ECOLOGY

UDC 621.314; 621.763; 621.926.9; 621.927.08; 537.528; 537.529
DOI: 10.15587/1729-4061.2024.296855

IDENTIFICATION OF THE EFFECT OF ELECTRIC PULSE DISCHARGES ON THE RECYCLING OF HOUSEHOLD GLASS

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The work was devoted to the study of the recycling of household glass waste by the electric pulse method. Cullet and glass containers were considered as the object of research. Cullet and used glass containers are considered suitable for recycling among solid household waste.

The treatment of solid household waste was carried out with the formation of electrical discharges in an inhomogeneous environment (glass fragments and glass products in an aqueous environment). The experiments were carried out at different values of pulse discharge voltage (from 12 kV to 37 kV), capacitor bank capacity (from 0.4 to 1.2 μF), number of pulse discharges (from 250 to 1,000) and frequency (from 0.3 Hz to 2 Hz). The dependence of the output of the finished product on the parameters of electric pulse discharges has been revealed from the research results. According to the main results of the research work, it was found that as the parameters of electric pulse discharges increase, the yield of the finished product increases. The data made it possible to assign effective parameters for processing cullet and glass products using the electric pulse method. The granulometric composition of the powder material obtained by this method has been determined. A product with a diameter of the largest fraction of 5–8 mm and a diameter of a small fraction of 0.4 mm and 0.7 mm was obtained.

The results of the experiment can be used in research on saving natural resources, energy conservation and solving environmental problems of solid waste recycling. Powdered glass is used as a thermal insulator and decorative material in construction. In addition, crushed glass is used in the production of concrete as an additional raw material

Keywords: solid waste, electric pulse device, electric discharges, output of the finished product

Received date 19.01.2024
Accepted date 27.03.2024
Published date 30.04.2024

How to Cite: *Khassenov, A., Karabekova, D., Bolatbekova, M., Nussupbekov, B., Kudussov, A., Chirkova, L., Kissabekova, P. (2024). Identification of the effect of electric pulse discharges on the recycling of household glass. Eastern-European Journal of Enterprise Technologies, 2 (10 (128)), 6–13. https://doi.org/10.15587/1729-4061.2024.296855*

1. Introduction

Glass materials are widely used as containers for water, various liquids, food and medicines. Many of these glass materials are reused as returnable bottles or used in the recycling process, recycling as raw materials for other glass containers. One of the processes of glass processing is the "cullet", which grinds into small fragments of glass [1]. Of course, for the reuse or recycling of glass, additional processes are required, such as washing glass bottles, to ensure the safe use of recyclable products. However, it takes a long time to wash the inside of glass materials in this way, and this procedure is difficult to perform automatically, since there are many different types of shapes of glass containers.

Recycling by standard methods on a large crushing machine is expensive, and therefore the utilization rate of this production method becomes lower compared to the recycling rate into reusable glass bottles. It is also worth considering that glass materials are easily broken, and the processing of glass materials of a mixed type is a difficult objective.

Among the variety of man-made waste, the glass boiler is allocated a volume that, being dumped into landfills, quickly fills and pollutes the environment. However, glass cutting is an effective secondary resource that can be used in the construction industry to create binders, mortars, concretes and structures [2].

In addition, in recent years, consumption has been increasing all over the world, which eventually leads to the depletion of resources and the spread of environmental pollution, so the environmental friendliness of raw materials is becoming an urgent problem. Various studies have been conducted on the ecological state of the environment of the mining regions of Kazakhstan, one of the findings is that during crude oil extraction and refining, harmful substances are released:

70 % pollute the atmosphere, 20 % – water, 5 % – land. However, many wastes are disposed of in landfills or incinerated due to economic constraints, resulting in landfills and incineration of waste causing many environmental problems such as air pollution and leaching of heavy metals [3].

Experimental research in the field of degradation and processing of raw materials using modern, effective technologies that reduce potential negative consequences for the ecosystem is becoming increasingly relevant in the world, and one of the directions is the use of an electrohydroimpulse installation [4].

Electrohydropulse installation is characterized by the use of high-voltage pulses to generate shock waves in water. This plant has been primarily designed for various purposes of solid material degradation and raw material recovery. The same principle can be effectively adapted to the destruction of glass.

This method of influence allows for a high degree of control and precise crushing of glass at the micro level. Therefore, to commercialize this method, it is necessary to determine the behavior of glass materials when destroyed by underwater shock waves, and there is also a need for a more in-depth investigation of the influence of this method on the structure and properties of glass [5].

Thus, the investigation of the destruction of glass materials using an electric pulse installation is an urgent and promising topic for the development of technologies in the field of glass processing. The introduction of such technologies supports the goals of sustainable development and contributes to the creation of a cleaner and healthier environment for future generations, and can also lead to significant benefits in industry and scientific research.

2. Literature review and problem statement

The paper [6] shows an analysis of the possibility of using cullet in the production of building materials. The study examined sources of cullet formation, such as municipal solid waste, the food and pharmaceutical industries, as well as cullet of specialty and window glass. It is noted that the main consumers of cullet are the glass industry, the construction and thermal insulation materials industry, as well as road construction. The structure of cullet consumption is dominated by colorless glass (BS), the share of which covers about 56 % of total consumption, a significant share in the consumption structure is green (20 %) and brown (15 %) glass. The level of cullet processing in Russia is shown to be 5–7 %, while in the EU countries up to 60 % of MSW is processed, and in Kazakhstan it is only 3–5 %. But there are still unresolved issues related to the lack of specific data on the amount of cullet produced, its consumption and disposal, which could make the study more comprehensive.

The paper [7] shows that the use of optimal methods for color sorting and crushing of cullet can significantly improve the process of its processing. Experimentation with various methods, such as optical sorting and selection of optimal crushing equipment, led to the determination of the best conditions for the production of glass chips and recycling as crushed glass. However, there are still unresolved issues related to the fractional composition. In this method, the yield of the fine-grained product is particles with a size of 5.0 – 2.5 mm and 2.5 – 1.2 mm. Analysis of the size distribution showed that an additional crushing step is necessary to achieve a standard size composition of the recycled glass aggregate. The reasons for this may be due to the need for thorough grinding, additional processing or changes in the parameters of crushing equipment. An option to overcome the corresponding difficulties may be further optimization of the crushing process and the introduction of additional or more efficient technologies. This approach is used in other similar studies in the field of glass processing, which emphasizes the relevance of research to optimize this process. All this allows us to assert that it is advisable to conduct additional research on further optimization of the cullet processing process, taking into account the size composition and requirements for the final products.

The paper [8] shows that an underwater shock wave affects glass bottles, leading to destruction and the formation of glassy fragments of various sizes. The size distribution of vitreous fragments is classified using three types of sieves, the sieve sizes are 1 mm, 2 mm, 4.75 mm and the weight of the sorted "cullet" was measured. The size distribution of glassy fragments was analyzed and the results indicate that the sizes of glassy fragments may depend on the distance between the explosive material and the sample. The formation of a small "cullet" is higher than 1 mm – 52 % than that of a large-sized 2 – 4.75 mm – 17 %. Visualization of the process of bottle destruction in air and in water allows us to identify differences in the intensity of destruction associated with air compressibility. These results may be useful for understanding the processes of glass destruction under the influence of a shock wave, which may be important for the effective recycling of materials. However, there are unresolved issues related to the influence of other parameters, such as the composition of the bottle, voltage of electrical discharges, capacitance of the capacitor bank, frequency, which can affect the destruction. The reasons for this may be limitations in the methodology used, which may make it difficult to take into account additional parameters. An option to overcome these difficulties may be to expand the study methodology to include additional parameters to more fully understand the impact of the shock wave. However, despite remaining questions and limitations, the results of this experiment provide valuable information about the effects of shock waves on glass bottles.

The paper [9] shows that most existing methods include crushing and dry grinding steps, applied directly at the waste treatment site. The authors propose the use of mechanochemical activation of vitrified waste to obtain alternative fire-resistant and heat-insulating materials. Despite the promise of this approach, technological, economic and environmental problems are identified. The paper proposes a solution to the problem using mechanochemical activation of multi-ton volumes of glass waste. The experiments used a mixture of different types of glassy fragments subjected to dry and wet grinding. Mechanochemical activation was carried out in the presence of various amounts of a mixture of NaOH and Na_2CO_3. Then a pre-prepared mixture was added to the resulting suspension, used as a foaming agent. Experiments have shown that varying the content of foaming agent and vitreous fragment powders makes it possible to control the properties of the resulting materials, such as density, porosity and hardening time. All this allows us to assert that it is advisable to conduct further research on the activation of glass waste. These studies may include more in-depth analysis of technological, economic and environmental aspects.

The paper [10] shows research into the effectiveness of using recycled glass as a water filtration medium, comparing it with sand filtration. The experimental conditions were set close to the pool water treatment conditions. The height of the filter layer was lower for sand: 800 mm, compared to cullet: 1,100 mm. Cullet had less uniform size and its filtration bed void fraction was greater: 53.9 % compared to 42 % in case of sand bed. Both materials had a similar particle size range, 300 to 1,000 μm. Experimental results show that both types of filtration layers significantly reduce water turbidity. Despite the differences in the structure of the filter material and its potential, cullet turns out to be comparable to sand in terms of filtration efficiency. However, questions remain regarding the optimal depth of the filtration layer, and some variation in the characteristics of the filtered particles has been observed. The use of recycled glass as a filter material is a promising direction that requires additional research to optimize its properties and increase the efficiency of particle separation in water.

The paper [11] shows a method of crushing glass for its subsequent processing using an underwater shock wave. These results could be useful in improving glass recycling efficiency and reducing the amount of material sent to landfills. However, unresolved issues remain, such as the difficulties associated with the process of disassembling and classifying materials, as well as the fundamental aspects of the impact of a shock wave on glass with resin. An option to overcome these difficulties may be to further improve the crushing and classification method, which may require additional research. However, it is the approach using an underwater shock wave that is chosen in this work. All this suggests that it is advisable to conduct additional research on optimizing this method of glass processing using an underwater shock wave.

The paper [12] shows that experiments conducted with exposure of glass bottles to underwater shock waves led to fragmentation into small fragments, called secondary glass. However, there are still unresolved questions related to the details of the fracture behavior of glass bottles under the influence of underwater waves. The reasons for this may be various factors, such as limitations associated with the peculiarities of the experimental methodology, ambiguities in the principles of glass destruction under the influence of shock waves. An option to overcome the corresponding difficulties may be an in-depth analysis of the mechanisms of glass fracture behavior under conditions of underwater explosions. However, despite the possible difficulties, it is precisely this approach that has been successfully used in previous studies in the field of the dynamics of destruction of materials under the influence of shock waves. All this suggests that it is advisable to conduct additional research devoted to a detailed analysis of the mechanisms of destruction of glass bottles under the influence of underwater shock waves. Such research can reveal unexplored aspects of the fracturing behavior of materials and provide valuable data.

The paper [13] shows that the use of raw materials such as recycled glass, Hosaenaclay, Arerofeldspar, AreroQuartz in the creation of ceramic insulators has prospects. However, unresolved questions remain related to certain aspects of the research process and application of these materials. The reasons for these unresolved issues may be objective difficulties, such as the analysis of the thermal properties of clay and other materials used in the experiments. Problems may also arise due to the fundamental impossibility of fully covering all parameters in the process of creating insulators due to the complexity of the chemical and physical interactions of various components. The costly portion of the plan associated with analyzing and characterizing materials and firing at different temperatures may make additional research less worthwhile. An option to overcome these difficulties may be a more in-depth analysis of the technical and economic aspects of the research, perhaps using new analysis techniques or process optimization. However, it is precisely this approach, based on a comprehensive analysis of the thermal, chemical and physical properties of the materials used to create insulators, that has been successfully used in previous research in this area. All this suggests that it is advisable to conduct additional research devoted to optimizing the processes of creating ceramic insulators using recycled glass.

The paper [14] presents the results of a study demonstrating that the use of cullet waste from the screen part of picture tubes in the process of vitrification of asbestos-cement materials is a promising direction. However, despite the positive findings, unresolved questions remain regarding certain aspects of this process. Obstacles may include objective difficulties, such as difficulties in technical implementation, possible inconsistencies in the process, or difficulties in controlling the effect of cullet on the properties of asbestos cement. Fundamental difficulties may also arise due to the characteristics of chemical interactions or other aspects that require additional research. One of the options to overcome these difficulties may be a more in-depth analysis and optimization of the vitrification process, adapted to the specifics of CRT cullet and asbestos cement. This may include more careful control of vitrification conditions, optimization of mixture composition and temperature control. Despite the possible difficulties, this approach, using CRT glass cullet in ACM vitrification, could be a key direction in the field of waste management and the creation of safe products for construction and road works. This justifies the feasibility of additional research aimed at in-depth study of issues that remain unresolved and optimization of this approach for practical use.

The paper [15] shows that the use of the "cullet" generation method using an underwater shock wave is a new and effective way to recycle glass bottles. However, unresolved questions remain regarding certain aspects of this process. Problems may arise due to objective difficulties, such as difficulty in controlling explosive conditions, as well as fundamental limitations associated with the safety and efficiency of the process. Expensive components of the plan, such as shock wave generation equipment, may make related research impractical. An option to overcome these difficulties may be to improve the technology for generating underwater shock waves or develop more effective methods for controlling explosive conditions. However, despite these challenges, this is the approach taken in this paper. The use of an underwater shock wave effectively crushes glass bottles, reducing recycling costs and improving the overall efficiency of the glass waste recycling system. All this confirms the feasibility of conducting additional research aimed at further improving this method of glass recycling.

To use an electric pulse installation to destroy and crush glass fragments, it is necessary to conduct research depending on the electrical parameters of pulse discharges. These studies are carried out through research work devoted to experiments on the processing of raw materials depending on the voltage of electrical pulse discharges and the number of discharges, the capacity of capacitor banks in the installation.

3. The aim and objectives of the study

The aim of the work is to study the effect of electrical pulse discharges during the processing of household glass waste in laboratory conditions. The results of scientific work can contribute to the design of electric pulse devices for processing solid household waste.

To achieve this aim, the following objectives were accomplished:

– to study the effects of the voltage of electric pulse discharges and the number of discharges on the grinding of glass;

– to study the effects of the capacitor bank capacity and the frequency of electric pulse discharges on the output of the finished product.

4. Materials and methods

The object of the study was considered one of the solid household waste – cullet and household glass containers (Fig. 1).

Fig. 1. Household glass waste

The main hypothesis of the study is the ability of the shock wave to perform useful work, accompanied by the occurrence of hydraulic pressures in the discharge zone by forming high-voltage electrical pulses in the volume of solid material in a liquid medium. In the work, it was supposed to obtain a powdered product by recycling glass waste under the influence of electric pulse discharges. In addition, it was supposed to determine the effective parameters of crushing solid household waste by the electric pulse method.

The simplifications adopted in the work include the following: an economically available liquid was used as a solid material processing medium – process water; part of household glass containers (medicinal bottles with a volume of 10–100 ml) did not require additional work before processing by the electric pulse method (washing glass containers and reducing its volume so that it could fit into an electric pulse device).

Analyses of the chemical composition of the studied object were studied and presented in Tables 1, 2. In the table, indicated by the number 1 is glass waste crushed in a cone mill, and 2 is powder material obtained by the electric pulse method.

The results of silicate analysis showed that the main component of glass waste is silicon oxide. Based on the results of semi-quantitative spectral analysis, it was found that the powder material does not contain the following elements: gold, hafnium, mercury, indium, platinum, tantalum, tellurium, thorium, thallium, uranium.

Since the research work is devoted to the processing of cullet using the electric pulse method, an experimental stand has been assembled for the production of glass powder. The basis of the developed electric pulse technology is the electrohydraulic Yutkin effect, widely used in the chemical industry [16]. The electric pulse installation is made in the form of functional blocks, consisting of a control panel, a generator with a spark gap, and a protection unit with a capacitor (Fig. 2) [17]. The equipment for grinding the material was a device (Fig. 3) consisting of a positive electrode (a metal electrode insulated with caprolon) and a metal cylindrical container (acting as a negative electrode).

Table 1

Silicate analysis results

Elements	Chemical symbols	Content %	
		1	2
Silicon oxide	SiO_2	69.63	70.11
Aluminium oxide	Al_2O_3	1.08	1.12
Iron(III) oxide	Fe_2O_3	0.34	0.36
Calcium oxide	CaO	9.53	9.46
Magnesium oxide	MgO	3.43	3.53
Potassium oxide	K_2O	0.35	0.30
Sodium oxide	Na_2O	13.89	13.76
Titanium(IV) oxide	TiO_2	0.063	0.053
Manganese oxide	MnO	<0.02	<0.02
Phosphorus(V) oxide	P_2O_5	0.082	0.083
Sulfur(VI) oxide	SO_3	<0.10	<0.10

Table 2

Results of semi-quantitative spectral analysis

Elements	Chemical symbols	Content %	
		1	2
Scandium	Sc	<0.0001	<0.0001
Phosphorus	P	<0.03	<0.03
Antimony	Sb	<0.0015	<0.0015
Manganese	Mn	0.0034	0.0035
Lead	Pb	0.0059	0.0070
Titanium	Ti	0.052	0.054
Zirconium	Zr	0.0071	0.0071
Arsenic	As	<0.01	<0.01
Gallium	Ga	0.0001	0.0001
Tungsten	W	<0.0005	<0.0005
Chromium	Cr	0.0016	0.0016
Nickel	Ni	<0.0002	<0.0002
Germanium	Ge	<0.00015	<0.00015
Bismuth	Bi	<0.0002	<0.0002
Barium	Ba	0.022	0.026
Beryllium	Be	<0.00003	<0.00003
Niobium	Nb	0.0011	0.0011
Molybdenum	Mo	0.00014	0.00014
Tin	Sn	0.0036	0.0038
Vanadium	V	0.0006	0.0006
Lithium	Li	<0.002	<0.002
Cadmium	Cd	<0.0005	<0.0005
Copper	Cu	0.0009	0.0012
Ytterbium	Yb	<0.00005	<0.00005
Yttrium	Y	<0.0005	<0.0005
Zinc	Zn	0.0049	0.0050
Cobalt	Co	0.0003	0.0002
Strontium	Sr	0.053	0.068
Bor	B	<0.03	<0.03

Processing of cullet using the electric pulse method is carried out as follows. Material mixed with water is placed into the working device. Due to the electric discharge formed between the positive and negative electrodes and the shock wave in a heterogeneous medium, the material is destroyed [18]. Grinding of cullet was carried out under the following parameters: capacitor capacity (C) – 0.4–1.2 μF; discharge voltage (U) – 12–37 kV; number of pulse discharges (N) – 250–1,000; discharge frequency (f) – 0.3–2 Hz.

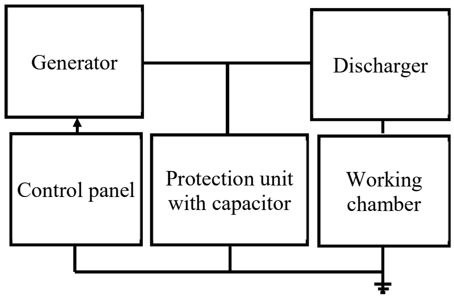

Fig. 2. Block diagram of electric pulse installation

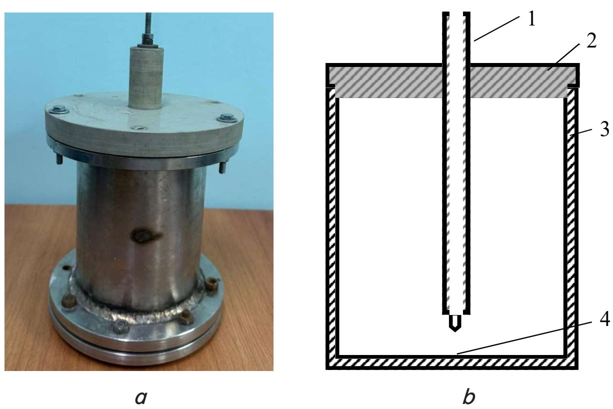

Fig. 3. Working chamber: *a* – photo; *b* – scheme; 1 – positive electrode; 2 – working chamber cover; 3 – metal cylindrical body; 4 – negative electrode

5. Results of research and analysis of the influence of electric pulse discharges on glass waste recycling

5. 1. Results of a study of the influence of electric pulse discharge voltage and the number of discharges on glass cullet grinding

Table 3 shows the results of grinding glass products and glass scrap after use in everyday life at different voltage values of electrical pulse discharges (U) and the number of discharges (N). The breakdown voltage of the air converter, the capacitance of the pulse capacitor and the number of pulse discharges are the main values for increasing the intensity of grinding materials using the electric pulse method. Therefore, the scientific work was devoted to studying the influence of the parameters of electric pulse discharges and the capacitance of the pulse capacitor on the grinding of solid household waste.

Experiments were carried out at a constant value of the pulse capacitor capacitance (C=0.4 μF). The voltage of the discharges was changed from 12 kV to 37 kV, and the number of discharges from 250 to 1,000. The mass of the starting material was measured using electronic scales and was constant for each experiment.

Analysis of the granulometric composition of the material processed by the electric pulse method was considered for crushed materials with a fraction diameter (d) of less than 0.4 mm and 0.7 mm, from 1 to 4 mm and from 5 to 8 mm. The yield of the finished product was determined as follows: $K=(m_1/m_2)\cdot 100$ %, m_1 – mass of the product obtained by the electric pulse method, m_2 – mass of raw materials. The mass of the product obtained by the electric pulse method is the average value of repeated experiments. The average value of the mass of the finished product was determined as follows: $m_n=(m_1+m_2+...+m_i)/(n_1+n_2+...+n_i)$, where: m_1, m_2, m_i – the mass of the resulting finished product after repeated experiments; n_1, n_2, n_i – the number of measurements.

Analysis of the granulometric composition of the raw materials provided valuable information on the size of the resulting product. From these results, the area of use of glass powder can be determined. It was observed that the yield of the powder product could be increased by varying the voltage of the electric pulse discharges and the number of discharges at different intervals.

Table 3

Results of the output of the finished product (K) obtained at different values of the voltage of the electric pulse discharges (U) and the number of discharges (N)

d, mm	*N*=250	*N*=500	*N*=750	*N*=1,000
	U=12 kV, *C*=0.4 μF			
	K, %			
d=5–8	58.5	63.2	66.4	74.9
d=1–4	15.8	21.6	27.3	15.7
d<0.7	–	–	–	–
d<0.4	–	–	–	–
d, mm	*N*=250	*N*=500	*N*=750	*N*=1,000
	U=19 kV, *C*=0.4 μF			
	K, %			
d=5–8	48.8	42.2	25.3	28.4
d=1–4	49.6	56.7	72.5	69.1
d<0.7	–	–	0.7	1.2
d<0.4	–	–	–	–
d, mm	*N*=250	*N*=500	*N*=750	*N*=1,000
	U=25 kV, *C*=0.4 μF			
	K, %			
d=5–8	24.1	18.5	14.6	10.1
d=1–4	73.3	78.2	78.8	80.9
d<0.7	1.5	1.8	2.3	4.5
d<0.4	–	–	2.7	3.2
d, mm	*N*=250	*N*=500	*N*=750	*N*=1,000
	U=32 kV, *C*=0.4 μF			
	K, %			
d=5–8	4.2	3.9	2.4	2.3
d=1–4	85.8	82.3	79.1	73.6
d<0.7	2.4	4.5	6.9	11.1
d<0.4	7.1	8.3	9.3	11.5
d, mm	*N*=250	*N*=500	*N*=750	*N*=1,000
	U=37 kV, *C*=0.4 μF			
	K, %			
d=5–8	3.7	1.8	2.2	1.1
d=1–4	80	79.5	80.6	77.6
d<0.7	3.4	3.6	3.6	4.5
d<0.4	10.1	12.9	12.8	14.9

5. 2. Results of a study of the influence of the capacity of the capacitor battery and the frequency of electric pulse discharges on the crushing of glass cullet

Table 4 shows the data after processing the cullet using the electric pulse method. During the research, the dependence of the yield of the finished product on the capacity of the capacitor bank and the frequency of electrical pulse discharges was found.

Table 4

Results of the output of the finished product (*K*) obtained at different values of the capacitance (*C*) of the capacitor bank and the frequency of electrical pulse discharges (*f*)

d, mm	*C*=0.4 µF	*C*=0.8 µF	*C*=1.2 µF
	U=35 kV, *N*=1,000, *f*=0.3 Hz		
	K, %		
d=5–8	15.5	18.4	11.7
d=1–4	72.6	59.7	71.2
d<0.7	7.3	14.8	9.5
d<0.4	3.2	5.9	6.7
d, mm	*C*=0.4 µF	*C*=0.8 µF	*C*=1.2 µF
	U=35 kV, *N*=1,000, *f*=0.7 Hz		
	K, %		
d=5–8	0.9	1.2	0.3
d=1–4	68.8	52.7	44.4
d<0.7	18.6	29.5	37.6
d<0.4	9.8	15.1	16.4
d, mm	*C*=0.4 µF	*C*=0.8 µF	*C*=1.2 µF
	U=35 kV, *N*=1,000, *f*=1.5 Hz		
	K, %		
d=5–8	1.1	0.7	0.9
d=1–4	69.3	52.5	49.2
d<0.7	20.9	26.3	34.1
d<0.4	7.4	18.4	13.2
d, mm	*C*=0.4 µF	*C*=0.8 µF	*C*=1.2 µF
	U=35 kV, *N*=1,000, *f*=2 Hz		
	K, %		
d=5–8	10.2	5.2	7.1
d=1–4	76.4	63.1	50.2
d<0.7	9.4	18.1	24.8
d<0.4	2.8	11.7	16.2

In the work, the capacitance of the capacitor was increased from 0.4 µF to 1.2 µF, and the frequency of electric pulse discharges was increased from 0.3 Hz to 2 Hz. For each experiment, the discharge voltage and number of discharges were constant (*U*=35 kV, *N*=1,000). Based on the results obtained, it was found that with an increase in the capacity of the capacitor bank and the frequency of electric pulse discharges, the yield of finished products with a diameter of less than 0.4 mm and 0.7 mm increases.

6. Discussion of the results of a study of the influence of electric pulse discharges on glass products and glass fragments

From Table 3 it can be seen that with a pulse capacitor capacitance *C*=0.4 µF and a discharge voltage of 12 kV, with an increase in the number of pulse discharges from 250 to 1,000, the yield of finished products with a fraction diameter of 1–4 mm was 15.7–27.3 %, and product fraction 5–8 mm – 58.5–74.9 %. With given capacitance values of capacitors and pulse discharges and a change in discharge voltage up to 19 kV when processing raw materials with electric pulse discharges, the yield of the finished product with a fraction of 1–4 mm is 49.6–72.5 %, the product with a fraction of 5–8 mm is 25.3–48.8 %, and a product with a diameter of 0.7 mm (*K*=0.7–1.2 %) was obtained only at 750, 1,000 discharges. As the discharge voltage increases from 25 kV to 37 kV, the yield of fine-fraction product increases, and the yield of large-fraction product decreases.

From Table 4, at constant values of discharge voltage and number of discharges (*U*=35 kV, *N*=1,000) and a discharge frequency of 0.3 Hz, with an increase in the capacitor capacitance from 0.4 µF to 1.2 µF, the output of the finished product with a diameter of 0.7 mm was 7.3–14.8 %, and the yield of small product with a diameter of 0.4 mm was 3.2–6.7 %. When the discharge frequency was changed to 0.7 Hz, the yield of the finished product with a diameter of 0.7 mm was 18.6–37.6 %, and the yield of a product with a diameter of 0.4 mm was 9.8–16.4 %. It was noticed that when the discharge frequency was increased by 1.5 Hz and 2 Hz, the yield of fine-fraction finished products did not change significantly. It was also found that at a pulse discharge frequency of 2 Hz, the size of the large-fraction material increases (*d*=1–4 mm, *d*=5–8 mm).

Before these studies, the authors crushed the remains of glass fragments with a diameter of 2–5 mm using the electric pulse method at a discharge voltage of 25 kV and 35 kV, with a capacitor capacity of 0.25–1 µF, and with a number of pulse discharges of 100–600. The results of the experiment yielded a powder of 0.1–1 mm [19]. This paper presents the results of experiments on the processing of scrap glass and glass products with an increase in the capacitor capacitance by 1.2 µF and the frequency of electric pulse discharges by 2 Hz, the number of discharges up to 1,000. The yield of the finished product was determined depending on the capacitance of the capacitor, the parameters of the electric pulse discharge and the diameter of the resulting glass powder. The research data can be used in work on the use of the electric pulse method in the processing of solid dielectric materials.

The limitations of the pilot plant include: the limit value of the discharge voltage of 40 kV, the capacity of the pulse capacitor of 0.4 µF, the limit voltage of the capacitor of 100 kV. Although the limit voltage of the capacitor is up to 100 kV, the limit value of the discharge voltage has been assigned in accordance with the maximum voltage value of the pulse generator output.

The main disadvantage of the work is that the size of the processed product must be limited (width, length and thickness should not exceed 45 mm). This limitation was chosen due to the distance between the positive electrode and the metal corpus in the working channel.

The main difficulties in research work arise in determining the voltage of pulse discharges in the working channel and the pressure of shock waves formed in the volume of liquid. To solve this problem, it is necessary to create a working device equipped with sensors and the necessary means of measuring pressure and voltage. In this regard, research work is planned to study the parameters of electrical discharges during the processing of solid household waste in a liquid medium.

7. Conclusions

1. From the data of the research work, it was found that as the voltage of the pulse discharges and the number of discharges increase, the output of the fine-grained (0.4–0.7 mm) product increases. The results of the study showed that the electric pulse grinding method allows you to adjust the granulometric composition of the finished product with increased selectivity.

2. The results of grinding of raw materials with the formation of pulsed electrical discharges in a liquid medium allowed us to assess the degree of grinding of the material. The optimum processing parameters of glass waste electropulse method accepted: for the voltage of electric pulse discharges – U=32 – 37 kV; for the battery capacity of the capacitor – C=0.8-1.2 μF; frequency of electric pulse discharges – f=1.5-2 Hz.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant No. AP14870607).

Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Acknowledgments

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant AP14870607).

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