N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES CHEMISTRY AND TECHNOLOGY
ISSN 2224-5286 **https://doi.org/10.32014/2020.2518-1491.41**
Volume 3, Number 441 (2020), 36 – 43

UDC 502.174.1

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STUDY OF THE EFFECT OF AIR CONSUMPTION, LIQUID LAYER HEIGHT AND TEMPERATURE ON THE PROCESS OF FLOTATION SEPARATION OF GROUND PLASTICS

Abstract. For separation of plastic wastes (polyamide (PA), acrylonitrile butadiene styrene (ABS) and polystyrene (PS)), a flotation method is proposed. Using this method, the effect of air consumption, liquid layer height and temperature were studied. As surface-active substances (surfactants), polidocanol, sulphanole and a mixture of surfactants containing sodium laureth sulfate and diethanolamide were used.

To analyze the research results of flotation separation of a mixture of ground plastic wastes, the extraction of the floating component ε and the purity of the concentrate β were calculated.

The research results on the extraction of polystyrene from the air consumption at various concentrations of a mixture of surfactants show that the extraction has a maximum at a certain air consumption. At low air consumption, the process is inefficient, since the working volume of the liquid is not saturated enough with gas bubbles. If the optimum value of air consumption is exceeded, many gas bubbles are formed that are not involved in the flotation process. Such bubbles, moving through a liquid, can create turbulent flows that impede flotation of particles. When moving in a turbulent liquid flow, the bubble-particle complex is prone to destruction, as particles and bubbles have different inertia (mass). In addition, it may be concluded that the air consumption value at which the maximum extraction of the floating component is achieved depends on the type of polymer and surfactant. The air consumption effect nature at different concentrations of surfactants is not changed – only the floating component extraction changes.

The research results on the extraction of polystyrene from the aerated liquid layer height at various concentrations of a mixture of surfactants indicate that at a low height of the aerated liquid layer the probability of collision of a plastic particle with an air bubble is low and some potentially floating particles sink to the bottom of the device, without having time to collide with an air bubble. The optimum height of the processed liquid layer corresponds to a certain air consumption. When the liquid layer height is less than optimal, the achievement of the required extraction degree of the dispersed phase is possible, for example, with an increase in air consumption.

When assessing the effect of liquid temperature on the flotation process, it was found that increasing the liquid temperature above 20°C leads to a sharp decrease in the ABS and PS extraction. This is possibly due to the fact that the dependence of the foaming capacity of surfactants on temperature is characterized by solubility curves and for most surfactants they have an extremum. Probably, an increase in the solution temperature leads to the dehydration of the dissolved surfactant molecules. Moreover, they separate as an independent macrophase, which leads to a decrease in the number of surfactant molecules involved in the flotation process.

Key words: flotation, plastic wastes, surfactants, concentration, air consumption, liquid layer height, temperature.

Introduction. In the world there is a constant increase in the consumption of polymer materials (PM) [1, 2], which occupy a leading position in terms of production of raw materials.

The accelerated growth in the production of polymer materials and the expansion of their applications in various industries is explained by their manufacturability, ease, convenience, cost-effectiveness, safety, a set of valuable operational properties and high aesthetics. Plastics are serious competitors to glass, ceramics and metal [3].

At the same time, the use of products from polymer materials certainly causes waste formation. The increase in PM production and consumption inevitably entails an increase in the amount of their wastes.

In recent years, the problem of processing plastic wastes has become to take an important place in the world, since the bulk of wastes is destroyed by inefficient methods [4-8].

Promising processes for the PM separation are flotation based on different wettability, since they are quite simple in hardware and reliable. The flotation process is close to the sedimentation process in flotation baths, which is widely used in the world. The flotation process may allow to separate plastics with fairly similar or equal densities. This requires the presence of surfactants and gas bubbles in the working volume of the device [9, 11].

Research methods. The methodology for experimental research of the flotation process of separation of plastics is as follows. It is necessary to prepare in advance a charge of the investigated ground plastics with a mass $m_{исх}$. Due to the complexity of further manual sorting of the concentrate in a multilateral research of the flotation process, it is recommended to feed a charge of a mixture of ground plastics weighing about 10 g. In a laboratory setup, it is possible to study the dependences of the extraction of certain types of plastics on physical and operational factors, while the charge with a mass $m_{исх}$ containing one type of ground plastic is fed to the flotation. It is also possible to study the separation of a mixture of several types of ground plastics. In the second case, the charge with a mass $m_{исх}$ should contain particles of ground hydrophobic plastic with a mass $m_{исх}^{фл}$ and particles of ground hydrophilic plastic with a mass $m_{исх}^{ос}$. When studying the separation of plastics, it is recommended to feed a mixture of plastics to the flotation in a 1:1 ratio.

Research results. In [12], the authors presented the research results of the effect of the concentration of surface-active substances (surfactants) on the process of separation of plastic wastes. The tables with experimental data presented in this work contain the results obtained by changing the air consumption, the liquid layer height and its temperature. When conducting the research, the plastic wastes were polyamide, acrylonitrile butadiene styrene and polystyrene. As surface-active substances, polidocanol, sulphanole and a mixture of surfactants containing sodium laureth sulfate and diethanolamide were used [13-15].

To analyze the research results of the flotation separation of a mixture of ground plastic wastes, the extraction of the floating component ε and the purity of the concentrate β were calculated by the formulas [16]:

$$\varepsilon = \frac{m_{конц}^{фл}}{m_{исх}^{фл}} \cdot 100\%, \qquad (4.1)$$

$$\beta = \frac{m_{конц}^{фл}}{m_{конц}} \cdot 100\%, \qquad (4.2)$$

where $m_{конц}^{фл}$ – a mass of the floating component (the particles of the ground hydrophilic plastic in the concentrate, kg; $m_{исх}^{фл}$ – a mass of the floating component (the particles of the ground hydrophilic plastic in the initial charge, kg; $m_{конц}$ – a mass of the concentrate, kg.

According to the calculation results of the extraction of the floating component ε and the purity of the concentrate β from the air consumption during the flotation separation of the mixture of the ground polyamide and acrylonitrile butadiene styrene using various surfactants, the dependences were obtained which are shown in figures 1-3.

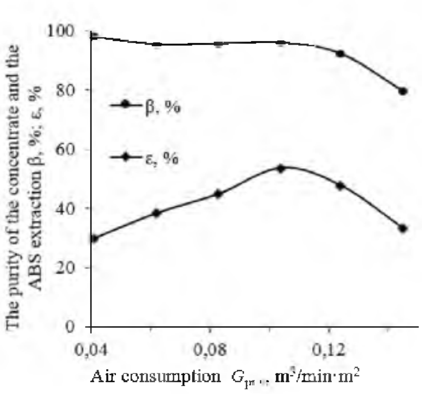

Figure 1 - Dependences of the purity of the concentrate and the ABS extraction from the air consumption at the concentration of sulphanole 11.56 · 10^{-3} kg/m^3

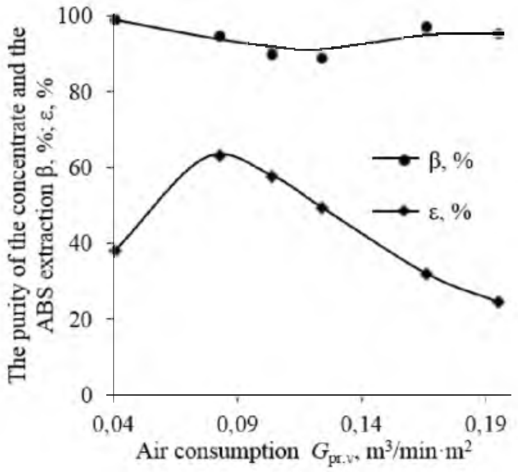

Figure 2 - Dependences of the purity of the concentrate and the ABS extraction from the air consumption at the concentration of polidocanol $8.89 \cdot 10^{-3}$ kg/m³

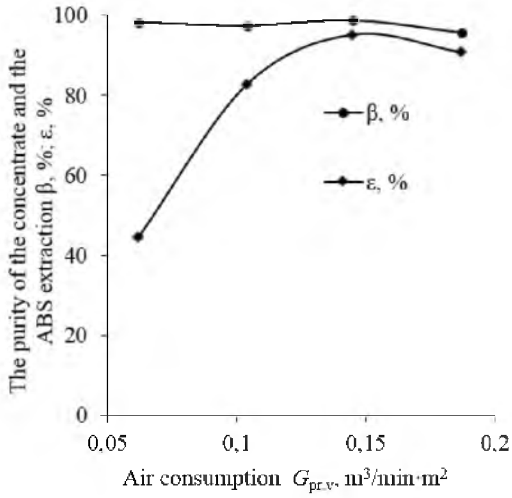

Figure 3 – Dependences of the purity of the concentrate and the ABS extraction from the air consumption at the concentration of the mixture of surfactants $2.7 \cdot 10^{-3}$ kg/m³

Further, according to the results given in [12], the dependences of the PS extraction on the air consumption are presented, obtained at the concentration of the mixture of surfactants of $5.41 \cdot 10^{-3}$ and $16.22 \cdot 10^{-3}$ kg/m³ (figure 4.).

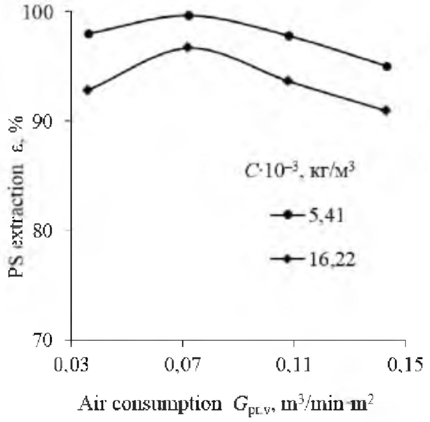

Figure 4 - Dependences of the PS extraction on the air consumption at various concentrations of the mixture of surfactants

As is seen from figures 1-4, the extraction has a maximum at a certain air consumption. The presence of the maximum extraction of the floating component in these figures suggests a characteristic effect of the air consumption on the flotation process of polymers. At low air consumptions, the process is inefficient, since the working volume of the liquid is not saturated enough with gas bubbles. If the optimum value of the air consumption is exceeded, many gas bubbles are formed that are not involved in the flotation process. Such bubbles, moving through a liquid, can create turbulent flows that impede the flotation of particles. When moving in the turbulent liquid flow, the bubble-particle complex is prone to destruction, as particles and bubbles have different inertia (mass) [17].

Also, from the above dependences, it may be concluded that the air consumption value at which the maximum extraction of the floating component is achieved depends on the type of polymer and surfactant. The air consumption effect nature at different concentrations of surfactants is not changed – only the floating component extraction changes.

When using polidocanol, the maximum extraction of ABS is 17% higher than when using sulphanole, and reaches 70.5%. However, the purity of the concentrate in this case is reduced by 2.5%, namely, to 93.5% [18]. When using the mixture of surfactants containing sodium laureth sulfate and diethanolamide, the ABS extraction reaches 95%, and the purity of the concentrate is 98.7%. And when using the same mixture of surfactants during the PS flotation, its extraction reaches 99%.

To determine the optimal height of the aerated working liquid layer from the experimental data presented in [12], the dependences of the PS extraction on the concentration of surfactants were determined at different heights of the aerated liquid layer, which are shown in figure 5.

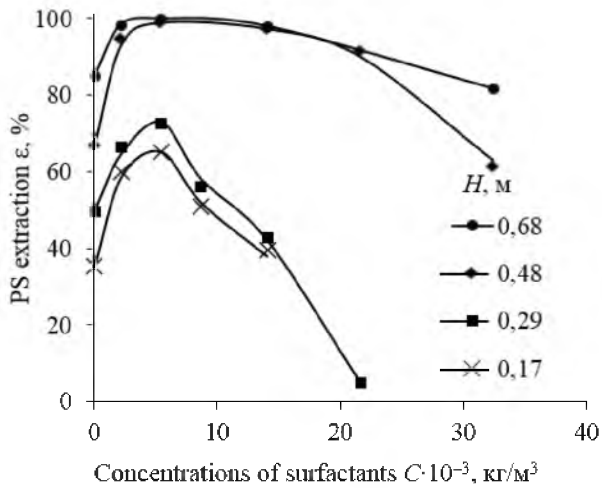

Figure 5 - Dependences of the PS extraction on the concentrations of surfactants at various heights of the aerated liquid layer

As is seen from figure 5, the PS extraction has a maximum at a low concentration of surfactants, namely $5.41 \cdot 10^{-3}$ kg/m^3, and reaches 99% with a sufficient height of the aerated liquid layer.

At a low height of the aerated liquid layer, the probability of collision of a plastic particle with an air bubble is low and some potentially floating particles sink to the bottom of the device, without having time to collide with an air bubble. The optimum height of the processed liquid layer $H_о$ corresponds to a certain air consumption. When the liquid layer height is less than optimal ($H_ж < H_о$) the achievement of the required extraction degree of the dispersed phase is possible, for example, with an increase in the air consumption [19].

In order to more clearly display the effect of the aerated liquid layer height on the PS extraction, the corresponding dependences were obtained at the concentration of surfactants of $2.16 \cdot 10^{-3}$ and $5.41 \cdot 10^{-3}$ kg/m^3, shown in figure 6.

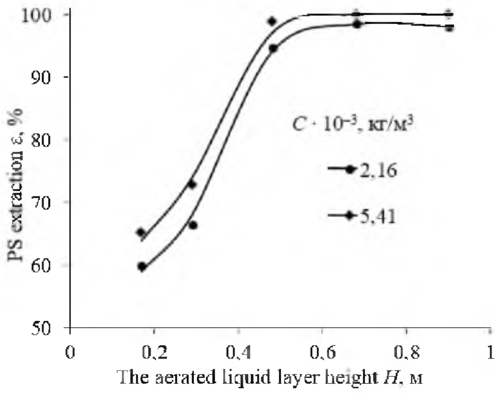

Figure 6 - Dependences of the PS extraction on the aerated liquid layer height at various concentrations of surfactants

As is seen from figure 6, a sufficient height of the aerated liquid layer is 0.5-0.6 m, its further increase does not have a strong effect on the PS extraction. Exceeding the optimum height of the aerated liquid layer leads to an increase in the material consumption of the device and an increased consumption of the working liquid and surfactant, as well as to an increase in the length of the movement of the bubble-particle complexes, which can increase the probability of their destruction [19].

The graphical dependences given above, as well as in [12], were obtained without additional heating of the working liquid (about 10-15°C). In assessing the effect of the liquid temperature on the flotation process, the experimental research was conducted, the results of which are reflected in [12]. After processing the results of this experimental research, the dependences of the ABS and PS flotation indices on the liquid temperature *t* were plotted, shown in figure 7, 8.

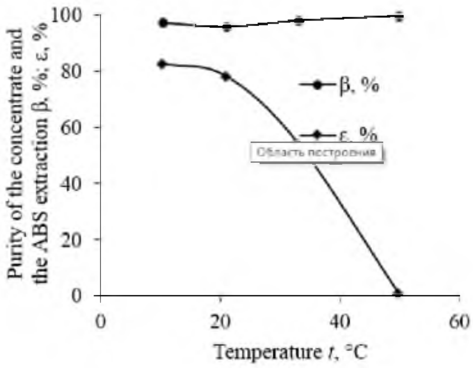

Figure 7 - Dependences of the purity of the concentrate and the ABS extraction on the liquid temperature at the concentration of the mixture of surfactants, containing sodium laureth sulfate and diethanolamide, $2.7 \cdot 10^{-3}$ kg/m^3 and at the air consumption of 0.104 m^3/min·m^2

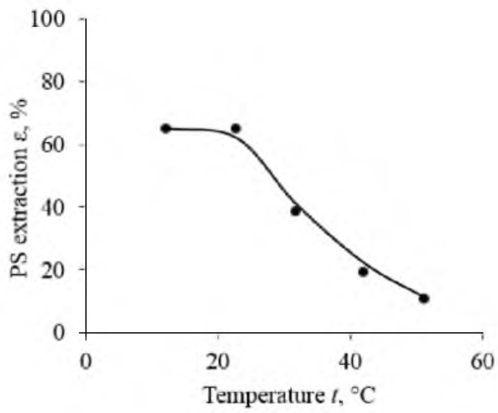

Figure 8 – Dependence of the PS extraction on the liquid temperature at the aerated liquid layer height of 0.17 m, the concentration of the mixture of surfactants of $5.41 \cdot 10^{-3}$ kg/m^3 and the air consumption of 0.072 m^3/h·m^2

As is seen from figures 7 and 8, an increase in the liquid temperature above 20°C leads to a sharp decrease in the ABS and PS extraction. It should be noted that in Figures 7 and 8 there is a pattern of the liquid temperature effect on the extraction of floating components. This is possibly due to the fact that the dependence of the foaming capacity of surfactants on the temperature is characterized by the solubility curves and for most surfactants they have an extremum [20, 21]. Probably, an increase in the solution temperature leads to the dehydration of the dissolved surfactant molecules. Moreover, they separate as an independent macrophase, which leads to a decrease in the number of surfactant molecules involved in the flotation process.

Conclusions. For separation of plastic wastes (polyamide, acrylonitrile butadiene styrene and polystyrene), the flotation method is proposed using surfactants (polidocanol, sulphanole and the mixture of surfactants containing sodium laureth sulfate and diethanolamide). When conducting this method, the effect of the air consumption, the liquid layer height and the temperature were studied.

The research results on the extraction of the floating component from the air consumption show that its maximum extraction depends on the type of polymer and surfactant. The air consumption effect nature at different concentrations of surfactants is not changed – only the floating component extraction changes.

The research results on the extraction of the floating component from the aerated liquid layer height show that the optimum height of the processed liquid layer corresponds to a certain air consumption, and when the liquid layer height is less than optimal, the achievement of the required extraction degree of the dispersed phase is possible, for example, with an increase in the air consumption.

When assessing the effect of the liquid temperature on the flotation process, it was found that increasing the liquid temperature above 20°C leads to the sharp decrease in the ABS and PS extraction. This is due to the fact that the dependence of the foaming capacity of surfactants on the temperature is characterized by the solubility curves and for most surfactants they have an extremum.

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Ұсақталған пластмассаларды флотациялық бөлу үдерісінің ауа шығыны, сұйықтық қабатыныц биіктігі және температура әсерін зерттеу

Аннотация. Пластмасса қалдықтарын бөлу үшін (полиамид (ПА), акрилонитрилбутадиенстирол (АБС) және полистирол (ПС) флотациялық әдіс ұсынылды. Аталған әдісті қолдану арқылы ауа шығыны, сұйықтық қабатының биіктігі және температураның әсері зерттелді. Беттік-белсенді заттар (ПБЗ) ретінде синтанол, сульфанол және құрамында натрий лауретсульфаты және диэтаноламид бар ПБЗ қоспасы қолданылды.

Пластмассаның ұсақталған қалдықтары қоспасының флотациялық бөлінуін зерттеу нәтижелерін талдау үшін флотацияланатын компонентті бөлу және β коннцентратының тазалығы есептелді.

ПБЗ қоспасының әр түрлі коннцентрациясы кезінде полистиролды ауа шығынынан бөліп алу зерттеулерінің нәтижелері ауаның кейбір шығынында ең көп шығарылу бар екенін көрсетеді. Ауаның аз шығынында процесс тиімсіз өтеді, өйткені сұйықтықтың жұмыс көлемі газ көпіршіктерімен жеткіліксіз қанығады. Ауа шығысының оңтайлы мәнінен асқан кезде флотация процесіне қатыспайтын көп газ көпіршіктері пайда болады. Мұндай көпіршіктер сұйықтық арқылы қозғала отырып, бөлшектердің флотациясына кедергі келтіретін турбулентті ағындарды жасай алады. Сұйықтықтың турбуленттік ағынында қозғалғанда "көпіршік – бөлшектер" кешені қирауға бейім, себебі бөлшектер мен көпіршіктер әртүрлі инерционды (масса) болады. Сонымен қатар, флотацияланатын компонентті барынша алуға қол жеткізетін ауа шығынының мәні полимер мен ПБЗ түріне байланысты екендігі туралы қорытынды жасауға болады. ПБЗ әртүрлі шоғырлануы кезінде ауа шығынының әсер ету сипаты өзгермейді-флотацияланатын компонентті алу ғана өзгереді.

Полистиролды ПБЗ қоспасының әр түрлі коннцентрациясы кезінде сұйықтықтың аэрирленетін қабатының биіктігінен бөліп алуды зерттеу нәтижелері сұйықтықтың аэрирленетін қабатының аз биіктігі кезінде пластмасса бөлшектің ауа көпіршігімен соқтығысу ықтималдығы төмен және кейбір әлеуетті флотацияланатын бөлшектер аппараттың түбіне түсіріледі, сонымен қатар ауа көпіршігімен соқтығыспай-ақ. Өңделетін сұйықтық қабатының оңтайлы биіктігіне ауаның белгілі бір шығыны сәйкес келеді. Ал сұйық қабатының биіктігі дисперсиялық фазаны алудың қажетті деңгейіне оңтайлы жетуден азырақ, мысалы, ауа шығыны жоғарылаған кезде мүмкін.

Флотация процессіне сұйықтық температурасының әсерін бағалау кезінде сұйықтық температурасының 20 ° С-тан жоғары көтерілуі АБС және КС шығуының күрт төмендеуіне әкеледі. Бұл ПБЗ-ның көбіктеу қабілетінің температураға тәуелділігі ерігіштің қисығымен сипатталады және ПБЗ-ның көпшілігі үшін экстремуммен түсіндіріледі. Ерітіндінің температурасының жоғарылауы баз ерітілген молекулаларының дегидратациясына әкеп соқтыруы мүмкін. Бұл ретте олар жеке макрофаз түрінде бөлінеді, бұл флотация процесіне қатысатын ПБЗ молекулаларының санының төмендеуіне әкеледі.

Түйін сөздер: флотация, пластмасса қалдықтары, беттік белсенді заттар, концентрация, ауа шығыны, сұйықтық қабатының биіктігі, температура.

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ИЗУЧЕНИЕ ВЛИЯНИЯ РАСХОДА ВОЗДУХА, ВЫСОТЫ СЛОЯ ЖИДКОСТИ И ТЕМПЕРАТУРЫ НА ПРОЦЕСС ФЛОТАЦИОННОГО РАЗДЕЛЕНИЯ ИЗМЕЛЬЧЕННЫХ ПЛАСТМАСС

Аннотация. Для разделения отходов пластмасс (полиамида (ПА), акрилонитрилбутадиенстирола (АБС) и полистирола (ПС)) предложен флотационный способ. С использованием указанного способа изучено влияние расхода воздуха, высоты слоя жидкости и температуры. В качестве поверхностно-активных веществ (ПАВ) использовались синтанол, сульфанол и смесь ПАВ, содержащая лауретсульфат натрия и диэтаноламид.

Для анализа результатов исследований флотационного разделения смеси измельченных отходов пластмасс были рассчитаны извлечение флотируемого компонента ε и чистота концентрата β.

Результаты исследований извлечения полистирола от расхода воздуха при различной концентрации смеси ПАВ показывают, что извлечение имеет максимум при некотором расходе воздуха. При малых расходах воздуха процесс протекает неэффективно, так как рабочий объем жидкости недостаточно насыщается пузырьками газа. При превышении оптимального значения расхода воздуха образуется много газовых пузырьков, не участвующих в процессе флотации. Такие пузырьки, двигаясь через жидкость, могут создавать турбулентные потоки, препятствующие флотации частиц. При движении в турбулентном потоке жидкости комплекс «пузырек – частица» склонен к разрушению, поскольку частицы и пузырьки имеют различную инерционность (массу). Кроме того, можно сделать вывод о том, что значение расхода воздуха, при котором достигается максимальное извлечение флотируемого компонента, зависит от типа полимера и ПАВ. Характер влияния расхода воздуха при различной концентрации ПАВ не изменяется – изменяется лишь извлечение флотируемого компонента.

Результаты исследований извлечения полистирола от высоты аэрируемого слоя жидкости при различной концентрации смеси ПАВ свидетельствуют о том, что при малой высоте аэрируемого слоя жидкости вероятность столкновения пластмассовой частицы с пузырьком воздуха низкая и некоторые потенциально флотируемые частицы опускаются на дно аппарата, так и не успев столкнуться с пузырьком воздуха. Оптимальной высоте слоя обрабатываемой жидкости соответствует определенный расход воздуха. А при высоте слоя жидкости меньше оптимальной достижение необходимой степени извлечения дисперсной фазы возможно, например, при повышении расхода воздуха.

При оценке влияния температуры жидкости на процесс флотации установлено, что повышение температуры жидкости выше 20°С приводит к резкому снижению извлечения АБС и ПС. Это, возможно, объясняется тем, что зависимость пенообразующей способности ПАВ от температуры характеризуется кривыми растворимости и для большинства ПАВ они имеют экстремум. Вероятно, повышение температуры раствора приводит к дегидратации растворенных молекул ПАВ. При этом они выделяются в виде отдельной макрофазы, что приводит к снижению количества молекул ПАВ, участвующих в процессе флотации.

Ключевые слова: флотация, отходы пластмасс, поверхностно-активные вещества, концентрация, расход воздуха, высота слоя жидкости, температура.

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