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Abstract: *Recycling of techno genic waste accumulated in recent years in Uzbekistan is currently a pressing problem. In this regard, this paper examines the issue of studying the process of enrichment of man-made waste in a cyclone with a fluidized bed. To conduct the experiment on experimental advanced devices with extended zones five types of samples of techno genic waste with the limits of 0.072÷0.078mm, 0.064÷0.070mm, 0.057÷0.063mm, 0.046÷0.055mm and 0.041÷0.044mm have been prepared. Nomograms have been obtained using mathematical models to determine particle size limits, which ensure good separation. Experiments have been carried out on the separation of techno genic waste in three structures of a cyclone with a fluidized bed: cylindrical, cylindrical with one extended zone and cylindrical with two extended zones. The best results are obtained in a fluidized bed machine with one extended zone. The following results were obtained for a sample with a 0.041÷0.044 mm limit size: the number of Mo increased 40 times, Ag increased 20 times, Mn increased 2.5 times, Cu increased 1 time, Ti increased 6.6 times, Ni decreased 125 times and the number of Si in the selected sample decreased from 20% to 12%.*

Key words: *techno genic waste, fluidized bed machine, mathematical model, computer model, extended zone pneumatic separator, fluidizing speed, removal speed, particle size limits.*

INTRODUCTION. The main volumes of techno genic resources of non-ferrous and noble metals in Uzbekistan are in the Central Kyzylkum and Pritashkent mining areas, which have a long history of development and mining of non-ferrous and noble metal ores. Since the beginning of processing of mineral deposits, Navoi and Almalyk MMC has accumulated over seven billion tons of techno genic waste of substandard minerals in warehouses and tailing dumps [1].

Overall, only forecasted resources of metals accumulated in the wastes of the mining and smelting operations of Navoi and Almalyk mining and smelting plants amount to approximately 1,000 tons of gold, over 1,300 tons of silver, approximately 2,000 tons of copper, over 30,000 tons of lead, over 117,000 tons of zinc, over 13,000 tons of sulphur, large amounts of iron, molybdenum and other useful components.

The major waste or technogenic resources of both mills can be divided into the following types:

1. Mineralized mass dumps;
2. Off-balance sheet ore stockpiles;
3. Intermediate wastes of ore processing schemes (magnetic fraction), hydrometallurgy (acid solutions of bio hydrometallurgy) and pyro metallurgy (slag, lead cake, clinker);
4. Tailings of processing plants and enrichment plants;
5. Liquid waste (non-uranium solutions).
6. Wastes of auxiliary services and divisions.

Among these types of waste, only off-balance sheet ores are recycled over time as a charge with ordinary ore. Overburden dumps, mineralized mass and tailings from processing plants are usually stored for decades without any use, causing only negative consequences. Intermediate waste from ore processing, hydrometallurgy and pyro metallurgy is also usually stored due to the priority need for basic production.

Mineralized rock dumps, off-balance sheet ore storage and tailings dumps cover over 80% of the area of any mining project, have higher safety requirements and have a significant negative impact on the environment.

Mineralized mass is the most abundant solid waste in the mining industry. To extract ore, it is necessary to open up a large amount of waste rock, a mineralized mass. Waste rock production varies greatly from mine to mine due to the geometry of the ore body and the way it is mined. The largest volumes of mineralized mass are formed during open pit mining.

Today in the world, metals are enriched by flotation, magnetic, electric and gravity methods. In turn, a cyclone with a fluidized bed can be included in the number of devices operating on the gravity method. The advantage of the proposed apparatus is that it has a simple structure and energy-saving characteristics.

Apparatus with a fluidized bed (FB) play an important role in a wide cross-industry spectrum of technological processes, therefore, the improvement and modernization of existing, as well as the development of new highly efficient designs of FB apparatus directly corresponds to the priority direction of technological development not only of chemical technology, but also of related industries, in the first place mining and metallurgical industry. The widespread use of devices with FB has led to the development of a significant number of models describing the hydromechanics of the fluidization process. Taking into account in such models various factors that determine the kinetics of the total process or its individual stages, has led to the formation of an even wider range of models for calculating chemical technological processes (CTP) in the layer. However, the existing variety of approaches has made little progress in engineering calculation methods, which continue to rely to a large extent on balance relations and the representation of the layer as a system with lumped parameters, where the real distribution of parameters is compensated by the introduction of numerous empirical coefficients, determined experimentally on existing FB devices. This approach is not always able to provide the required forecast accuracy, especially when the structural elements of the apparatus are changed or when the operating parameters go beyond the studied range. In addition, the formulation and solution of problems of optimal control of processes is excluded, which can constitute a significant reserve for increasing the efficiency of their implementation. Various models that offer a deeper mathematical analysis of processes in the FB and, as a rule, consider the conditionally infinitesimal volume of the layer (considered representative for description) could provide answers to many questions arising during operation and design. However, these models are virtually inaccessible to engineering practice because of their complexity and computational cumbersomeness, and most importantly because they are overloaded with numerous parameters that are difficult or impossible to identify. Thus, the development of effective mathematical tools for describing processes in fluidized bed machines (FB) remains valid [2, 3].

Studies have shown the possibility of enrichment of expensive rare metals accumulated in the mining and metallurgical plants of Uzbekistan in a cyclone apparatus with a fluidized bed.

On the basis of mathematical and computer models, it is possible to determine the optimal performances of the periodic and continuous process of pneumatic separation of industrial waste in an apparatus with a FB.

METHODS. At optimizing and controlling this technological process of pneumatic separation of industrial waste in a fluidized bed, the effects of particle dispersion, the dependence of the rate of fluidization and entrainment of particles on their size and density, and also taking into account the shape of the particle, it is necessary to determine the initial velocity and velocity of entrainment of particles in the process [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16].

It is well known that the density of components in techno genic waste varies. In pneumatic separators with different structures, bulk materials (depending on density and particle size) are divided into fractions by centrifugal, gravitational and mechanical forces. Moreover, in the process of separating metals available as part of manmade waste into fractions in a cyclone with a fluidized bed, there are several additional factors affecting metal enrichment. They have an impact on determining the optimum airflow rate. These factors include the porosity of a stationary layer in a fluidized bed cyclone, hydraulic resistance, pressure drop in the device, particle shape, etc. A methodology has been developed to calculate the optimum airflow rate for the selected component using Archimedes (Ar) and Reynolds (Re) criteria, when dividing into fractions of metals of different densities (Table 1), which are available as part of techno genic waste [4]:

$$Ar = \frac{d^3 * p_y^2\, g}{\mu_y^2} * \frac{p_{\text{т}} - p_y}{p_y}. \tag{1}$$

Here: d^3 - particle diameter, m, p_y^2 - air density, kg/m^3, $p_{\text{т}}$- high density particle, kg/m^3, p_y- air density, kg/m^3, μ_y^2-dynamic viscosity, (Pa*s) is calculated at a normal temperature of 20^{o}C.

$$Re_{FB} = \frac{Ar}{1400 + 5.22\sqrt{Ar}}, \tag{2}$$

$$\omega_{FB} = \frac{Re * \mu}{d * \rho}, \tag{3}$$

$$Re_{vit} = \frac{Ar}{18 + 0.575\sqrt{Ar}}, \tag{4}$$

$$\omega_{vit} = \frac{Re_{vit} * \mu}{d * \rho}. \tag{5}$$

Techno genic waste was used to conduct the experiments and its composition is shown in Table 1.

Table 1.

№	Component name	Density of components, kg/m^3	Mass fraction, %	№	Component name	Density of components, kg/m^3	Mass fraction, %
1.	Si	2330	20	15.	Ag	10500	0.00002
2.	Al	2712	0.2	16.	Cu	8930	0,1
3.	Ca	1550	0.3	17.	Pb	11340	–
4.	Na	970	0.1	18.	As	5720	0.3
5.	K	860	0.1	19.	Bi	9800	0.003
6.	Fe	7860	8	20.	Ni	8900	0.004
7.	Mg	1740	0.1	21.	Co	8900	0.006
8.	P	1820	0.04	22.	Mo	10200	0.001
9.	Ba	3500	–	23.	W	19300	6
10.	Sr	2600	–	24.	Sn	7300	0.004
11.	Mn	7430	0.04	25.	Be	1850	–
12.	V	6110	–	26.	Zr	6490	0.01
13.	Ti	4510	0.06	27.	Ga	5900	0.003
14.	Cr	7190	0.04	28.	Ge	5300	–

The process mathematical and computer models were obtained, with the help of which the initial liquefaction and removal rates were calculated (Table 2) and diagrams of the change (nomogram) of the removal rate of particles of different density and size were obtained (Figures 1, 2, 3, 4, 5).

Table 2.

Dependence of the initial velocity and the velocity of the unit on the size and density of the particle

№	Particle size, (m)	Ag	Cu	Fe	Mn
		Initial speed, m/s			
1.	0.000041	0.00674	0.00576	0.00506	0.00478
2.	0.000046	0.00845	0.00720	0.00634	0.00600
3.	0.000057	0.01286	0.01100	0.00967	0.00915
4.	0.000064	0.01612	0.01379	0.01213	0.01147
5.	0.000072	0.02025	0.01734	0.01525	0.01443
№	Particle size, (m)	Ag	Cu	Fe	Mn
		Entrainment speed, m/s			
6.	0.000041	0.45679	0.39415	0.34876	0.33085
7.	0.000046	0.55969	0.48379	0.42866	0.40688
8.	0.000057	0.80791	0.70104	0.62305	0.59215
9.	0.000064	0.97811	0.85078	0.75757	0.72057
10.	0.000072	1.18113	1.03013	0.91924	0.89494

DISCUSSION. We concluded from the analysis of the curves for different particle densities and sizes that, in order to ensure good separation, the sample sizes taken for enrichment should be within the limits for a speed setting slightly lower than the minimum particle size of the enriched component to be carried from the fluidized bed to the cyclone. To illustrate this, in a graph of the change in the rate of entrainment from a point corresponding to the minimum particle size of the enriched component, a horizontal line is drawn until it crosses the line of lightweight component entrainment velocity. As a result of the analysis of the curves of the departure velocity of particles of different density and size, five limit (boundary) particle sizes have been determined: 0.072÷0.078 mm, 0.064÷0.070 mm, 0.057÷0.063 mm, 0.046÷0.055 mm and 0.041÷0.044 mm.

It can be seen from the plots of the entrainment rate (Fig. 1) that when Mn is enriched in a sample of industrial waste for particles in the range from 0.072 mm to 0.078 mm, it is necessary that the entrainment rate is no more than 0.89 m/s, and then heavy components (Pb, Ag, Mo, Bi, Cu, Fe, Mn, etc.) remain in the fluidized bed, and the light (Zr, V, Ti, Si, Mg, Ca) are carried away from the fluidized bed apparatus into the cyclone. In the nomogram (Fig. 1), a horizontal line drawn from a point with coordinates 0.072 mm, 0.89 m/s separates the lines of the entrainment rate of heavy and light components, i.e. this is the entrainment rate of the light components.

The first limiting particle size of crushed industrial waste is 0.078–0.072 mm. As shown in Figure 1, from the number of particles that passed through a sieve with a size of 0.078 mm, but did not pass through a sieve with a size of 0.071 mm, if the entrainment rate for the Mn component with a particle size of 0.072 mm is in the range 0.88-0.89 m/s (Table 2), then the components Zr, V, Ti, Si, Mg and Ca with a lower density and particle size - from 0.072 mm to 0.078 mm, present in the mixture, are carried away with the air flow from the apparatus with a fluidized bed into the cyclone. Thus, as shown in the nomogram, components with a higher density, such as Pb, Ag, Mo, Bi, Cu, Fe, and Mn, settle in a fluidized bed apparatus (Fig. 1).

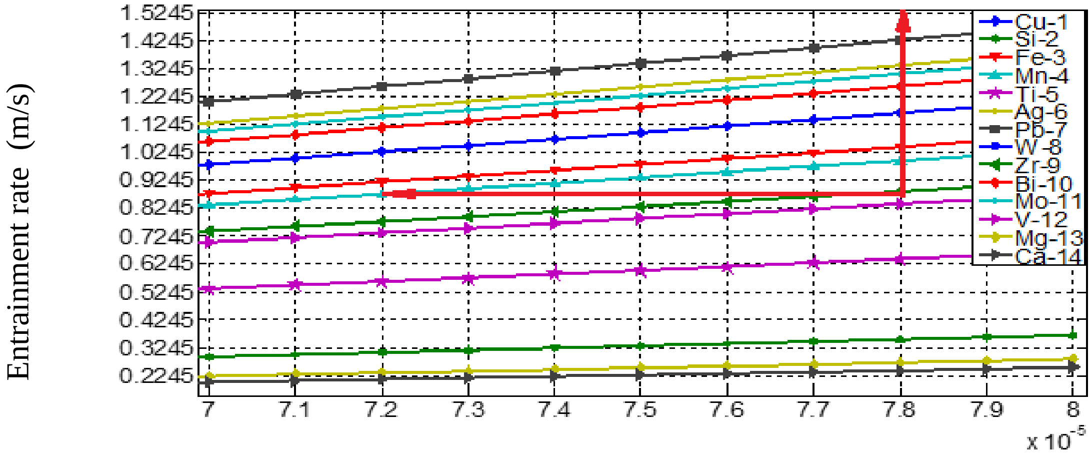


Fig.1 - Dependences of the entrainment rate on the diameter and type of particles (for the Mn component with a particle size of 0.000072 ÷ 0.000078m)

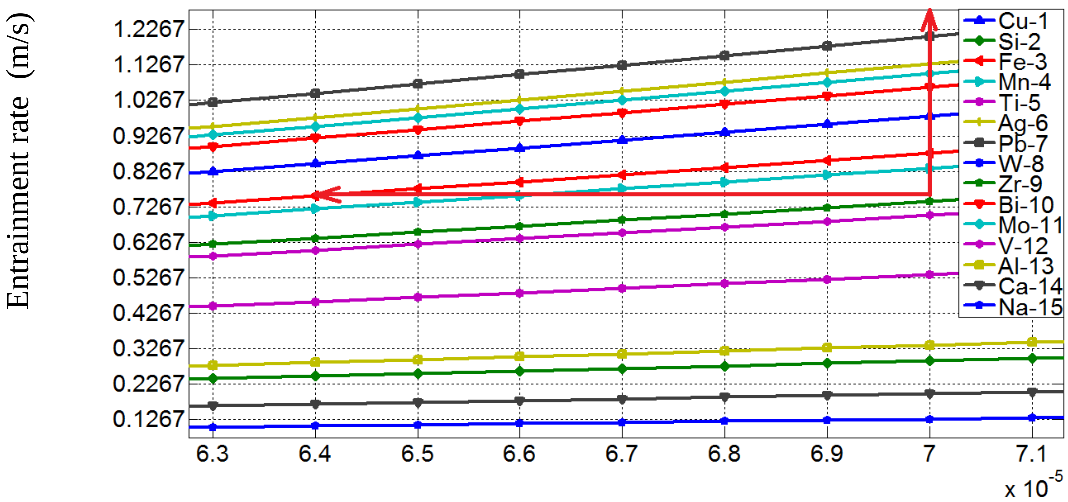


Fig.2 - Dependences of the entrainment rate on the diameter and type of particles (for the Fe component with a particle size of 0.000064 ÷ 0.000070m)

0.070-0.064 mm is chosen as the second limiting particle size. As shown in the nomogram (Fig. 2), if the entrainment rate for the Fe component with a particle size of 0.064 mm is supplied in the range of 0.74-0.75 m/s, then the components in the mixture with a lower density and a particle size of 0.064 mm up to 0.070mm (Zr, V, Ti, Si, Mg and Na) are carried away with the air flow from the fluidized bed apparatus into the cyclone. At the same time, in the apparatus with a fluidized bed (along with Fe), such components as Pb, Mg, Mo, Bi and Cu are deposited (along with Fe).

As shown in the nomogram (Fig. 3), particles with sizes from 0.057 mm to 0.063 mm, passed through a sieve with a size of 0.063 mm, but did not pass through a sieve with a size of 0.056 mm, is the third limiting particle size. If the entrainment rate for the Cu component is in the range of 0.69–0.70 m /s, then Fe with a particle size of 0.057 mm to 0.061 mm, as well as Mn, Zr, V, Ti and Si with a particle size from 0.057mm to 0.063mm are carried away with the air flow from the fluidized bed apparatus into the cyclone. Pb, Mg, Mo, Bi, Cu remain in the apparatus with a fluidized bed.

The size of the fourth limiting boundary (Fig. 4) is 0.055-0.046 mm. For particles passing through a 0.055 mm sieve but not passing through a 0.045 mm sieve, the initial particle boundary for Ag is 0.045 mm. If the entrainment rate for the Ag component is 0.44-0.45 m / s, then the components in the mixture with a particle size of 0.046 mm to 0.055 mm (Fe, Mn, Zn, Ti, Si, Mg, and Na) are carried away with air flow from the fluidized bed apparatus into the cyclone, and in the fluidized bed apparatus, Pb and Ag are deposited.

The size of the last fifth limiting boundary (Fig. 5) is 0.045-0.041 mm. For particles passing through a 0.045 mm sieve but not passing through a 0.040 mm sieve, the initial particle boundary is Mn with a particle size of 0.041 mm. If the entrainment rate for the Mn component is 0.32-0.33 m / s, then the components present in the mixture with a particle size of 0.041 mm to 0.044 mm (Mn, W, Cu, Bi Zn, Ti, Si, Mg and Na) are carried away with the air flow from the fluidized bed apparatus into the cyclone, and Pb and Ag are deposited in the fluidized bed apparatus.

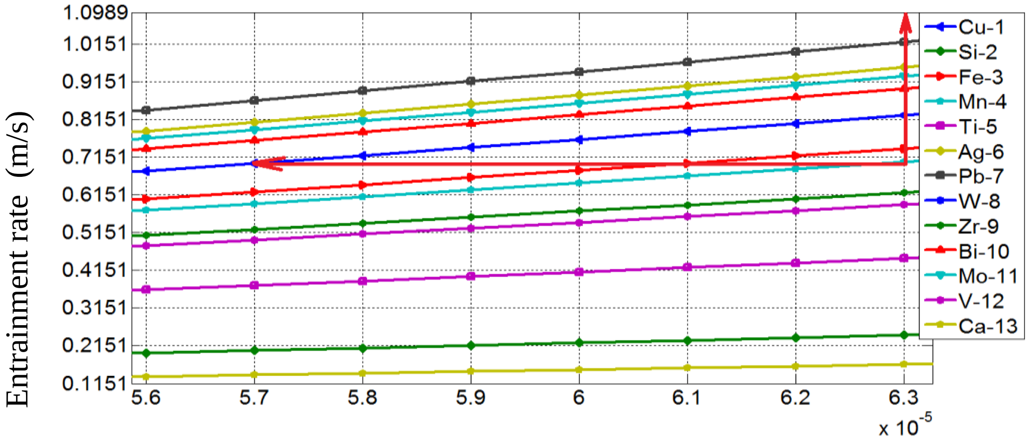
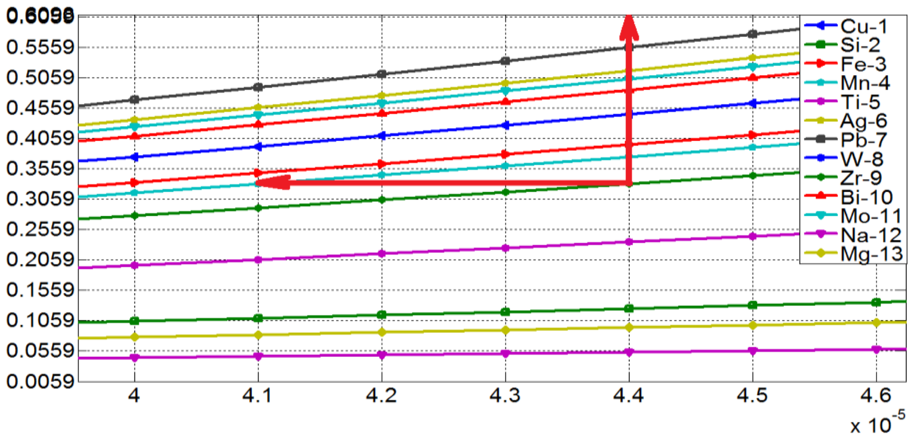


Fig.3 - Dependences of the entrainment rate on the diameter and type of particles (for the Cu component with a particle size of 0.000057 ÷ 0.000063m)



Diameter of particles, (m)

Fig. 4. Dependences of the ablation rate on the diameter and type of particles (for the Ag component with a particle size of 0.000046 ÷ 0.000055m)

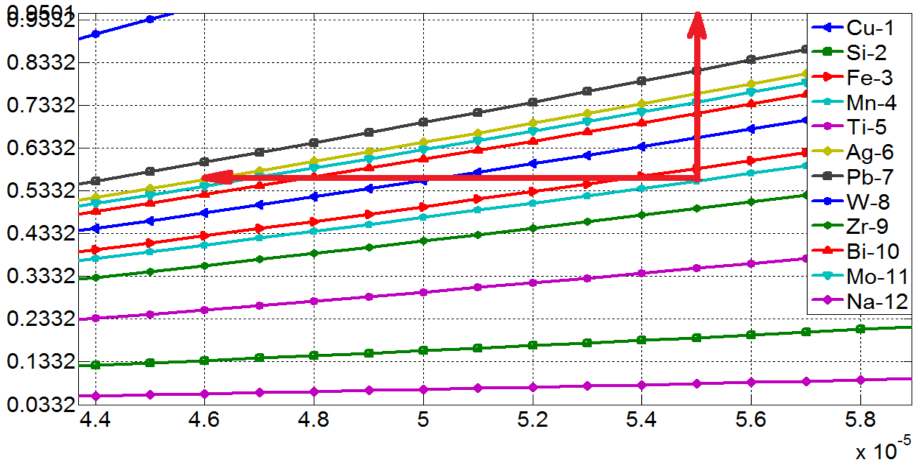


Fig. 5. The dependence of the entrainment rate on the diameter and type of particles(for the Mn component with a particle size of 0.000041 ÷ 0.000045m)

Experiments were conducted on the separation of man-made waste in a cyclone machine with a fluidized bed of three structures: cylindrical, cylindrical with one extended zone and cylindrical with two extended zones (Figures 6, 7, 8). The laboratory unit consists of a compressor 1, a rotameter 3, needle valves 2 and 4 designed to control the air flow rate supplied via grid 5 to the laboratory pneumatic separation unit 6 and a cyclone 7 connected in series to capture light particles.

The glass rotameter 3 was calibrated using a volumetric meter before the experiments were started. The air flow rate was regulated using needle valves 2 and 4.

Experiments on the improved cyclone devices with a fluidized bed have been carried out in laboratory conditions on the basis of the State Unitary Enterprise “Fan va taraqqiyot” at the Tashkent State Technical University named after I. Karimov. Quantitative emission spectral analysis has been carried out in the central laboratory of the State Committee of Mineralogy and Geology of the Republic of Uzbekistan.

For the first experiment, 100 g of technogenic waste with particle sizes ranging from 0.072 to 0.078 mm was selected. The task was to isolate high-density particles from this category of industrial waste, such as W, Pb, Ag, Cu, Fe and Mn. For example, in the nomogram (Fig. 1) and Table 2, you can find the drift rate corresponding to the Mn component. For separation from a mixture of Mn with a particle size of 0.072 mm at an entrainment rate of 0.88–89 m / s in a batch mode in an improved cyclone fluidized bed with an expanded zone (Fig. 7), heavy fractions are collected in a fluidized bed, and in a cyclone - light fractions. As a result, the mass fraction of Mn in the composition of the heavy fraction remaining in the cyclone apparatus of the fluidized bed

with an expanded zone increased from 0.04% to 0.3%. The mass fraction of Si decreased from 25% to 20%.
For the second experiment, 100 g of industrial waste with a particle size in the range from 0.064 mm to 0.070 mm was selected. To separate the Fe component with a particle size of 0.064 mm from the mixture, an entrainment rate in the range of 0.74–0.75 m / s was applied. As a result, industrial waste with a heavy fraction has accumulated in the fluidized bed. At the same time, the mass fraction of the Fe component in the heavy fraction remaining in the cyclone apparatus of the fluidized bed with an expanded zone increased from 8% to 10%, Mn - from 0.04% to 0.3%, Cu - from 0.1% up to 0.3%. The mass fraction of components in the cyclone also increased: Mn - from 0.04% to 0.06%, Na - from 0.1% to 0.2%, Ca - from 0.3% to 1%.

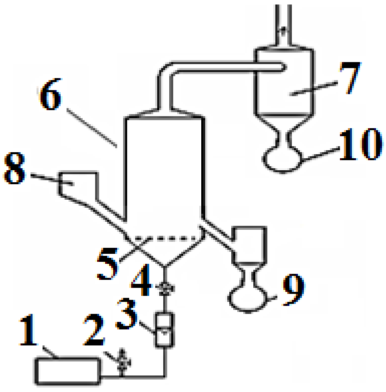


Fig. 6. Cylindrical laboratory experimental apparatus with a fluidized bed

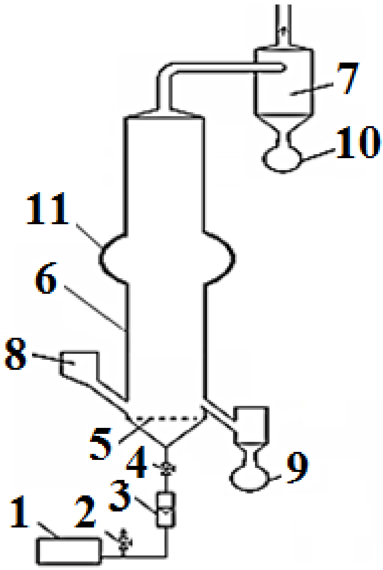


Figure 7 - Advanced laboratory experiment apparatus with one expanded zone fluidized bed

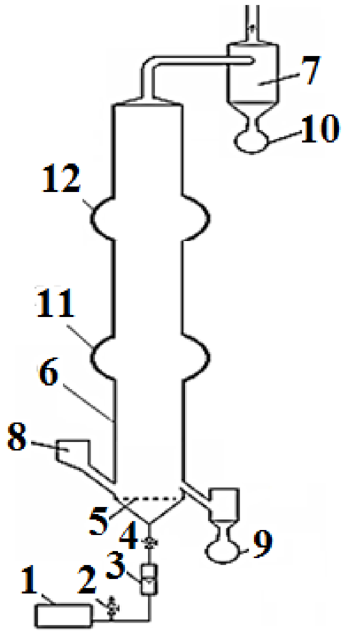


Figure 8 - Advanced laboratory experiment apparatus with two expanded zones fluidized bed

The following experiment has been also carried out on man-made waste (second sample) with a particle size of 0.056mm to 0.063mm in an improved laboratory fluidized bed experimental setup with one expanded zone. The mass fraction of Al increased from 4% to 10%, Ag - from 0.0001% to 0.0005%, Cr - from 0.004% to 0.01%, Fe - from 3% to 4%, Cu - from 0.005% to 0.008% and Sn - from 0.0001% to 0.0004%, the mass fraction of Si decreased from 25% to 20%.
To conduct the next experiment, 100 g of techno genic waste with particle size ranging from 0.057 to 0.062 mm was selected. To separate the Cu component from the mixture of man-made waste with a particle size of 0.057 mm, a removal rate in the range of 0.69-0.70 m/s was applied. As a result, man-made waste with a heavy fraction has accumulated in the fluidized bed and light fraction in the cyclone. At the same time, the mass fraction of Fe component in the heavy fraction remaining in the cyclone fluidized bed with extended zone increased from 8% to 10%, Mn - from 0.04% to 0.1%, Cu - from 0.1% to 0.3%. The mass fraction of components in a cyclone also increased: Ti - from 0.06% to 0.1%, Mg - from 0.1% to 0.2%, Ca - from 0.3% to 4%, and Si mass fraction decreased from 20% to 15%.
The next experiment was carried out with a particle size of 0.045 to 0.055 mm; to isolate the 0.045 mm Ag component, an entrainment rate in the range of 0.54–0.55 m/s was applied. As a result, technogenic waste with a heavy fraction accumulated in the fluidized bed, and light fractions in the cyclone. At the same time, the mass fraction of the Ag component in the composition of the heavy fraction remaining in the cyclone apparatus of the fluidized bed with an expanded zone increased from 0.00002% to 0.0003%, Fe - from 8% to 10%, Mn - from 0.04% up to 0.2%, Cu -

from 0.1% to 0.3% and Ti - from 0.06% to 0.1%. The mass fraction of the components in the cyclone also increased: Ti - from 0.06% to 0.1%, Mg - from 0.1% to 0.2%, Na - from 0.1% to 0.2% and the mass fraction of Si decreased from 20% to 10%.

For the next experiment, man-made waste with a particle size of 0.045 to 0.055 mm was selected. To separate the Mn component with a particle size of 0.041 mm from the mixture, an entrainment rate in the range of 0.32-0.33 m/s was applied. As a result, industrial waste with a heavy fraction has accumulated in the fluidized bed. In the remaining mass of heavy fractions, the proportion of W increased from 0.08% to 0.5%, Ag - from 0.00002% to 0.0004%, Mo - from 0.001% to 0.006%, Cu - from 0.06% to 0 , 1%, Ni - from 0.003% to 0.004%. The content of Si component remaining in the expanded zone fluidized bed apparatus decreased from 20% to 12%.

In the third sample, an experiment has been also carried out in a cyclone fluidized bed with an expanded zone with a particle size of 0.041 mm to 0.044 mm. To isolate high density components (W, Ag, Ni, Cu and Fe) from the mixture, an entrainment rate in the range of 0.44-0.45 m / s was applied, corresponding to the Ag component with a particle size of 0.041 mm. As a result, the composition of heavy fractions increased Ag - from 0.00002% to 0.0004%, Mo - from 0.001% to 0.04%, Cu - from 0.1% to 0.2%, Ni - from 0.004% to 0.5%, Fe - from 8% to 10%, Mn - from 0.04% to 0.1%, Ti - from 0.06% to 0.4%.

Experiments carried out in a laboratory pilot plant with a fluidized bed showed that the results of enrichment in plants without an expanded zone and with two expanded zones did not give good results compared to the results obtained in a plant with a single expanded zone. The best results were obtained in a fluidized bed apparatus with one expanded zone for a sample with the limiting dimensions of 0.041 ÷ 0.044 mm: the amount of Mo increased 40 times, Ag - 20 times, Mn - 2.5 times, Cu - 1 times, Ti - 6.6 times, Ni - 125 times, and the amount of Si in the selected sample decreased from 20% to 12%.

CONCLUSION. On the basis of mathematical and computer models, graphs of changes (nomograms) of the entrainment rate of particles of different densities and sizes were obtained. The possibility of determining the limiting size of particles of different sizes and densities providing good separation has been revealed. The experiments have been carried out on man-made waste with the limiting dimensions of 0.072÷0.078mm, 0.064÷0.070mm, 0.057÷0.063mm, 0.046÷0.055mm, and 0.041÷0.044mm in cyclone fluidized bed apparatus with an expanded zone. The results of the experiment on the enrichment of industrial waste with a particle size of 0.041÷0.044 mm in a cyclone fluidized bed with one expanded zone, operating in a periodic mode, showed: the mass fraction of Mo increased 40 times, Ag - 20 times, Ni - 125 times, Cu - 1 times, Mn - 2.5 times, Ti - 6.6 times, and the Si component decreased from 20% to 12%. Experimental results show the efficiency of separation of bulk materials in a cyclone fluidized bed with an expanded zone.

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