The food-type polymers recycling into nano-sized carbon powder at atmospheric electric arc processing

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Abstract. The paper shows the possibility of recycling food-type polymeric material in an ultradisperse powdered carbon product. The process is realized in the plasma of a direct current (DC) arc discharge, initiated in an open air between graphite electrodes. According to X-ray diffractometry, the product consists of 21.7% of graphite and 78.3% of X-ray amorphous fraction. The product is represented by rounded particles with average sizes less than 100 nm. The maximum particle size distribution is in the range from 50 nm to 75 nm.

1. Introduction
In the modern world, the volume of polymer waste grows, which requires the development of methods for its utilization. One of the possible approaches is the plasma treatment of the polymer using plasmatron technology [1], including at the open air-conditions [2]. A possible useful product of this process in the condensed state is the carbon nano-sized particles [3]. The production of carbon ultradispersed materials in the plasma of an arc discharge of a direct, alternating and pulsed current is used in the world scientific practice [4]. Various designs of the electrode system, various initial reagents are used, the discharge is initiated in various gas and liquid media at different pressures. One of the modern ways of developing this subject of electric arc synthesis of carbon nanosized materials is the generation of arc discharge plasma in an oxygen-saturated medium, including in air [5]. Particular interest represents the direction of research using open air [6]. This approach ensures the simplicity of implementation and a significant reduction in the cost of production of nanoscale carbon materials, especially nanotubes [7-9]. At present, the mechanisms of growth of such structures in the considered conditions for burning plasma in the air are not fully understood, and there is a discussion of this issue in the world academic journals [3].

At Tomsk Polytechnic University, an electric arc direct current (DC) device is being developed that generates an arc discharge on graphite electrodes in the air atmosphere. Such DC electric arc systems are relatively simple and cheap, effective [10]. A series of experiments was carried out to investigate the possible application of this system to the problem of processing polymeric materials into carbon nano-sized particles.

2. Methods of research
A series of experiments was carried out on a laboratory direct current plasma-chemical reactor. As a power source the Condor Colt 200 rectifier-inverter welding transformer was used with a range of operating currents from 20 to 200 A. The raw material was a «PET-polymer» obtained by grinding a
plastic bottle from drinking water, the particle size in the form of plates was about 2–3 mm in width and length (at a standard thickness for plastic bottles). The feedstock was loaded into the arc discharge formation zone between the graphite electrodes. The current was controlled by the regulator in the power supply by the current controller. The voltage on the arc discharge was recorded by means of an ohmic voltage divider (10:1) connected to a digital oscilloscope. The discharge was initiated by a short contact of the electrodes; discharge extinction was realized by increasing the length of the discharge gap. The duration of the process was maintained from 5 to 20 seconds. The operating current of the system was set up at 50 A by means of the power supply regulator. As a result of a series of experiments, it was possible to realize the transformation of a polymeric material into a carbon ultra-dispersed product. A simplified diagram of the laboratory setup is shown in figure 1.

![Simplified diagram of a laboratory direct current installation.](image)

The powder product material was collected from the surface of the electrodes, was analyzed by X-ray diffractometry (XRD, Shimadzu XRD7000s) and scanning electron microscopy SEM (JEOL JSM 7500F). The particle size distribution was analyzed by a series of high resolution images from a scanning electron microscope; the total number of particles in the sample was about 300 pieces.

3. Results and its discussion
A typical oscillogram of the voltage on the arc discharge and the calculated energy release curve are shown in figure 2. The no-load voltage of the power supply according to its technical characteristics was 63 V, on the oscillogram it is seen that the voltage of the arc discharge was about 60 V. After ignition of the arc discharge, the voltage at the electrodes is reduced to about 30 V. At a current value of about 50 A, the electric power of the discharge is about 1.5 kW. This provides an energy release of about 30 kJ for 20 seconds.

Figure 3 shows a typical X-ray diffraction pattern of the DC arc discharge produced by the polymer material processing. The graphite etalon is plotted on the X-ray diffraction pattern. It can be seen that the main part of the product is X-ray amorphous, containing graphite in its composition. According to the software of Shimadzu diffractometer data, the degree of crystallinity of the sample is 21.7%. Probably, the bulk of the product is the result of processing the polymer material in the X-ray amorphous carbon fraction, and graphite is the product of electric erosion of the electrodes. The presence of electrodes material in the product of the synthesis due to its electro erosion is a known fact [4]. An analysis of the obtained X-ray diffraction pattern in the Powder Cell 2.4 software package revealed that the average size of the coherent phase scattering regions of graphite was 9.1 nm; the parameters of the graphite lattice were $a=0.245$ nm, $c=0.672$ nm. Also in the X-ray diffraction pattern, traces in the range from 16 deg to 19 deg are identified, which are close to the main diffraction maximum (hkl 220) of the fullerene $C_{60}$ phase. The presence of this phase in the product should not be considered proven, but the presence...
of traces close to this phase is not in doubt. It should be noted that the international database of diffraction data PDF4+ contains a huge number of different carbon phases, including graphite-like and fullerenes. Therefore, within the framework of this work, it was not possible to determine the specific international card database number for unambiguous identification of the crystalline phases obtained.

According to scanning electron microscopy, a typical SEM-image is shown in figure 4, the product consists of particles with dimensions less than 100 nm and a round shape. The histogram of particle size distribution is constructed from a series of similar images. It is seen that the maximum is in the range of sizes from 50 nm to 75 nm. The distribution is relatively narrow.

Nowadays DC arc technologies are widely used for nano-sized carbon production. The new direction of the research is atmospheric plasma application for simplification of the arc plasma setup [5, 6]. Also the initial source of carbon is necessary part of experimental research and future production technology, for example the coal can be source of the initial carbon [11]. This paper describes the possibility of plastic waste decomposition to nano-sized carbon, it is one of ways to develop DC arc technologies of nano-sized production and plastic waste utilization the same time. One of advantages of this technology is ability plasma to neutralize viruses, bacteria, organic waste during the arc discharge processing [12, 13]. It means that powdered product is cleaned of possible dangerous initial plastic waste components. The plastic waste is an excellent cheap source of initial carbon for DC arc discharge methods of nano-sized carbon production. Another direction of this process is synthetic fuel gas generation [2], but it is not topic of our paper discussion.

![Figure 2](image2.png)

**Figure 2.** Oscillogram of the voltage of the working cycle and the curve of energy release.

![Figure 3](image3.png)

**Figure 3.** A typical X-ray diffraction pattern of the obtained product.
As a result of a series of experiments it was possible to accumulate about 0.5 g of product at the cost of the initial polymer raw material by at least an order of magnitude greater mass. About 1 g of polymeric raw material is consumed in a working cycle with a duration to 20 s at a current of 50 A and a voltage on the arc discharge about 30 V. Thus, the energy intensity of processing the polymer material into nano-sized carbon is about 30 kJ/g. This value should be considered appraisal, because the construction of the electrode system at this stage of the study was not optimized as well as the regime parameters of the installation; this work on a series of experiments showed the possibility of implementing the claimed process on the developed direct-current electric arc device.

4. Conclusion
Thus, the process of conversion a polymeric material into a carbon nanoscale product in electric-arc atmospheric plasma has been experimentally realized. The product mainly consists of an X-ray amorphous nano-sized fraction with graphite impurities. The maximum particle size distribution corresponds to a range from 50 nm to 75 nm. An estimate of the energy intensity of the process showed that 1 g of processed polymeric material requires about 30 kJ of energy.

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