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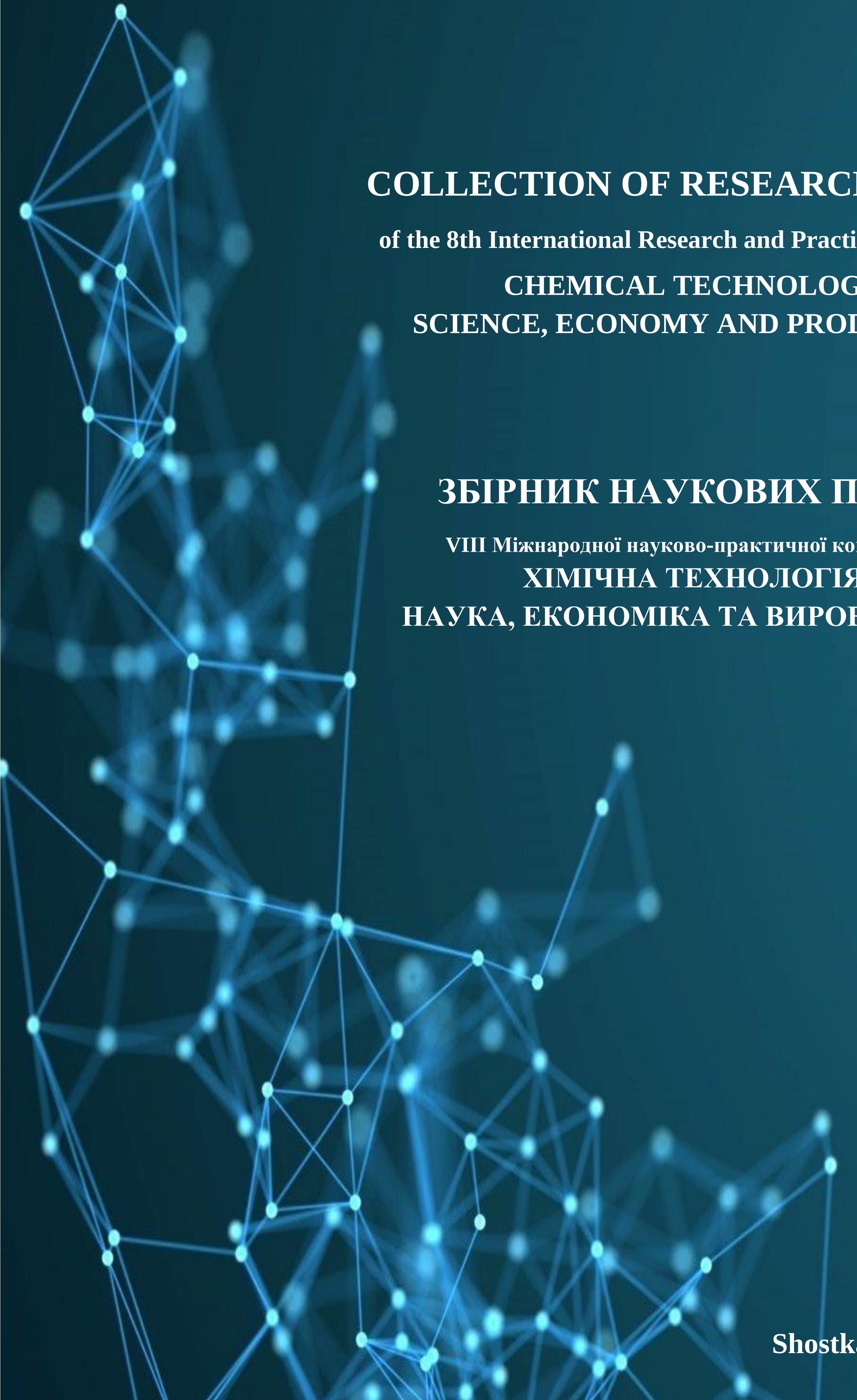

COLLECTION OF RESEARCH PAPERS

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CHEMICAL TECHNOLOGY:
SCIENCE, ECONOMY AND PRODUCTION

ЗБІРНИК НАУКОВИХ ПРАЦЬ

VIII Міжнародної науково-практичної конференції

ХІМІЧНА ТЕХНОЛОГІЯ:
НАУКА, ЕКОНОМІКА ТА ВИРОБНИЦТВО

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Збірник наукових праць VIII Міжнародної науково-практичної конференції «Хімічна технологія: наука, економіка та виробництво», м. Шостка, 27 - 29 листопада 2024 року. – Суми : Сумський державний університет, 2024. – 242 с.
ISSN 2786-4898.

Збірник містить наукові праці учасників VIII Міжнародної науково-практичної конференції «Хімічна технологія: наука, економіка та виробництво», що складаються з узагальнених матеріалів науково-дослідних робіт науковців різних галузей виробництв та наукових закладів України.

У збірнику висвітлюються актуальні питання спеціальної хімічної технології і виробництва боєприпасів, утилізації відходів виробництв різних галузей, енергозбереження, моделювання технологічних процесів, соціально-економічні аспекти виробництва та природокористування в умовах війни.

Збірник корисний робітникам хімічної промисловості, науковим співробітникам, аспірантам і студентам спеціальностей хіміко-технологічного та соціально-економічного профілів, фахівцям інформаційних технологій виробництва.

Наукові праці учасників конференції подаються в авторській редакції.

LEACHING KINETICS OF POLYDISPERSE PARTICLES OF DIFFERENT SHAPES

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Leaching – extraction of one or more components from solid bodies (ores, concentrates, intermediate products, production waste) with an aqueous solution containing alkali, acid or other reagent. Usually, leaching is accompanied by a chemical reaction, as a result of which the extracted component changes from a water-insoluble form to a soluble one. At the end of leaching, in contrast to dissolution, a solid phase always remains, that is, the degree of leaching is less than 100 %. As a rule, crushed material of different granulometric composition is received for leaching. In the process of leaching, the surface of such material changes, which, together with a decrease in the concentration of reagents and the accumulation of products, leads to a decrease in the rate of leaching.

If the leaching reaction is irreversible and is not accompanied by the formation of a shell of a solid product, the leaching rate W can be expressed by the equation:

$$W=-dG/d\tau=K\cdot C^{n}\cdot S, \tag{1}$$

where G is the mass of the solid phase; τ – reaction time; K is the rate constant; C – reagent concentration; n is the order of the reagent, S is the surface of the solid phase.

The value of the surface depends on the shape of the particles (sphere, cube, plate and needle) of the monodisperse material. In practice, it is often necessary to deal with polydisperse materials with a wide range of particle sizes, while in the process of dissolution, not only the surface of the particles changes, but also their number, since small fractions first dissolve and disappear.

Much and constant attention is paid to the leaching process in the scientific literature [1–3]. From the array of various information, it is possible to conditionally single out works devoted to the course of leaching in the diffusion region [4–7] with the provision of the corresponding kinetic equations. There are also works [8–10] in which the authors note the course of leaching in the kinetic region. The authors of [11] processed the data according to 18 kinetic equations that reflect various mechanisms on a solid material, but do not take into account the influence of the concentration of the solvent.

In article [12] the case of the course of leaching in the kinetic region for a polydisperse material of spherical shape is considered. The process speed equation was obtained, taking into account the dependence of the particle surface on the degree of leaching. It was established that the order of the solid material for polydisperse spherical particles can vary from 2/3 to 1.

The analysis of equation (1) shows that it is enough to simply take into account the change in the concentration of C of the solvent, and the change in the process of leaching the surface of the solid material is proposed to be carried out as follows.

At the initial mass of the solid phase G_0 at the moment of reaching mass G, the degree of leaching α is equal to:

$$\alpha=(G_0-G)/G_0=1-G/G_0, \text{ whence } G=G_0(1-\alpha) \text{ and } dG=-G_0 d\alpha. \tag{2}$$

At the initial concentration of the liquid reagent C_0, the current concentration is determined as:

$$C=C_0\cdot(\gamma-\alpha)/\gamma, \qquad (3)$$

where γ is the excess (shortage) of the reagent against stoichiometry; with the stoichiometric ratio $\gamma=1$.

Taking into account expressions (2) and (3), equation (1) takes the form:

$$W=d\alpha/d\tau=K\cdot S\cdot((C_0(\gamma-\alpha)/\gamma))^n/G_0. \qquad (4)$$

To establish the functional dependence between the size of the surface S and the degree of leaching, we assume the spherical shape of solid particles, the surface of which decreases due to the reduction of their radius r and the number of particles N. In general, the distribution function can be expressed by the equation:

$$N=a\cdot r^b, \qquad (5)$$

where a and b are constants.

If $b=0$, then $N=a=const$, the function is represented by a point and all particles have the same initial radius r_0. If $0<b<1$, then the function (5) is expressed by a convex curve, when $b>1$ – by a concave curve. If $b=1$, then the number of particles depends linearly on their radius.

Therefore, if the number of particles with a radius of r_0 and less is expressed by the function (5), then the number of particles with a radius from r to $r+dr$ is equal to:

$$dN=a\cdot b\cdot r^{b-1}\cdot dr. \qquad (6)$$

The mass of particles with a radius in the interval from r to $r+dr$ is equal to:

$$dG=(4/3)\cdot\pi\cdot r^3\cdot\rho\cdot dN=(4/3)\cdot\pi\cdot r^{(b+2)}\cdot\rho\cdot a\cdot b\cdot dr, \qquad (7)$$

where ρ is the density of the solid material.

The total mass of particles in the limits of integration over r from 0 to r is equal to:

$$G=(4/3)\cdot\pi\cdot\rho\cdot a\cdot b\cdot\int r^{(b+2)}dr=(4/3)\cdot\pi\cdot\rho\cdot a\cdot b\cdot r^{(b+3)}/(b+3). \qquad (8)$$

The initial mass of particles in the limits of integration over r from 0 to r_0 is equal to:

$$G_0=(4/3)\cdot\pi\cdot\rho\cdot a\cdot b\cdot\int r^{(b+2)}dr=(4/3)\cdot\pi\cdot\rho\cdot a\cdot b\cdot r_0^{(b+3)}/(b+3). \qquad (9)$$

These formulas are valid for all values of b except $b=0$, since in this case the function (5) has a discontinuity and the total mass of the particles is equal to:

$$G=(4/3)\cdot\pi\cdot\rho\cdot a\cdot r^3.$$

Taking into account expressions (8) and (9), the degree of leaching can be expressed in terms of particle radius:

$$\alpha=(G_0-G)/G_0=(r_0^{b+3}-r^{b+3})/r_0^{b+3}=1-r^{b+3}/r_0^{b+3}. \qquad (10)$$

From equation (10), we obtain the dependence of the radius of the particles on the degree of leaching:

$$r=r_0(1-\alpha)^{1/(b+3)}. \qquad (11)$$

The surface of particles with a radius in the interval from r to $r+dr$, taking into account expression (6), is equal to:

$$dS=4\cdot\pi\cdot r^{2}\cdot dN=4\cdot\pi\cdot r^{b+1}a\cdot b\cdot dr.$$

The total surface of all particles in the limits of integration over r from 0 to r:

$$S=4\cdot\pi\cdot a\cdot b\cdot\int r^{b+1}dr=4\cdot\pi\cdot a\cdot b\cdot r^{b+2}/(b+2). \qquad (12)$$

This formula, like formula (9), is valid for all values of b, except $b=0$. For $b=0$, the outer surface of the spherical particles is equal to:

$$S=4\cdot\pi\cdot a\cdot r^{2}.$$

Taking into account expression (11), the total surface of all particles:

$$S=4\cdot\pi\cdot a\cdot b\cdot r_{0}{}^{b+2}(1-\alpha)^{(b+2)/b+3)}/(b+2). \qquad (13)$$

After substituting the initial mass of particles according to equation (9) and the total surface of all particles according to equation (13) into equation (4), we get the leaching rate equation:

$$W=d\alpha/d\tau=K^{*}((C_{0}(\gamma-\alpha)/\gamma))^{n}(1-\alpha)^{m}, \qquad (14)$$

where $K^{*}=3\cdot K\cdot(b+3)/((\rho\cdot(b+2)\cdot r_{0}))$, $m=(b+2)/(b+3)$.

Note that when $b\rightarrow\infty$, the order in the solid material is $m\rightarrow1$. When $b=0$, $m=2/3$ is the case of the shrinking sphere equation. Therefore, the order of the solid material for polydisperse spherical particles can vary from 2/3 to 1.

With a stoichiometric ratio of liquid and solid $\gamma=1$, equation (14) is simplified:

$$W=d\alpha/d\tau=K^{*}((C_{0}(1-\alpha))^{n}(1-\alpha)^{m}. \qquad (15)$$

To establish the functional dependence between the size of the surface S and the degree of leaching α, we take the needle-like shape of solid particles with a diameter d, the surface of which decreases due to a decrease in their length l and the number of particles N. It is assumed that $l>>d$. In general, the distribution function can be expressed by the equation is similar to dependence (5):

$$N=a\cdot l^{b}.$$

By analogy with equation (6-14), we obtain expressions for needle-shaped particles:

$dN=a\cdot b\cdot l^{b-1}\cdot dl.$

$dG=\pi\cdot(d/2)^{2}\cdot l\cdot\rho\cdot dN=\pi\,(d/2)^{2}\cdot l^{b}\cdot\rho\cdot a\cdot b\cdot dl.$

$G=\pi\cdot(d/2)^{2}\cdot\rho\cdot a\cdot b\cdot\int l^{b}dl=\pi\,(d/2)^{2}\cdot\rho\cdot a\cdot b\cdot l^{(b+1)}/(b+1).$

$G_{0}=\pi\cdot(d/2)^{2}\cdot\rho\cdot a\cdot b\cdot\int l^{b}dl=\pi\,(d/2)^{2}\cdot\rho\cdot a\cdot b\cdot l_{0}^{(b+1)}/(b+1).$

$\alpha=(G_{0}-G)/G_{0}=(l_{0}^{b+1}-l^{b+1})/l_{0}^{b+1}=1-l^{b+1}/l_{0}^{b+1}.$

$l=l_{0}(1-\alpha)^{1/(b+1)}.$

$S=\pi\cdot d\cdot a\cdot b\cdot\int l^{b}dl=\pi\cdot d\cdot a\cdot b\cdot l^{b+1}/(b+1).$

$S=\pi\cdot d\cdot a\cdot b\cdot l_{0}^{(b+1)}\cdot(1-\alpha)/(b+1).$

$$W=d\alpha/d\tau=K^{*}((C_{0}(\gamma-\alpha)/\gamma))^{n}(1-\alpha). \qquad (16)$$

where $K^{*}=4K/(d\cdot\rho)$.

To establish the functional dependence between the size of the surface S and the degree of leaching α, we take the plate-shaped of solid particles (square plates) with a width w, the surface of which decreases due to a decrease in their width w and the number of particles N. It is assumed that a thickness h<<w. In general, the distribution function can

be expressed by the equation (5). In general, the distribution function can be expressed by the equation is similar to dependence (5):

$$N=a\cdot wb.$$

By analogy with equation (6-14), we obtain expressions for plate-shaped particles:

$dN=a\cdot b\cdot wb-1\cdot dw.$

$dG=h\cdot w2\cdot \rho\cdot dN=h\cdot w(b+1)\cdot \rho\cdot a\cdot b\cdot dw.$

$G=h\cdot \rho\cdot a\cdot b\cdot \int w(b+1)dw=h\cdot \rho\cdot a\cdot b\cdot w(b+2)/(b+2).$

$G0=h\cdot \rho\cdot a\cdot b\cdot \int w(b+1)dw=h\cdot \rho\cdot a\cdot b\cdot w0(b+2)/(b+2).$

$\alpha=(G0-G)/G0=(w0b+2-wb+2)/w0b+2=1-wb+2/w0b+2.$

$w=w0(1-\alpha)1/(b+2).$

$S=2\cdot a\cdot b\cdot \int wb+1dw=2\cdot a\cdot b\cdot wb+2/(b+2).$

$S=2\cdot a\cdot b\cdot w0\ b+2(1-\alpha)\ /(b+2).$

$$W=d\alpha/d\tau=K^*((C0(\gamma-\alpha)/\gamma))n(1-\alpha). \qquad (17)$$

where $K^*=2\cdot K/(\ h\cdot \rho)$.

Therefore, according to the obtained equations, the order of the solid material can vary from 2/3 to 1 for polydisperse particles of a spherical shape (15) and is the first for particles in the form of a needle or a plate (16, 17). Experimental studies and calculations [12] established values of orders close to the first: for nitric acid n=0.83 and for magnetite m=1.2.

References

1. Investigation of Leaching Kinetics of Copper from Malachite Ore in Ammonium Nitrate Solutions / A. Ekmekyapar, et al. // Metallurgical and materials transactions B. – 2012. – 43B. – pp. 764 – 772. Available at: https://zero.sci-hub.se/1267/57f68e48242c55c1f60432aaadc8623a/ekmekyapar2012.pdf

2. Leaching of malachite ore in ammonium sulfate solutions and production of copper oxide / A. Ekmekyapar, et al. // Braz. J. Chem. Eng. – 2015. – 32(1). – pp. 155 – 165. Available at: https://www.scielo.br/j/bjce/a/fmGwVnZb8b3fXq6hKKcq8kB/?format=pdf&lang=en

3. Leaching of copper oxide with different acid solutions / N. Habbache, et al. // Chemical Engineering Journal. – 2009. – 152. – pp. 503–508. Available at: https://www.researchgate.net/publication/244362463_Leaching_of_copper_oxide_with_different_acid_solutions

4. Nazarov H.M., Mirsaidov I.U., Rahmatov N.N. Kinetika processa vyshelachivaniya supeschanyh uransoderzhashih pochv. Agentstvo po yadernoj i radiacionnoj bezopasnosti AN Respubliki Tadzhikistan. 2015 g.

5. Available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/49/039/49039294.pdf

6. Mudila Dhanunjaya Rao, Kamalesh K. Singh, Carole A. Morrison, Jason B. Love. Optimization of process parameters for the selective leaching of copp