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STUDY INTO THE FEASIBILITY OF ELECTRIC DISCHARGE DISINTEGRATION OF GLASSLIKE RAW MATERIAL TO MICRON FRACTION

A literature review of various methods of breaking and grinding of materials was performed, based on which a method of electric discharge disintegration (EDD) was chosen. It allows achieving of micron values fractional composition of the processed material. Mechanisms of material destruction under the influence of high-voltage electric discharge in water were considered.

Used glassware (UG) was selected as raw material for disintegration due to economic and environmental reasons. Methodologies of UG preliminary preparation for disintegration and further grain-size analysis were developed.

Calculation of compression wave (CW) parameters at different distances from the discharge channel for given discharge circuit initial parameters was performed. Maximum distance at which CW has required destructive effect was determined based on the comparison of physical and mechanical properties of glass and results of performed calculations.

Appropriate discharge circuit properties (e.g., useful power) necessary for EDD grinding of UG to micron fraction was determined based on the parameters of the discharge circuit and practically achievable switch frequency.

The results of previous processing which was carried out with set circuit parameters in the chamber providing the required maximum radius of destruction in pure water and in water with the addition of surfactants, were obtained to evaluate the possibilities (primarily, achievable dispersion) of UG EDD.

The grain-size analysis of dispersion composition showed the possibility of disintegration of the glass into the micron fraction (with grains of size ranging from 5 to 7 microns – up to 30 weight percentage).

Keywords: Electric discharge disintegration, used glassware, glasslike raw material, thermal insulation material.

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ДОСЛІДЖЕННЯ МОЖЛИВОСТІ РОЗРЯДНО-ІМПУЛЬСНОЇ ДЕЗІНТЕГРАЦІЇ СКЛОПОДІБНОЇ СИРОВИНИ ДО МІКРОННОЇ ФРАКЦІЇ

Проведено літературний огляд різних методів дроблення і подрібнення матеріалів, на основі якого був обраний метод розрядно-імпульсної дезінтеграції, який дає змогу досягти мікронних значень фракційного складу оброблюваного матеріалу. Розглянуто механізми руйнування матеріалів під впливом високовольтного електричного розряду у воді.

В якості сировини для дезінтеграції з економічних і екологічних міркувань вибрана скляна тара (СТ). Розроблено методики підготовки СТ до дезінтеграції та подальшого гранулометричного аналізу дисперсії.

Проведено розрахунок параметрів хвилі тиску (ХТ) на різних відстанях від каналу розряду для заданих початкових параметрів розрядного контуру. На підставі зіставлення фізико-механічних властивостей скла і результатів проведених розрахунків визначено максимальну відстань, на якому ХТ здійснює руйнівний вплив.

За параметрами розрядного контуру і практично досяжною частоти за умовами роботи комутатора вибрані необхідні для розрядно-імпульсної дезінтеграції характеристики розрядного контуру (в першу чергу, корисна потужність) для подрібнення СТ до мікронних розмірів.

Отримано результати попередніх обробок для оцінки можливостей (в першу чергу, по дисперсності) розрядно-імпульсної дезінтеграції СТ, які проведені для заданих параметрів контуру в камері, що забезпечує необхідний максимальний радіус руйнування в чистій воді і в воді з додаванням поверхнево-активних речовин.

Аналіз гранулометричного складу дисперсії показав можливість дезінтеграції скла до мікронної фракції (від 5 до 7 мкм – 30 %).

Ключові слова: розрядно-імпульсна дезінтеграція, скляна тара, піноскляний матеріал, теплоізоляційний матеріал.

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ИССЛЕДОВАНИЕ ВОЗМОЖНОСТИ РАЗРЯДНО-ИМПУЛЬСНОЙ ДЕЗИНТЕГРАЦИИ СТЕКЛОПОДОБНОГО СЫРЬЯ ДО МИКРОННОЙ ФРАКЦИИ

Проведен литературный обзор различных методов дробления и измельчения материалов, на основе которого был выбран метод разрядно-импульсной дезинтеграции, который позволяет достичь микронных значений фракционного состава обрабатываемого материала. Рассмотрены механизмы разрушения материалов под воздействием высоковольтного электрического разряда в воде.

В качестве сырья для дезинтеграции по экономическим и экологическим соображениям была выбрана стеклянная тара (СТ). Разработаны методики подготовки СТ к дезинтеграции и последующего гранулометрического анализа дисперсии.

Проведен расчет параметров волны давления (ВД) на различных расстояниях от канала разряда для заданных начальных параметров разрядного контура. На основании сопоставления физико-механических свойств стекла и результатов проведенных расчетов определено максимальное расстояние, на котором ВД оказывает разрушительное воздействие.

По параметрам разрядной цепи и практически достижимой частоты по условиям работы коммутатора выбраны необходимые для разрядно-импульсной дезинтеграции характеристики разрядного контура (в первую очередь, полезная мощность) для измельчения СТ до микронных размеров.

Получены результаты предыдущих обработок для оценки возможностей (в первую очередь, по дисперсности) разрядно-импульсной дезинтеграции СТ проведенные для заданных параметров цепи в камере, обеспечивающей необходимый максимальный радиус разрушения в чистой воде и в воде с добавлением поверхностно-активных веществ.

Анализ гранулометрического состава дисперсии показал возможность дезинтеграции стекла в микронной фракции (от 5 до 7 мкм – 30 %).

Ключевые слова: Разрядно-импульсная дезинтеграция, стеклянная тара, пеностеклянный материал, теплоизоляционный материал.

Introduction. Development of effective, environmentally friendly, fire and moisture resistant, lightweight and with a long lifespan thermal insulation materials is a relevant scientific and technical task of present days due to the current acute problem of energy saving.

To date, foam polystyrene (foam plastic) is mainly used for thermal insulation, which has a relatively short lifespan (20-30 years), is prone to absorption of moisture, decomposes under the influence of solar radiation and fungi influence, is not fire resistant and releases toxic substances while burning. For these reasons, in USA, Canada and EU this material is already forbidden to use for thermal insulation of buildings. Natural (mineral) composite materials made of foam glass could very well act as the solution to safe thermal insulation. While having equal to the foam plastic values of thermal conductivity, foam glass composite materials have a number of competitive advantages: they are non-combustible, with high humidity and frost resistance, have a shelf life of at least 100 years and are made of environmentally friendly raw materials.

Foam glass production technological process is based on the foaming of a rare-glass mixture that consists of water, glass material, foaming additives, etc. Prominent companies also include an intermediate stage for obtaining of main component of future thermal insulation material – glass, production of which consumes a huge amount of natural resources and fuel.

Among the all unique properties that the glass holds, its ability to reprocess into the new glass product for virtually unlimited number of times without losing their qualities should be especially noted. Thus, the glass belongs to materials with a full cycle of recycling.

The use of secondary raw materials (used glassware (UG), glass scrap, etc.) in foam glass production provides solution to several important problems:

– Energy saving – UG is smelted at a much lower temperature than the raw material from which the glass is usually melt;

– Reduction of carbon dioxide emissions into the atmosphere during production;

– Reducing the consumption of natural resources, since UG is de facto used as the raw material;

– Reduced waste from the production of packaging materials in landfills.

UG eliminates the need for fossil raw materials and energy for glass production. However, effective usage of such material requires preliminary grinding with the most common technique of multi-stage grinding in mechanical crushers and mills with the addition of special additives that affect the properties and end-points of the foam glass mixture solid components [1, 2, 3]. The use of such methods of disintegration remains rather complicated: it does not allow achieving micron fraction grinding; resulting foam glass foaming ability is poor while containing thermally conductive metal impurities and being relatively expensive due to required foaming additives [4]. Also, properties such as density, heat conductivity, strength of the produced thermal insulation material (foam glass rubble or blocks) directly depend on the fractional composition of fillers and dispersion of the solid phase [5].

As the fractional composition of the glass component plays an important role in the production of foam glass products, technological advancement of glass component grinding methods remains a relevant scientific and technical task.

1 Analysis of modern material grinding methods

Existing methods of grinding were considered. Disperse materials production methods that found widespread industry use can be divided into three distinct groups:

1. Mechanical methods in which raw material grinding occurs during deformation of its original structure by crushing, splitting, abrasion and impact. Despite the fact that the mechanical grinding method is the most common and well-studied, it belongs to the group with lowest productivity, high energy consumption and limited dispersion possibilities.

2. Physical fields' energy dispersion methods include technologies that affect the material by ultrasonic and electrohydraulic effect. Both methods increase the dispersion of initial powders by several orders of magnitude compared to mechanical grinding. Disadvantage of the ultrasonic method is relatively low power, so it is suitable only for the destruction of soft materials and conglomerates of particles [6, 7], while the electrohydraulic technology is characterized by a higher power of influence on a material of any hardness and conductivity.

3. Among numerous plasma methods of finely-dispersed particles production, the following ones should be singled out: conductor electric explosion [8], electric erosion dispersion [9] and plasma chemical synthesis [10-11]. The mechanism of finely-dispersed particles production in this group of methods is based on the effect of material ablation in liquid and gaseous phase from material's surface under the influence of highly concentrated energy flows and thus is suitable only for conductive materials.

Of all the above-mentioned finely-dispersed particles production methods, the most promising to use for glass grinding is clearly an electrohydraulic effect method. This method has a much greater potential than the traditional ball or rod mills grinding of glass material; it allows getting a product with low-scale fractional composition and necessary rheological properties of rare-glass mixture which minimizes possible contamination by hardware metal and significantly reduces capital and energy costs while keeping insignificant equipment dimensions [12]. Electric discharge grinding compare favorably with known methods, it is characterized by a multitude of rather complex phenomena, ranging from breakdown of liquid to material destruction and allows the most rational use of electricity while achieving a high degree of destruction of materials at the lowest cost of electricity [13, 14].

The aim of this work was to research the grinding of glass material up to a micron fraction using the method of electric discharge disintegration (EDD), which generates hydraulic flows and shock compression waves (CW).

1.1 Features of electric discharge disintegration of materials

Energy released in the discharge channel (see Fig. 1) is mainly spent on the heating of material in the discharge channel and on channel's expansion which turns into compression energy and pulsation energy of the vapor-gas cavity [13, 15]. Discharge channel's energy input, energy of compression waves and vapor-gas cavity can be altered by electric discharge regime change.

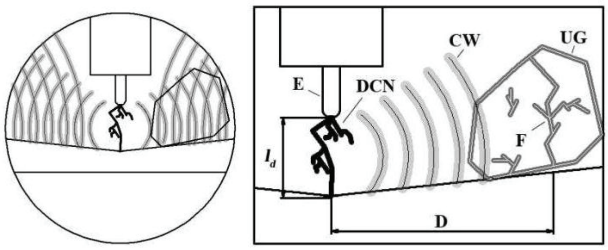

Figure 1 – Discharge channel influence on the used glassware: E – electrode; DCN – discharge channel; CW – compression wave; UG – used glassware; F – fractures; l_d – discharge gap; D – distance from the axis of discharge to the area of influence

Crushing or rupturing of material in the zone adjacent to the discharge channel (DCN) as well as formation and development of penetrating fractures occur at during discharge with sufficient CW amplitude. CW partially reflects from an open surface forming a tension wave in the material which causes the formation of spallation fractures, surface bulging and destruction. Simultaneously, CW permeates into the material forming a system of penetrating fractures, on the number and depth of which the efficiency of subsequent discharges destruction depends.

An effective radius of CW as the main performance indicator of electric discharge devices is set according to the level of destruction. It is necessary to establish the dependence of material destruction parameters on its properties and durability characteristics to achieve maximum productivity of electric discharge devices. This will ensure optimal energy consumption while keeping maximum productivity of electric discharge destruction process.

CW pulse momentum, J_0 which destroys the material during the electric discharge in water, can be approximated [16] by the formula:

$$J_0 = 2{,}1\frac{\sqrt[3]{l_p U_0^2}}{D}, \qquad (1)$$

where D – distance from the axis of discharge to the area of influence, m; l_d – discharge gap, m; U_0 – charging voltage of the capacitor battery, kV.

2 Calculation of compression waves in the material processing area of the technological unit and selection of laboratory equipment electrical parameters

Processed UG fragments are placed in the zone of EDD power factors effective influence after preemptive reduction in sizes to a required fraction in devices such as shredder or hammer crusher.

It should be taken into account when choosing processing scheme that it will probably be necessary to manually load UG intothe discharge chamber (DCM) (see Figure 2) with a certain orientation relative to electrode systems. In addition, a possible variant of UG grinding with intermediate selection and separation of conditioned product is possible.

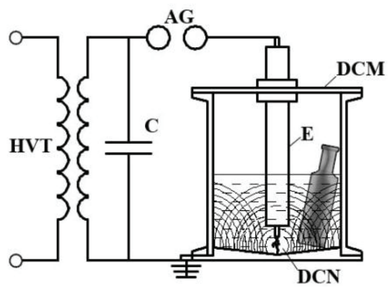

Figure2 – Discharge chamber

Effect of UG grinding to micron values grain-size necessary for the subsequent process of foam glass production.

To calculate the required magnitude of the destructive load, we will use the physical-mechanical characteristics of ordinary glass (see Table 1) [17].

Table 1 – Physical-mechanical properties of glass

Compression pressure, MPa	from 500 to 2,000
Fracture pressure, MPa	40
Elasticity, MPa	from 48·103 to 12·104
Tension (bending) pressure, MPa	from 35 to 100
Shear pressure at σ ≥ 0.5, MPa	from 20,000 to 30,000
Impact strength (fragility), kJ/m2	from 1,5 to 2
Density, kg/m3	from 2,200 to 2,600

A functional connection between CW amplitude and electric discharge equipment electrical parameters is established for cylindrical symmetry zone [14]

$$p = \frac{U_0^{5/4} C^{1/4}}{r^{1/2} L^{3/8} l_{\text{р.п.}}^{5/8}}, \qquad (2)$$

where C – capacitor battery capacitance, μF; r_c – distance from destructed object to discharge channel, m; L – circuit inductance, μH.

Applying the coefficient of proportionality (k) which characterizes the excess of CW amplitude over the strength limit (σ_s) of UG, we can write down next relation:

$$\frac{U_0^{5/4} C^{1/4}}{r^{1/2} L^{3/8} l_{\text{р.п.}}^{5/8}} = k\sigma_{\text{пр}}, \qquad (3)$$

where σ_s – strength limit, MPa (can be the limit of compressive strength, tensile strength, shear strength, bending strength, etc.).

All types of deformations take place when disintegrating materials in the electric discharge generated CW zone. At the same time, processed object does not feel sufficient destructive action outside these waves in the so-called dead zones. Thus, it is necessary to take into account the geometrical features of DCM construction (size, location of the electrode in relation to the material being processed, bottom of the chamber) for full distribution of destructive waves.

Relying on the fact that the efficiency of destruction depends on electric discharge regime, for further calculations of CW amplitude we will use following initial parameters of EDD equipment (see Table 2).

Table 2 – Technical characteristics of experimental laboratory equipment

Parameter	Value
Capacitor battery voltage U_0, kV	from 30 to 50
Capacitor battery C, F	from $1\cdot10^{-6}$ to $2\cdot10^{-6}$
Stored energy value range W, kJ	from 1 to 2
Pulse frequency f, Hz	from 1 to 4
Inductance L, H	from $2\cdot10^{-6}$ to $6.0\cdot10^{-6}$
Discharge chamber volume (with inner radiusof 0,1 m), l	10
Loaded glass mass, kg	0,3
Regulated discharge gap l_d, m	from 0,03 to 0,07

Calculations of CW amplitudes generated by stored energy release in the discharge channel of the experimental equipment in its active zone according to above-mentioned formulas are presented in Table 3.

Table 3 – Calculation of CW amplitude depending on capacity (C) and distance (r) from the object of destruction to the discharge channel

$C\cdot10^{-6}$, F	r, m							
	0,01	0,05	0,09	0,1	0,12	0,15	0,20	0,22
	$p\cdot10^6$, Pa							
1,0	139,654	62,455	46,01	44,162	40,314	36,058	24,518	13,01
1,5	154,551	69,117	51,517	48,872	44,615	39,905	25,113	15,02
2,0	166,076	74,274	55,359	52,518	47,942	42,881	28,512	18,07

Power action of the electric discharge in DCM should be enough to provide sufficient deformation forces so that the pressure near discharge zone should be at least equal to glass limit of compressive strength.

Comparing the calculation results of Table 3 with the values of physical and mechanical properties of processed glass in Table 1, we can conclude that the stored energy W_0 must be not less than 1 kJ while the inner radius of technological unit should be not more than 0,1 m. With inner radius of reactor greater than 0,1 m, dead zones are formed due to the lack of sufficient force influence since at $W_0 \leq 1$ kJ the pressure will be less than the glass limit of compressive strength. Thus, stored energy for a technological unit with 0.1 m inner radius should range from 1 to 2 kJ.

3 Methodology and laboratory equipment for electric discharge disintegration of used glassware

The experimental method consists of the usage of powerful pulse discharges in the inter-electrode gap which creates the necessary conditions sufficient for the destruction of UG.

Previous active zone CW amplitude calculations were used in order to determine energy parameters and UG processing regimes while establishing discharge chamber's size for the efficient glass disintegration.

Experimental electric discharge disintegration equipment was developed and assembled carry out experiments on UG grinding. This equipment includes:

– technological unit consisting of the discharge chamber with a "point - surface" electrode system;

– pulse currents generator (PCG);

– control system.

PCG is based on the high-voltage transformer HVTO 30/50; inductance-capacitance converter (ICC) based on the complex of charging capacitors JFS-13 50 μF – 450 V and inductive choking winding DR-6 with power of 30 kW; IC 50 capacitor battery with capacity of 1-2 μF and toroidal-shaped air discharge switch responsive to the overvoltage in the air gap. Capacitor battery charging voltage U_0 was controlled by the electrostatic kilovoltmeter C 196 and resistive voltage divider.

Figure 3 shows EDD laboratory.

Figure 3 – Laboratory equipment

Power circuit parameters (Table 2) remained unchanged during the whole experiment: charging circuit voltage U_0 = 30-50 kV, capacitor battery capacitance C = 1-2 µF, pulse energy W = 1,25 kJ, pulsed discharge average frequency f_{av} = 1-4 Hz.

Glass was processed in the 10 l DCM filled with the pre-emptively crashed 3 kg of UG and 6 l of water. The result of the glass EDD is shown on Fig. 4.

Two experiments were carried out: the first one consisted of the processing of glass in the water; the second one featured the addition of surfactants to the aqueous medium (see Table 4).

Liquid penetrates into the pores of the crushed material while reducing its strength as the grinding process is carried out in the aqueous medium. Surfactants adsorption from the environment in the absence of chemical interaction can significantly reduce the boundary of elasticity, strength and hardness, facilitate the destruction of fragile bodies and increase the plasticity of metals. Temporary wedge microcracks that can close after lifting the load develop during the deformation of a solid in its surface layer. Adsorption layers migrate on the surface and reach their peaks and prevent clogging.

a *b* *c*

Figure 4 – The result of the electric discharge disintegration of the glass;
a – before processing; *b* – paste-like processed disintegrated glass; *c* – dried glass

Table 4 – Glass EDD in the water (1) and in the water with added surfactants (2)

Experiment no.	W, kJ	V, l	m_g, kg	t, s	f_{av}, Hz
1	1,25	6	3	240	3
2	1,25	6	3	240	3

3.1 Research methodology of the morphological properties of obtained powdered glass mixtures

Processed paste-like disintegrated glass was completely removed from the DCM, dried, and then sieved through a 300 µm cell. Afterwards, its morphological properties were methodically researched in accordance with [18] by examining dispersion, form factor and specific surface of the glass powders before and after processing. The following equipment was used for such research: optical microscope BIOLAM-I with a maximum magnification of x1350, digital camera and appropriate software. Powder samples for optical microscopy were selected in accordance with State Standard no. 23402-78 [19]. Photos were taken after obtaining a clear image with set magnification using which the researched materials' geometric characteristics were further analyzed.

3.2 Experimental tests results

According to the results of experiment no. 1 research (see Table 4), it should be noted that these samples consist of particles with a narrower fraction range . No particles smaller than 3 microns, no particles larger than 700 microns, no particles larger than 500 microns. The main range of fraction composition is from 5 microns to 300 microns.

Experiment no. 1 has the following granulometric composition. Particles of minimum size of 5 µm consist up to 20 % of mass, of 300 µm average size – up to 40 %, of 600 µm maximum size – up to 40 %.

Experiment no. 2 has the following granulometric composition. Samples contain small particles (less than 10 microns in size) that partially stick together, but the overall level of aggregation is low. The minimum particle size is from 4 microns to 6 microns (30 percent by volume), the average particle size is from 14 microns to 20 microns (about 50 percent), there is a significant amount (about 10 percent) of a fraction of about 300 microns , the maximum particle size is from 500 µm to 700 µm (10%).

The results of two experiments are summarized in the diagram (see Figure 5).

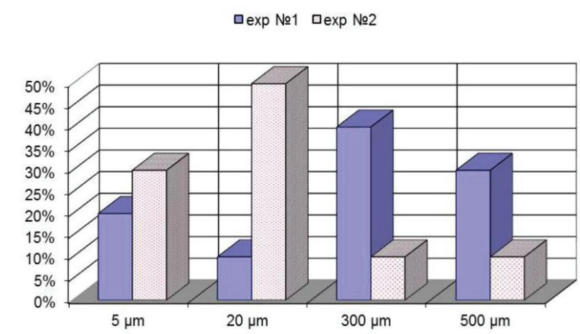

Figure 5 – The results of the granulometric analysis of glass EDD: Experiment no. 1 – in a volume of water; Experiment no. 2 – in a volume of water with surfactants

Form factor of particles in both samples is the same. The particles in the form are close to the sphere, regardless of their size. Even individual particles smaller than 5 microns also have this form factor. The micro-photos are shown on Figure 6.

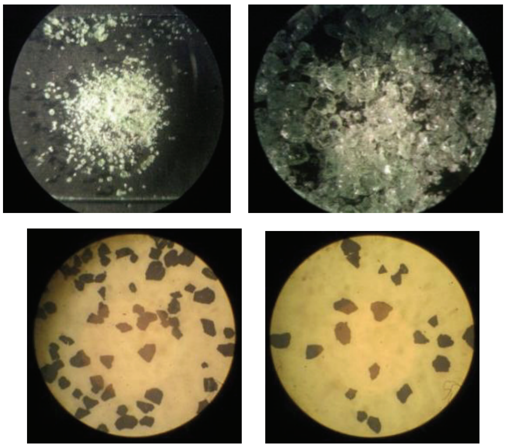

Figure 6 – The micro-photos of particles electric discharge disintegration of the glass

Conclusions. Method of electric discharge disintegration as most promising and allowing the achievement of micron values of the processed material fractional composition was chosen based on the literary review of various methods of crushing and grinding of materials. The mechanisms of material destruction under the influence of high-voltage electric discharge in water were analyzed.

Used glassware (UG) were selected as raw materials for disintegration for economic and environmental reasons. Methods of preparation of UG for disintegration and further granulometric analysis of dispersion were developed.

The calculation of the parameters of the compression wave (CW) amplitudes at different distances from the discharge channel for the given parameters of the discharge circuit (U_0 = 50 kV, C = 0,1 μF, L = 6 μH) is carried out. Based on the comparison of physical and mechanical properties of glass and results of the calculations performed, the maximum distance (r = 0,1 m), on which the UG has a destructive effect was determined.

By the parameters of the discharge circuit, the necessary characteristics for the electric discharge disintegration (first of all, power) that are necessary for grinding of UG up to micron sizes were selected.

The results of the glass EDD were obtained for the estimation of the possibilities (first of all, by dispersion) of the EDD of UG, carried out for the specified parameters of the discharge circuit in the chamber, which provides the required maximum radius of destruction in pure water and in water with surfactants.

The analysis of the granulometric composition of the dispersion showed the possibility of disintegration of the glass up to the micron fraction:

– in water: 5 μm – 20 %, 300 μm – 40 %, 600 μm – 40 %;

– in water with surfactanst: from 4 microns to 6 microns – 30 %, from 14 microns to 20 microns – 50 %, from 500 microns to 700 microns – 10 %.

The indicated result shows that EDD is a perspective method for the glass micron fraction grinding and requires further development.

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