Compact plasmatron with diverging rod electrodes

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Abstract. A device for treating polymer surfaces with low-temperature plasma is described. The basic principle of the device is based on the increasement of the surface energy resulting from plasma treatment of the polymer. Plasma is generated by the breakdown of atmospheric pressure air with a high voltage of 15-20 kV. The discharge current reached 10-20 mA. Goniometric measurements of wetting angles showed improved wetting of the surface of the polymers.

1. Introduction
For science and technology, it is necessary to develop a method of material coating of low surface wettability. The effect of improving the wettability of the surface of polymers by treatment with plasma before coating was experimentally discovered [1],[2]. At present, massive industrial machines are engaged in processing before coating sheet parts with various paints and varnishes, which cannot work with products of small sizes or complex shapes [3]. Thus, there is a need for hand-held compact plasmatrons. Plasma treatment can be used when corona discharge treatment is not acceptable - for processing various non-standard polymer products before painting or gluing [4]. In this work, a new compact plasmatron is presented. Several mixtures plasma-forming gases can be utilised.

2. Operating procedures
The plasma torch consists of a compact high-voltage power supply with the voltage up to 20 kV, power consumption 250 W (220 V) and a compact discharge chamber. The air under atmospheric pressure enters the discharge chamber at speed of 1.2-1.5 m / s. Avalanche ionization due to the high voltage between the electrodes takes place and forms a plasma torch [5]. Surface treatment with plasma introduces the necessary difference between the work of adhesion and surface energy, reducing the contact angle and increasing the wettability. Due to the introduction of molecular oxygen into the structure of the treated surface, the long molecular chains of the polymer are destroyed, improving the bond with the molecules of paint, glue or various inks. Moreover, in the air gap due to the collisions of oxygen molecules and electrons accelerated by an electric field, oxygen dissociates into atoms, forming ozone - an unstable compound with an extremely high oxidizing ability, which also contributes to an increase in surface energy. The properties of the polymer material do not change, since the modification affects a thin surface layer. An equally important result is that the surface at the micro level becomes rough and its effective area of adhesion of the paint increases. It is important to note that the plasma does not heat the surface of the sample during processing. Usually, the temperature does not exceed 30°C.
3. Properties of the device
The working plasma-forming gas is atmospheric pressure air or a mixture of air with argon. The electrodes are made of copper wire with a diameter of 2 mm, the interelectrode distance varies from 1 cm to 8 cm, the voltage at the electrodes is 15 - 20 kV. The duration of the discharge is limited by the processing time of the sample. The compact design of the plasma torch allows the operator to carry out plasma processing of the surface of the parts made of polymeric materials in air at atmospheric pressure of any shape and size. Surface treatment time varies from 1 second to 1 minute, depending on the material being processed. The effect lasts for at least 15 minutes.

![Schematic of the device](image)

**Fig. 1.** Schematic of the device.

4. Experimental results
Experimental data on the wetting angles before and after plasma treatment with plasmatron were obtained, as well as the discharge spectrum of the plasma torch. The measurements were carried out at a low discharge power, with a small amount of ozone emitted. Fig. (2) demonstrates the change in the contact angle of the surface wetting with a water drop of 5 μl.

|          | PVC       | ABS       |
|----------|-----------|-----------|
| Before treatment | 94.2°     | 86.9°     |
| After treatment  | 64.1°     | 55.1°     |

*Table 1 Wetting angle measurement data for ABS and PVC.*
Fig. 2. View of a 5 μl water drop on the surface of a PVC sample: (a) before the plasma treatment. (b) after the plasma treatment

View of the surface under a microscope show the effectiveness of processing polymer materials with a plasma discharge. It can be seen that the applied test marker spreads relatively well on the surface. With an increase in the discharge power, the effect increases until all the applied material spreads evenly. This happens due to an increase in the concentration and energy of ions, as well as due to an increase in the amount of ozone released.

Fig. 3. View of the surface of PVC coated with alkyd varnish, after applying the marker (green): (a) before the plasma treatment. (b) after the plasma treatment.

The discharge spectrum reflects the composition of the working gas. Atmospheric pressure air was used as the working gas. The data obtained (Fig. 4 (b)-(d)) show that a large amount of molecular oxygen O₂, as well as NO, OH, NH, Cu, and some others, are present in the plasma, which confirms the effectiveness of surface treatment by this type of plasma discharge.
5. Conclusion
A new plasmatron which allow to increase efficiently the surface energy of many polymers by processing with a low-temperature plasma discharge was designed and constructed. The device has a small size, which is convenient for processing various polymer products of complex shape. Using various working gases and changing the discharge energy, one can achieve the best results on the wettability and adhesion of materials.

References
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