls were placed in a cardboard ring as shown in Fig. 5. The ring prevented movement of the silica gel balls between the two mesh electrodes during experiments. Quartz glass placed directly on one mesh electrode was used in the research on impermeable dielectric.

Fig. 1 Plasma reactor with mesh electrodes

E. Gnapowski is with the Lublin University of Technology in Lublin, Department Electrical Engineering and Computer Science Faculty. ul. Nadbystrzycka 38A, 20-618 Lublin, Poland, (e-mail: insp@o2.pl).
S. Gnapowski is with the Kumamoto University, Department Frontier Technology for Electrical Energy, 2-39-1 Kurokami, Kumamoto, 860-8555, Japan (e-mail: sgnapowski@wp.pl).

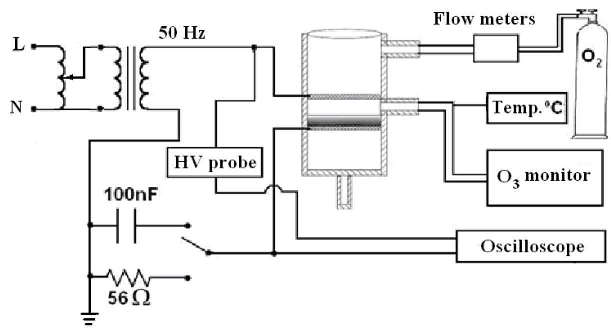


Fig. 2 Schematic measurement system

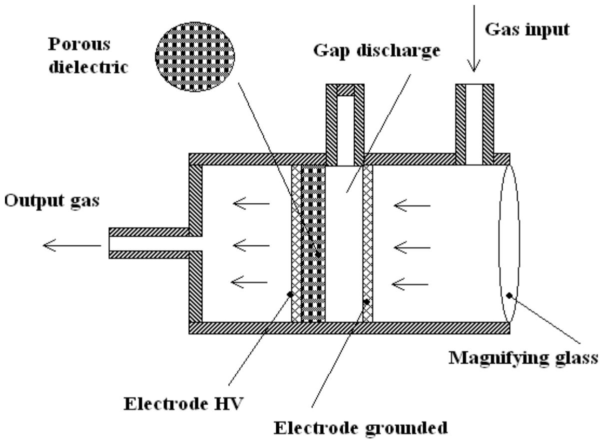


Fig. 3 Configuration of reactor with porous dielectric

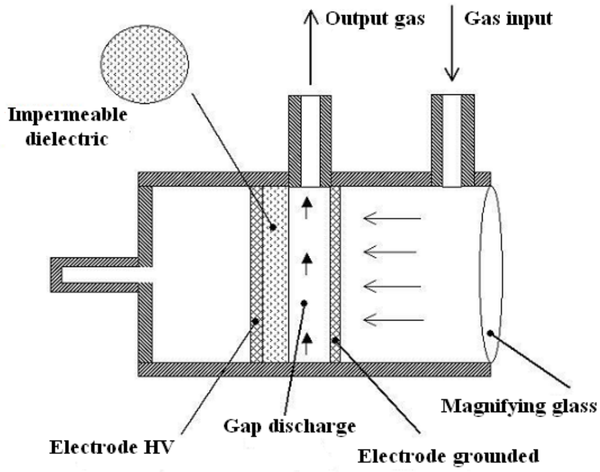


Fig. 4 Configuration of reactor with impermeable dielectric

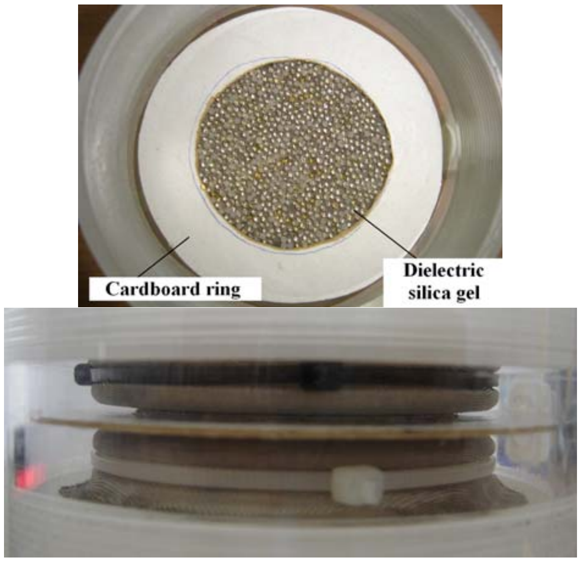


Fig. 5 Cardboard ring with silica gel balls

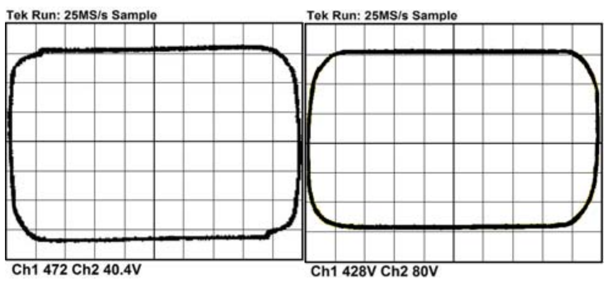
TABLE I
EXPERIMENT PARAMETERS

Parameter	Settings used
Surface electrodes, cm^2	18.8
Gap discharge, mm	0.15, 0.5, 1, 2
Frequency, Hz	50
Gas flow, $L \cdot min^{-1}$	0.5
Gas	Oxygen
Silica gel balls	Ø 1.6 and Ø 2.6 mm

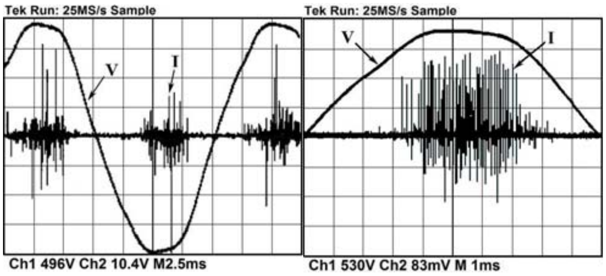
In studies using the porous dielectric, silica gel beads of diameter Ø 1.6 and Ø 2.6mm touched the surface of the 01x01 mm mesh electrodes.

III. Results and Discussion

The reactor was configured for porous dielectric as shown in Fig. 3. During the research, Lissajous figures of selected waveforms were recorded as shown in Figs. 6 (a) and (b), respectively for silica gel beads Ø 1.6mm for voltage 2200 V and 2.6mm for the voltage 2000 V. Figs. 6 (c) and (d) show waveforms of current pulses and voltage for silica gel dielectric Ø 1.6mm at a supply voltage of 1800 V and silica gel ball Ø 2.6mm at a supply voltage of 1900 V.



(a) (b)



(c) (d)

Fig. 6 Lissajous figures for silica gel dielectric: (a) Ø 1.6mm power supply 2200V, (b) Ø 2.6mm power supply 2000V, and ignition voltage (c) 1500V for power supply 1800V to silica gel dielectric Ø 1.6mm, (d) 1600V for power supply 1900V to silica gel dielectric Ø 2.6mm

The calculations include maximum power and ozone concentration of the given range of voltages due to dynamic process changes. As can be seen in Figs. 6 (c) and (d) of waveform current pulse, voltage and Lissajous figures, ignition voltage is almost equal to supply voltage, which indicates the nature of the discharge streamer resistance. Ignition voltage is interpreted by the Lissajous figure shapes, and peak voltage V_m are almost the same values, indicating streamer - resistive discharges characteristics. Graphs presented in Figs. 7 and 8 show the relationship ozone concentration and generation efficiency in function discharge power for each gap discharge.

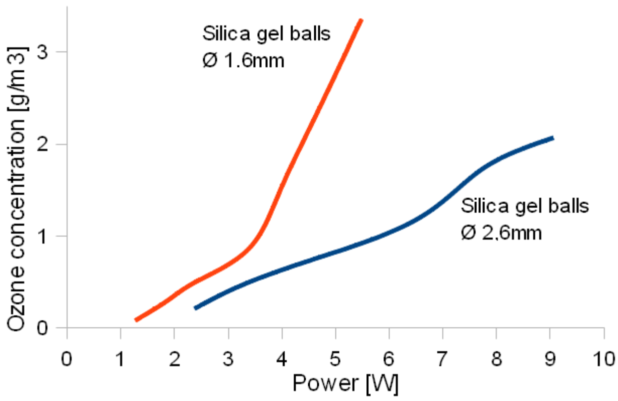


Fig. 7 Relationship of ozone concentration vs. reactor input power for silica gel dielectric Ø 1.6mm and Ø 2.6mm

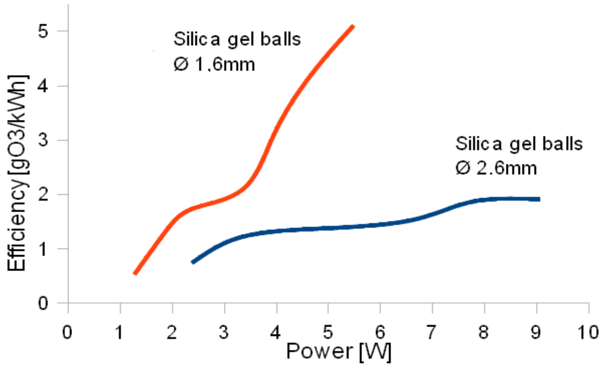


Fig. 8 Relationship of ozone generation efficiency vs. reactor input power for silica gel dielectric Ø 1.6mm and Ø 2.6mm

Analysis of results found that the highest power, 5.5W, was obtained with silica gel dielectric Ø 1.6mm, with ozone concentration 3.35g/m^3, while the lowest was 1.3W, with ozone concentration equal to 0.1g/m^3. The use of silica gel beads with a diameter of 2.6mm allowed an increase in power to the value of 9.1W and ozone concentration of 2.1g/m^3. Discharge power obtained utilizing the porous dielectric was higher than that obtained using the impermeable glass dielectric because the discharge type changed from dielectric barrier discharge to streamer-resistive. Discharge gap length was changed from 2.0mm using the glass dielectric to 2.6 mm using the porous dielectric. Increasing power did not increase efficiency ozone generation, which decreased to 1.9g O_3/kWh. This can be explained by increases in temperature in gap discharge in the absence of a cooling system, causing the collapse of ozone to molecular oxygen. The maximum efficiency of ozone generation with the use of the silica gel dielectric, 5.1g O_3/kWh, was obtained for silica gel beads with a diameter of Ø 1.6mm, a supply voltage of 2200V, and power of 5.5W

To compare obtained input power using silica gel beads and mesh electrodes with dimensions of 0.1x0.1mm, we performed an experiment using an impermeable glass dielectric. Results for experiments conducted using a glass dielectric with a thickness of 1.1mm and gap discharge lengths of 0.15, 0.5, 1.0 and 2.0mm are shown in Table II.

To analyze the discharge power, one series of research results was selected with the greatest power discharge for selected discharge gap. Fig. 10 shows a graph of dependency of discharge power on the supply voltage.

Analysis of experimental results and Figs. 9 and 10 indicate that the highest power, equal to 9.1W, was obtained using porous dielectric silica gel of Ø 2.6mm, with a supply voltage of 2000V and mesh electrodes of 0.1x1.0mm. Analysis of experimental results and Figs. 9 and 10 indicate that the highest power, equal to 9.1W, was obtained using porous dielectric silica gel of Ø 2.6mm, with a supply voltage of 2000V and mesh electrodes of 0.1x1.0mm. The lowest discharge power, 2.4W, was obtained using silica gel dielectric diameter of Ø 2.6mm at a voltage of 600V, though this itself was 60% higher than the maximum power obtained using the impermeable glass dielectric, which was 1.5W for a 2mm gap discharge. The intensity discharge for silica gel dielectric diameter Ø 2.6mm is much higher than that obtained for the other configurations of the system, because the maximum power using the porous dielectric is six times higher than that obtained using the glass dielectric.

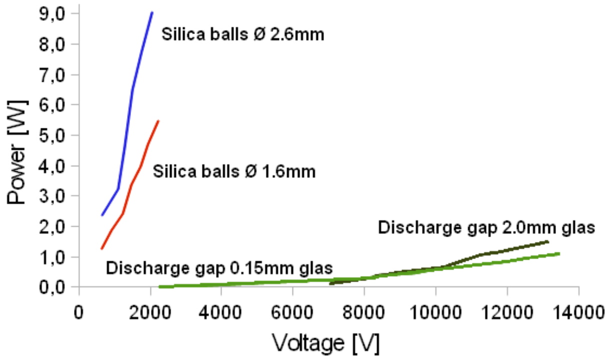
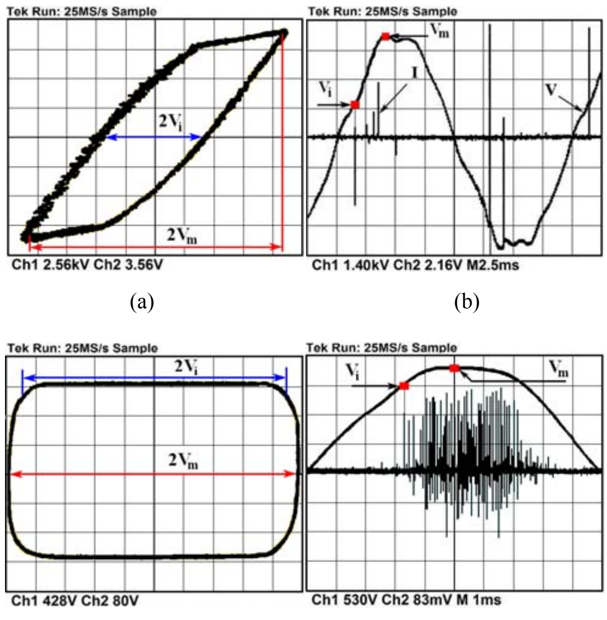


Fig. 9 Dependency of discharge power on input voltage



(c) (d)

Fig. 10 Comparison ignition voltage V_i and the peak voltage V_m for dielectric glass, and silica gel, (a) Lissajous figure for the voltage 10700V for dielectric glass 1.1mm, (b) ignition voltage 2300V for gap 1mm at a supply voltage 5000V, (c) Ø 2.6mm voltage 2000V, (d) ignition voltage for balls diameter Ø 2.6mm 1600V at a supply voltage 1900V

TABLE II
SELECTED RESULTS OF THE MEASUREMENTS FOR MESH ELECTRODES 0.1X0.1MM WITH GLASS DIELECTRIC THICKNESS 1.1MM

Gap discharge	Voltage range	Ignition voltage	Maximum power	Concentration range, O_3	Maximum efficiency generation, O_3
d_g	V_m	V_i	P	C_{O3}	η_{O3}
mm	V	V	W	gO_3/m^3	gO_3/kWh
0.15	2200 ÷ 12800	700	1.1	0.05 ÷ 3.50	70.1
0.50	3200 ÷ 13100	1400	1.3	0.15 ÷ 5.40	74.0
1.0	3800 ÷ 13000	2100	1.4	0.20 ÷ 6.10	56.6
2.0	6700 ÷ 12500	2700	1.5	0.85 ÷ 6.05	49.4

Use of the mesh electrode of dimensions 0.1x0.1mm, and dielectric silica gel balls diameter Ø 1.6mm, allows for reducing ignition and operation voltage reactor to a value 600V. Ignition voltages and operation of the reactor have almost the same value because discharge was streamer-resistive nature. Table III compares the lowest ignition and operating voltage of the reactor using the porous dielectric and impermeable glass dielectric.

TABLE III
THE IGNITION VOLTAGE FOR POROUS SILICA GEL DIELECTRIC AND IMPERMEABLE GLASS DIELECTRIC

Mesh electrodes 0.1x0.1 mm				
Ignition voltage	Gap discharge	Voltage range	Maximum power	Dielectric
V_i	d_g	V_m	P	
V	mm	V	W	
700	0.15	2200 ÷ 12800	1.1	glass 1.1
500	Ø 1.6	600 ÷ 2200	5.5	silica gel
600	Ø 2.6	700 ÷ 2000	9.1	

Analyzing Fig. 10, visible are variations in the shape of Lissajous figures between discharges barrier and streamer-resistive. In Fig. 10 (a) differences can be observed several times between a supply voltage and ignition voltage for the glass dielectric, which is respectively V_m = 10700V and V_i= 1500V, while for the porous dielectric, the values are V_i= 1800V and V_m = 2000V. The difference between the supply voltage and the ignition discharge are respectively for the glass dielectric ΔV = 9200V and for the porous dielectric ΔV = 200V in the case of silica gel beads use. The operating voltage and ignition voltage for silica gel beads are of comparable value, with a difference of about 11%. The smallest ignition voltage obtained using the glass dielectric, V_i= 700V, is higher than that obtained using the silica gel beads, V_i= 500V (V_m = 600V); they have been obtained at a supply voltage V_m =2200V, which is 3.5 times higher than that using the porous dielectric.

The second parameter which confirms the reduction of the ignition voltage by using a porous dielectric was the length of the discharge gap, which was for the glass dielectric 0.15mm and for the porous dielectric Ø 1.6mm. Despite the more than ten times higher gap discharge for porous dielectric 1.6mm, the discharge ignition voltage of 70V was lower than that obtained for the glass dielectric and discharge gap 0.15mm. The ignition voltage decrease and voltage reactor operation were results due to the different nature of the discharge streamer-resistive. The length of the discharge gap in the discharge space was very small, and the gap distance was zero because the dielectric was in direct contact with the electrode mesh (gas was only in the spaces between the balls, with no free space between the electrodes). This zero-gap discharge made possible reduction of the ignition voltage and the operation of the reactor.

Another factor influencing the operation of reactor it is a porous dielectric material. Silica gel beads are made of SiO_2. Dielectric is highly porous with a surface area of about $800m^2/g$. The high porosity/surface area shape and the material of porous dielectric allowed obtain a resistance discharge streamer. These parameters allow for the reduction of the operating voltage of reactor and increased of discharge power.

IV. Conclusion

1) The use of porous dielectric in the form of silica gel beads made it possible to reduce the ignition voltage to a value V_i = 500V for the discharge gap length 1.6mm; in comparison, use of the glass dielectric resulted in V_i = 700V and a discharge gap of size of 0.15mm, ten times smaller.
2) Discharge ignition voltage and the operation of the reactor with silica gel beads was almost the same value.
3) Ignition voltage of the dielectric glass was V_i = 700V and supply V_m = 2200V of the porous V_i = 500V at a supply voltage V_m = 600V.
4) The voltage difference between the supply voltage and the ignition voltage for the lowest values for both dielectrics was ΔV = 1500V for the glass dielectric and ΔV = 100V the porous dielectric.
5) Increasing discharge power to the 9.1W at a supply voltage V_m = 2200V in comparison with the glass dielectric resulted in 1.5W at a supply voltage V_m = 12500V.
6) The power obtained using the porous dielectric was more than 6 times higher with a supply voltage more than 5 fold lower compared to the glass dielectric.
7) The use of the porous silica gel dielectric and mesh electrodes allowed the free flow of gas across the two mesh electrodes and porous dielectric, which is impossible with a solid electrode and impermeable dielectric. This has an impact on improvement of the reactor cooling and input power.

References

[1] S. Gnapowski, E. Gnapowski, "Effects of Rotating Electrode during Plasma Generation", *ISBN 978-3-659-51292-6*, LAP Lambert Academic Publishing 2014.

[2] S. Sousa, G. Bauville, B. Lacour, V. Puech, M. Touzeau, "Atmospheric pressure generation of $O_2(a^1\Delta g)$by micro-plasma", *Hakone XI*, Oléron, Island, September 7-12, 2008.

[3] Z. Buntat, I. R. Smith, N. A. M. Raza, "Generation of a Homogeneous GlowDischarge: A Comparative Studybetween the Use of Fine Wire Mesh and Perforated Aluminium Electrodes", *ISSN 1916-9639,* Published by Canadian Center of Science and Education, Vol. 3, Number 1, May 2011, pp. 15-28.

[4] S. Okazaki, M. Kogoma, M. Uehara, Y. Kimura, "Appearance of stable glow discharge in air, argon, oxygen and nitrogen at atmospheric pressure using a 50 Hz source", *Journal of Physics*, Vol. 26, Number 5, 1993.

[5] M. Kogoma, S. Okazaki, "Raising of ozone formation efficiency in a homogeneous glow discharge plasma at atmospheric pressure", *Journal of Physics*, Volume 27, Number 9, 1985.

[6] S. Gnapowski, C. Yamabe, S. Ihara, "Long time operation of Ozonizer with a Rotating Type Electrode", *19th Ozone World Congress - International Ozone Association & Japan Ozone Association*, Tokyo, Japan, August 29 - 03 September, 2009.

[7] E. Gnapowski, H.D. Stryczewska, "Ozone generator with mesh metal electrodes and porous dielectrics", *Hakone XI*, Oléron, Island, September 7-12, 2008, pp. 7-12.

[8] C. Yamabe, S. Gnapowski, K. Kayashima, S. Ihara, "Ozone-Zero Phenomena and a Nitrogen Addition Effect on an Ozone Generation", *The 16th International Conference on Oxidation Technologies for Treatment of Water*, Air and Soil AOTs-16.

[9] H. Baumgärtner, V. Fuenzalida, I. Eisele, "Ozone cleaning of the Si-SiO_2 system", *Applied Physics A. Solids and Surfaces*, Vol. 43, 2007, pp.223-226.

[10] H. Eto, Y. Ono, A. Ogino, M. Nagatsu, "Sterilization of Tubular Medical Instruments Using Wire-type Dielectric Barrier Discharge", *J. Plasma Fusion Res. SERIES*, Vol. 8, (2009), pp. 569-572.

[11] S. Gnapowski, A. Murai, C. Yamabe and S. Ihara, "A Study of Keeping a High Efficiency in the Ozone Production Using a Pure Oxygen as Supplied Gas", *24th Conference On Energy, Economy, and Environment*, Tokyo 2008, Japan, January 27-29, (2008), pp. 99.

[12] E. Gnapowski, „Plasma reactor with barrier discharges", *Materials VII Seminar Doctoral Faculty of Electrical Engineering and Computer Science Technical University of Lublin*, Lublin, 2005.

[13] E. Gnapowski, "Investigations of a metal mesh electrodes and glass wool packing to barrier discharges intensity", *Works Institute of Electrical and Electrotechnology*, Vol. 239, 2008, pp. 43-53.

[14] S. Kanazawa, M. Kogoma, T. Moriwaki and S. Okazaki, "Stable glow plasma at atmospheric pressure", *Journal of Physics D: Applied Physics*, 1988.

[15] H. D. Stryczewska, E. Gnapowski, G. Komarzyniec, "Experimental investigations of the barrier discharge reactor with mesh and porous dielectric", *International Workshop Ozotech, Bratislava, Slovakia, 25th - 27th November*, 2007, pp. 69-72.

[16] E. Gnapowski, "Investigations of the DBD reactor with metal mesh electrodes and glass wool dielectric", *Conference ELMECO 6*, June 24-27, 2008, pp. 17-18.

[17] E. Gnapowski, "Plasma reactor – discharges barrier ozonizer", *Polish Patent Office*. Patent applications P.397157, (2011).