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Diamond — an adsorbent of a new type

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Abstract

Carbon-containing adsorbents are widely used in various industries, medicine, and pharmacology. The most abundant of them are activated coals, graphitized thermal carbon black, molecular sieves, etc. [Active Coals and their Industrial Applications (1984), 214]. Synthetic diamond presents a new class of carbon containing adsorbents. Diamond is a universal adsorbent that is characterized by chemical inertness and high strength. Another welcome effect is the possibility to modify and recover the diamond surface and, hence, to use the adsorbent repeatedly. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The aim of our present work is to study adsorption properties of various types of synthetic diamond in gas and liquid media. As compared with conventional adsorbents, like activated coal [1], the adsorbents under study fall into the group having a relatively low value of specific surface ranging from 10 to 250 m^2/g [2,3].

As adsorbents, we have chosen diamond powders of two types:

1. Diamond submicron powders produced by hydrostatic deposition of a diamond raw material (recovered from the synthesis product and crushed), which was synthesized in the Ni–Mn–C growth system using cylindrical high-pressure apparatuses. We have studied ACM-type diamond powders of grit sizes 1/0.5 and 0.5/0.1 μm.
2. UDA-type nanodiamonds 4–40 nm in size produced by the ALIT Company, Ukraine, by detonation of an explosive having a negative oxygen balance.

For comparison studies, the known silicon-containing kaolin and silard (highly dispersed SiO_2) and carbon-containing acetylene black adsorbents have been taken.

2. Experimental techniques

The adsorptivity of diamond was studied from:

- nitrogen adsorption/desorption,
- water vapor adsorption,
- adsorption of ions of heavy metals.

The nitrogen adsorption/desorption was studied by the BET (Brunauer–Emett–Teller) method using an Acusorb-2100 device. The essence of the method is that the amount of nitrogen which is physically adsorbed at the surface of a solid at the liquid nitrogen temperature is determined [4,5].

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Adsorption isotherms have been taken at $P/P_s = 0.05-1$ (where P is the equilibrium pressure of nitrogen and P_s is the pressure, at which the diamond surface is saturated with nitrogen) according to a specially developed program.

From nitrogen adsorption/desorption isotherms, the following adsorption and structural characteristics have been found: the limiting saturation of diamond surface with nitrogen (Γ_∞, ml/g), the specific surface of diamond powders (S_s, ml/g), the volume of a nitrogen monolayer adsorbed at the diamond surface (V_m, ml/g), the total volume of pores in diamond powder (V_p, ml/g), the adsorption potential (A, J/g), the specific adsorption potential (A′, J/m^2) and the size distribution of pores.

The water vapor adsorption was found from the free energy of saturation with water vapor of the surface of 1 g of diamond adsorbent (ΔC_{sat}) by the Eq. (1) [6]

$$\Delta C_{\text{sat}} = RT\ n \ln P/P_{\text{sat}}, \tag{1}$$

where R is the universal gas constant that equals 8.31 J/mole, T is the temperature (in K), n is the number of water moles adsorbed by a gram of the adsorbent under study, P_{sat} is the pressure of saturated water vapor under the experimental conditions, P is the partial pressure of water vapor found by

$$P = P_{\text{sat}} - 0.0065(t_d - t_w)b, \tag{2}$$

where b is the atmospheric pressure, t_d and t_w are the readings of the 'dry' and 'wet' thermometers, respectively.

The evaluation of the adsorption of ions of heavy metals involved taking cathode potentiodynamic curves of adsorption and formation of molecular hydrogen from 1 N sulfuric acid, that was an initial solution, and from sulfuric acid solutions with additions of ions of heavy metals [7]. A diamond film of a mixture of diamonds and fluoroplastic lacquer in the ratio of 10:1 dissolved in acetone was applied to an electrode of isotropic graphite. The curves were recorded on a P-5848 potentiostat in an argon atmosphere. The charge spent for adsorption of hydrogen was found by

$$Q = \int_{t_1}^{t_2} I \cdot t \cdot \mathrm{d}t, \tag{3}$$

where $I \cdot t$ is the charge per unit surface under the cathode curve with potentials restricted to 0.05–0.85 V, t_1, t_2 are the time of the beginning and the end of the hydrogen adsorption process, respectively.

The occupancy of the surface with ions of heavy metals was found by the equation

$$\theta = (Q_1 - Q_2)/Q_1 \cdot 100\%, \tag{4}$$

where Q_1 is the charge spent on the adsorption of hydrogen from the initial solution, Q_2 is the charge spent on adsorption of hydrogen from the solution containing ions of heavy metals [8].

3. Results and discussion

Table 1 gives the main adsorption and structural characteristics of the adsorbents being studied. The most important energetic parameter of the adsorption process is the specific adsorption potential (A') of a square meter of the adsorbent. It follows from Table 1 that ACM 1/05 and ACM 0.5/0.1 diamond powders exhibit the highest adsorption activities (A′ = 7.8 and 9.3 J/m^2, respectively).

The specific adsorption potential of the UDA ultradispersed diamond is much lower and is equal to that of silard. The lower A′ value of the UDA diamond as compared with the ACM diamond is attributable in our opinion to a considerable preadsorption of oxygencontaining groups at the UDA diamond surface. This is also demonstrated by the high free energy of the water vapor saturation. For UDA diamond, $\Delta C_s = 3000$ J/g mol, while for ACM 1/0.5 diamond $\Delta C_s = -67.3$ J/g mol.

However, due to a high specific surface, in the long run the UDA diamond have the higher adsorption

Table 1
Adsorption and structural characteristics of various adsorbents

Adsorbents	Γ_∞ (ml/g)	S_s (m^2/g)	V_m (ml/g)	V_p (ml/g)	A (J/g)	A' (J/m^2)
ACM 1/0.5 diamond	9.0	5.8	1.46	0.0177	45.0	7.8
ACM 0.5/0.1 diamond	45.0	12.15	3.06	0.071	112.0	9.3
Ultradispersed diamond UDA	250.0	178.0	45.0	0.83	528.0	2.96
Acetylene black	150.0	76.0	19.0	0.32	288.0	3.8
Kaolin	10.06	4.6	1.16	0.0188	22.7	4.9
Silard	185.67	206.6	51.96	0.37	599.0	2.9