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METHODS OF CARRYING OUT FLOTATION PROCESSES

Abstract. Within the scope of work on separation of polymer waste by the flotation method, there has been made a review of methods for carrying out flotation processes and the equipment used. There have been considered the existing schemes for classification of flotation processes by objects, interfacial boundaries, design features of flotators, aeration method, technological purpose, and there has been done the analysis of the completeness of accounting for all characteristic features.

Based on the analysis done, there has been suggested the classification of flotation processes by the following types: extraction of the valuable (target) component, type of the raw material, type of devices, process mode in the apparatus, interfacial surfaces. Among the methods of flotation separation on interfacial surfaces, the phase foam flotation is most widely presented in the industry. By the method of feeding gas to the liquid, flotation is divided into pneumatic, pneumomechanical, cascade, ejector, vacuum, pressure, electrical, reagent and thermal.

Flotation devices are also proposed to be classified by type into trough (direct flow), chamber (cascade) and column (tank) ones.

When choosing the most suitable flotation method for a particular task, it is necessary to take into account all types of flotation and know the features, advantages and disadvantages of each of them. The suggested scheme for classification of flotation processes lets us systematize and characterize completely most of the existing flotation processes.

Keywords: flotation, classification, raw materials, concentrate, target component, process mode, interfacial surface, aeration, equipment.

Introduction. Flotation as a method of mineral concentration is known since the 19th century. The English inventor William Haynes was the first who patented the use of oil flotation on February 23, 1860 [1]. Flotation varies by objects, interfacial boundaries, design features of flotators, aeration method, technological purposeand other characteristics [2–5].

Recently, the flotation process on the basis of various wettability is used to sort plastics. It is very promising because of the simplicity of hardware design and reliability in operation. It can be used to separate plastics with fairly close or equal densities. This requires the presence of surfactants and gas bubbles in the working volume of the device.

The purpose of this article is to review the methods of carrying out flotation processes and the equipment used, as well as to develop the flotation process classification scheme, ensuring the completeness of accounting for all characteristic features.

Study methods. Each of the considered methods of carrying out the flotation process has its own specific features of carrying out the studies.

Study results.

In the existing literary sources, there is a description of flotation types only by separate features. In the mining encyclopedia [6] there is a flotation process classification scheme, shown in figure 1. But it also does not contain a complete list of features and is difficult for perception.

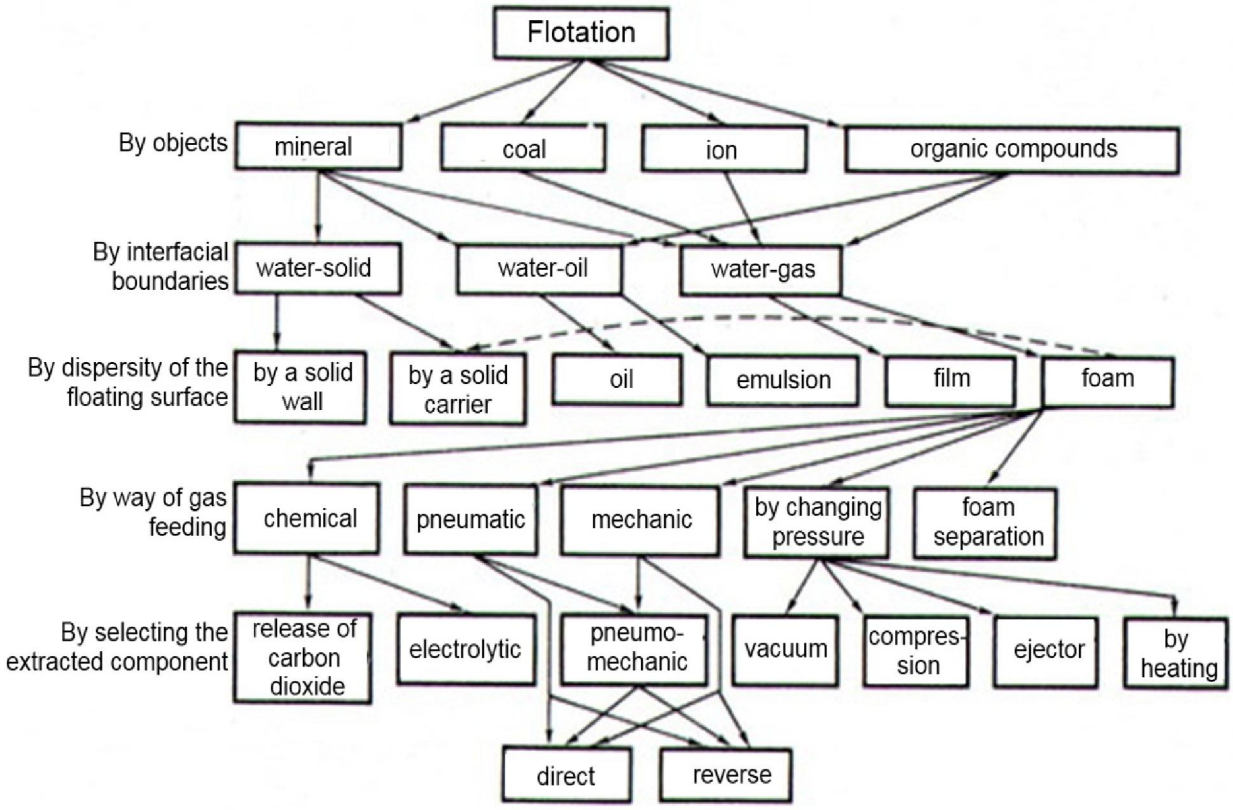

Figure 1 –Classification of flotation

Therefore, based on the literature data on flotation methods and their hardware design, the authors proposed the most complete scheme for classification of existing flotation processes, shown in figure 2.

The proposed scheme includes the following types of classification. By the extraction of a valuable (target) component, flotation can be direct or reverse; selective or collective. ***Direct*** flotation is an operation, in which the extracted useful material is concentrated in foam [7-9]. If during flotation the gangue is extracted into the foam and the concentrate is a chamber product, such flotation is called ***reverse*** [10, 11].

During the flotation of ores with obtaining several concentrates, depending on the order of separation of valuable components, there are distinguished selective and collective types of flotation. At the beginning of flotation process development, there was used only separation of gangue and target components, extracted into a collective (generic) concentrate with its following separation. Such flotation is called ***collective.*** Later on, there were developed the methods of separation into several products with the release of valuable components into various concentrates– so there appeared the ***selective*** flotation [12, 13].

Depending on the type of extracted material, flotation is divided into ***organic*** [10, 14, 15], ***mineral*** [16] and ***ion*** [17–20].

Flotation separation is carried out on the following phase interfaces:

– liquid-liquid (oil and emulsion flotation);

- liquid-gas (film and foam flotation);

– liquid-solid (coagulation and flotation with a carrier).

Oil flotation consists in different wetting of separated particles by immiscible liquids, dispersed in water in the form of small drops [15]. As a result, there are formed "particle – oil" complexes, floating to the surface. In Mariupol (1904) such a process was applied for the purpose of graphite ore concentration. Subsequently, this method was improved: the oil was dispersed to ***an emulsion***, which made it possible to extract fine tailings [21].

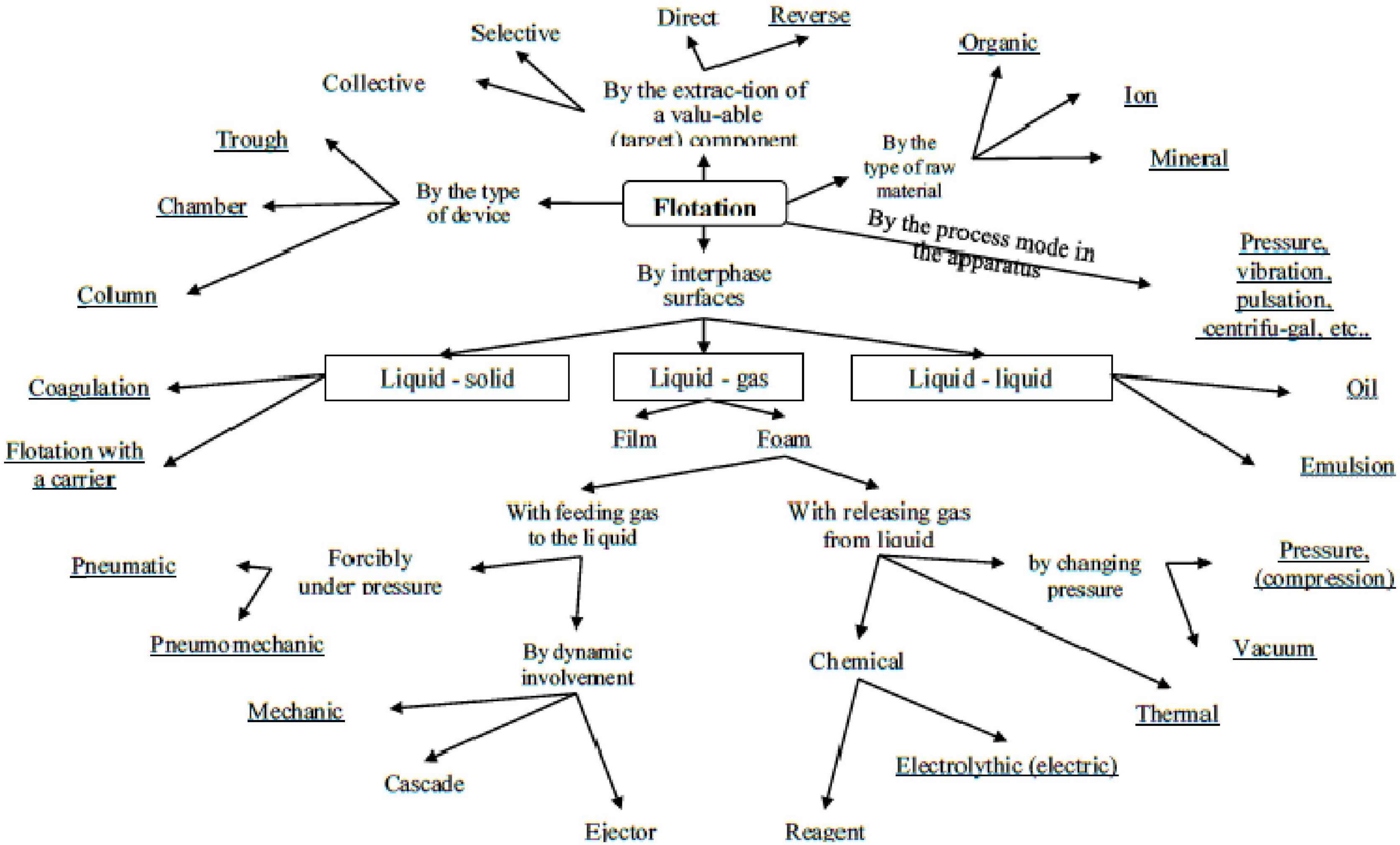

Figure 2 – Classification of flotation

During ***film*** flotation, the separated particles are poured from a certain height to the surface of the working fluid [22-25]. Non-wetted particles are kept on its surface and separated as a concentrate, while those wetted with water – sink and get into another product.

Oil and film flotation have low efficiency. Foam flotation is most widely presented in the industry.

Foam flotation is carried out in a three–phase medium "particles –liquid-gas", which contains flotation reagents. The flotation principle is as follows. In an aqueous medium, the gas bubble and the particle's hydrophobic surface, the adhesion (adherence) of which to liquid is less than the cohesion (repulsion) of liquid, come together. The water layer, separating them, reaches a certain thickness, at which it becomes unstable and spontaneously breaks. Then the particle and the bubble stick together. Due to the fact that the density of "bubble-particle" complexes is less than the density of liquid, they float to its surface and form a foam product that is withdrawn from the flotation machine. Wetted particles do not adhere to the bubbles, remaining in the volume of liquid, or settle to the bottom [26, 27]. This method was first patented by brothers Arthur and Adolf Bessel (Germany, 1877).) [28].

The foam layer can be formed in two ways - when feeding gas to the liquid or when gas being released from the liquid. Gas is fed to the liquid either forcedly under pressure (pneumatic and pneumomechanical flotation), or with dynamic involvement (mechanical, cascade, ejector flotation).

By the method of feeding gas to the liquid, as a defining feature of classification of flotation machines, there are distinguished the following methods of flotation [4]:

– ***pneumatic*** – flotation by gas bubbles, appearing, when gas is passed through porous aerators (branch pipes, filters, porous plates, caps, etc.)[29, 30];

– ***pneumomechanical*** – flotation by bubbles, formed during dispersion of the compressed gas, fed by mechanical agitators [31];

– ***mechanical*** – flotation by bubbles, drawn into the liquid from atmosphere, with intensive mixing of liquid by various agitators [31, 32, 33];

– ***cascade*** – flotation by bubbles, drawn into liquid from atmosphere as a result of the jet of the same liquid, falling into it from a certain height [34];

– ***ejector***– flotation by bubbles, drawn into liquid from atmosphere as a result of the flow of a jet of the same liquid at a high speed in a tube with a narrowing and air access gap [35, 36, 37].

Gas is separated from the liquid thermally, chemically (reagent or electroflotation) and by changing the pressure (pressure, vacuum):

– ***vacuum*** – flotation by gas bubbles, dissolved in the liquid, which are released under vacuum [38, 39];

– ***pressure*** (compression) – flotation by bubbles, released at atmospheric pressure from oversaturated under pressure solutions of gases in the liquid [40, 41];

– ***electroflotation*** – flotation by bubbles, arising in electrolysis, usually on the cathode [42, 43];

– ***reagent*** – flotation by bubbles, which are obtained as a result of the influence of acids or alkalis on the liquid;

– ***thermal*** – flotation by bubbles, released from the liquid as a result of its heating above the boiling point of the liquid, oversaturated with gas.

Reagent and thermal methods of flotation are very expensive and recently do not find a wide practical application. There are also combined methods of flotation, in which the liquid is aerated in several ways [44–46].

In machines of ***mechanical***type, air from the atmosphere is sucked due to the mechanical action of the mixer-aerator blades on the pulp. Strong mixing in the chamber creates the pulp turbulent flows in it. The pulp has a horizontal circular motion around the impeller shaft and a vertical circulation. Large air bubbles, trapped in the working fluid, are broken by a stirrer and pulp flows into small bubbles. Mechanical floatation is characterized by a variability of air suction with time, high power consumption, strong agitation of the pulp.

The specific feature of ***pneumomechanical*** flotation devices is that in such devices the impeller rotates only to hold the particles in suspended state and to disperse the air, supplied to the device from the blower, which makes it possible, in comparison with mechanical flotation devices, to ensure constant air flow in the device regardless of the wear of aerators. With this method, strong mixing of the pulp is carried out too.

Pneumatic flotation is characterized by the design simplicity, low cost (no impellers, pumps are needed). However, it is characterized by frequent clogging of aerator holes, the difficulty of uniform aeration. The efficiency of pneumatic flotation depends on the holes and material of the aerator, pressure and air flow, duration of the process, depth of liquid in the apparatus [47]. The low efficiency of separation is determined by the fact that when air is supplied through aerators, there are appearing large bubbles (1–3 mm) [48]. However, currently there are developed the aerators, providing a fine aeration (up to 0.3 mm). With such aerators there are equipped modern flotation devices with pneumatic aeration [49], and their use in pneumatic flotators increases the efficiency.

Gas separation from the solution with changing the pressure is applied for liquids that contain very small particles. This possibility was grounded by Klassen [50]. In this case, bubbles appear on the surface of the particles. This is done, in accordance with Henry's law, by reducing the solubility of gas in liquids with a decrease in pressure. The essence of the method is in formation of an oversaturated gas solution in the liquid. When pressure is released, from the solution there begin to separate the gas bubbles, which float hydrophobic particles. There are distinguished vacuum and pressure types of flotation.

By the method of ***vacuum*** flotation, the liquid under atmospheric pressure is saturated with air in the aeration chamber, and then transferred to the flotation unit, where the vacuum pump maintains the vacuum of 30-40 kPa. The bubbles released in this case float part of the dispersed particles to the surface. The advantages of vacuum flotation are that the process is carried out in a still medium, the possibility of destruction of flotation complexes is minimal and energy costs are low. The disadvantages of vacuum flotation include a limited by small pressure difference amount of liquid saturation with gas. This limits its application to separation of suspended particles with a concentration of up to 0.3 kg/m^3. One more disadvantage of vacuum flotation is the presence of sealed reservoirs with scraper mechanisms, which causes certain structural and operational difficulties.

Pressure flotation devices are more common than vacuum ones. Pressure flotation makes it possible to separate the material with a concentration of suspensions in liquid up to 5 kg/m^3. They are simple and reliable in operation. The saturation of liquid with gas occurs at elevated pressures in pressure tanks. The flotation unit operates at atmospheric pressure in this case. The solubility of gas in it decreases, and in the entire volume there are released the bubbles, which collide with the particles and float them.

Electroflotation is a process of separation of particles, suspended in liquid, by gas bubbles of hydrogen and oxygen, released during electrolysis. This method has distinctive features, which at the same time are its advantages. During electrolysis the finely dispersed gases are released [51, 52]. The bubbles of electrolysis gases are the same in size, they are little inclined to coalescence and during their residence in liquid they retain their diameters.

Electroflotation is a complex hydro-mechanical and electrochemical process. The speed and efficiency of this process is significantly influenced by the density of the electric current. The most serious drawback of the electroflotation separation method is that as electricity passes through the liquid, salt deposits occur on the electrodes, which can provoke a complete stop of the process. The electrodes work more effectively in an acidic medium. Uneven gas release on the electrodes leads to the concentration of bubbles in certain areas of the flotation device. Because of this, it produces the undesirable circulation of liquid [53, 54].

The process of electro-flotation, apparently, will not receive widespread adoption in large-tonnage production. This is primarily due to the low performance of electric flotators, as well as their instability, caused by the latch-up of the interelectrode area [55, 56].

Flotation devices are also classified by type to trough (direct-flow), chamber (cascade) and column (tank).

Flotation devices of a ***trough*** type have a form of a bath, stretched in length. The working fluid is supplied from one side and goes out on the other side together with the sludge. The foam is taken along the entire length through the side boards into the troughs (usually by gravity). The height of the working fluid is regulated by the intensity of discharge.

Chamber [57] flotation devices consist of separate chambers, with one or more aerators used in each of them. Among the features of chamber machines there are: the need to adjust the height of the working fluid in each chamber; lowering the level of the working fluid along the machine, due to which in each chamber there are different heights of foam threshold and foam scraper blades.

Flotation apparatuses of ***column*** type [2, 58-81] are vertical tanks of different sections (round, elliptical or rectangular). The foam product is removed from the top and the sediment - from the bottom of the column. Power is supplied most often to the middle part of the column.

Flotation in the column apparatus is carried out with the counter-current movement of the bubbles and the working fluid. The liquid is discharged through the discharge pipe at the bottom of the column, and bubbles float towards it. On the surface of liquid they form the foam, which is withdrawn at the top of the column. The speed of the working fluid should be less than the relative speed (float) of the bubbles. The high velocity of liquid can result in the accumulation of bubbles, their coalescence and the release of gas locks.

The flotation column is smaller in size than other flotation units of the same capacity; it is generally free of moving parts, which reduces the energy consumption and maintenance costs. The main difficulties, arising during the operation of column apparatus are associated with clogging of aerators [81].

Chamber machines can be of mechanical and pneumomechanical types, trough machines – of any other types, column machines - of a pneumatic type only.

The mode of motion of bubbles and particles is a significant factor, affecting the possibility of flotation complex formation, flotation intensity and energy consumption of the process. The probability of collision of a bubble and a particle, as well as the formation of a flotation complex depends on the relative speed of their movement, the duration of contact and the forces of inertia. By the mode of movement of phases in the machine, flotation is also divided into numerous types: pressure, vibration, pulsation, centrifugal, etc. In this work we'll consider only those modes of movement of phases, which are most commonly found in the basic designs of flotation machines.

In mechanical and pneumomechanical machines the nature of liquid and solid phases' motion is similar to perfect mixing. This is necessary to maintain the suspension in a suspended state, to disperse the bubbles and increase the time they stay in the working volume of the apparatus. However, intensive mixing can cause the destruction of the bubble – particle complex due to the inertia forces, especially during the flotation of large particles [2]. In addition, the use of the impeller reduces the efficiency of the flotation unit, since a significant part of the energy is used to maintain the working medium in a suspended state, which is not directly related to the flotation process.

The counter-flow of the working fluid and bubbles in the column apparatus reduces the speed of the constrained (group) motion of bubbles, which increases their residence time in the working fluid, the efficiency of gas use and the specific productivity of the flotator. In the column, the forces of inertia are insignificant due to the absence of mechanical devices and low turbulence of flows.

As it can be seen from the listed types, flotation is a complex and multi-faceted process. When choosing the most suitable method of flotation for a particular task, it is necessary to take into account all types of flotation and know the features, advantages and disadvantages of each of them. The suggested scheme for classification of flotation methods lets us systematize and characterize completely most of the existing flotation processes.

Conclusions. There have been made a review and analysis of methods for carrying out flotation processes and the equipment used. The existing schemes of classification of flotation processes do not contain a complete list of features and are difficult for perception.

There has been suggested the classification of flotation processes, the main components of which are the methods of extraction of a valuable (target) component, the type of raw materials, the type of devices used, the process modes in the apparatus, the interfacial surfaces used. The suggested scheme for classification of flotation methods lets us systematize and characterize completely most of the existing flotation processes.

Foam flotation is noted as a method, most widely used in the industry. There have been considered the designs of flotation machines.

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ФЛОТАЦИЯЛЫҚПРОЦЕССТЕРДІЖҮРГІЗУӘДІСТЕРІ

Аннотация. Флотация арқылы полимерлік қалдықтарды бөліп шығару бойынша жұмыстардың шеңберінде флотациялық үрдістерді және қолданылатын жабдықты жүргізу әдістеріне шолу жасалды. Нысандар, фазааралық шекара, флотаторлардың конструктивті белгілері, аэрациялау тәсілдері, технологиялық тағайындалулары бойынша қолданыстағы флотациялау процесстерінің классификациялық сұлбасы қарастырылды және оларға тән барлық белгілерді есепке алынып талданды.

Жүргізілген талдаудан кейін флотация процестерін келесі типтер бойынша жіктеу ұсынылады: бағалы (мақсатты) компонентті алу бойынша, шикізат түрі бойынша, құрылғылардың түрі бойынша, аппараттардағы процестің бойынша, фазааралық беттер бойынша. Фазаларды беттік бойымен бөлумен флотационды бөлу әдістерінің ішінде көбікті флотация өнеркәсіпте кеңінен ұсынылған. Газды сұйықтыққа беру тәсілі бойынша флотация пневматикалық, пневмомеханикалық, каскадты, эжекторлы, вакуумды, қысымды, электрофлотациялық, реагентті және термиялық болып бөлінеді.

Флотациялық аппараттар типі бойынша жіктелу (тік сызық), камералы (каскад), баған (шанда) бойынша ұсынылады.

Белгілі бір тапсырма үшін флотацияның ең қолайлы әдісін таңдағанда, флотацияның барлық түрлерін ескеріп, әрқайсысының ерекшеліктерін, артықшылықтарын және кемшіліктерін білу қажет. Флотациялық әдістерді жіктеудің ұсынылған сұлбасы қолданыстағы флотация процестерінің көпшілігін жүйелеуге және сипаттауға мүмкіндік береді.

Түйін сөздер: флотация, классификация, шикізат, концентрат, мақсатты компонент, процесс тәртібі, фазааралық бет, аэрация, жабдық.

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МЕТОДЫ ПРОВЕДЕНИЯ ФЛОТАЦИОННЫХ ПРОЦЕССОВ

Аннотация. В рамках проведения работы по разделению полимерных отходов методом флотации проведен обзор методов проведения флотационных процессов и применяемого оборудования. Рассмотрены существующие схемы классификации процессов флотации по объектам, межфазным границам, конструктивным признакам флотаторов, способу аэрации, технологическому назначениюи выполнен анализ полноты учета всех характерных признаков.

Исходя из проведенного анализа, предложена классификация процессов флотации по следующим типам: по извлечению ценного (целевого) компонента, по виду сырья, по типу устройств, по режиму процесса в аппарате, по межфазным поверхностям. Среди методов флотационного разделения на поверхностях раздела фазпенная флотация наиболее широко представлена в промышленности.По способу подачи газа в жидкость флотация подразделяется на пневматическую, пневмомеханическую, каскадную, эжекторную, вакуумную, напорную, электрофлотацию, реагентную и термическую.

Флотационные аппараты предложено также классифицировать по типу накорытные (прямоточные),камерные (каскадные),колонные (чановые).

При выборе наиболее подходящего способа флотации для той или иной задачи необходимо учитывать все типы флотации и знать особенности, достоинства и недостатки каждого из них. Предлагаемая схемаклассификации методов флотации позволяет полностью систематизировать и охарактеризовать большинство существующих процессов флотации.

Ключевые слова: флотация, классификация, сырье, концентрат, целевой компонент, режим процесса, межфазная поверхность, аэрация, оборудование.

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