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ENERGY CHARACTERISTICS OF FINEST COAL PARTICLES SURFACES VERSUS THEIR UPGRADING USING FLOTATION

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The paper presents selected results of investigations on energy properties of the fine coal particles, and methodological grounds for conducting such investigations. Using the discussed relationships, values of contact angle of coal particles with various degree of coalification in the range defined by the energy nonhomogeneity of the surfaces were computed. There have been determined the values of the contact angles of coal particles with hydrophobic and hydrophilic surfaces after coating with nonpolar and polar reagents. The energy state of the surfaces of coal particles in the feeds and products of industrial flotation were determined, which enabled to evaluate this process.

Key words: surface tension, surface energy, separation, coal, flotation

INTRODUCTION

As a consequence of coal mechanical mining and its transportation to the preparation plant as well as coal processing, a substantial part of coal is in the form of fine coal slurry. The coal slurry is contaminated with ash-generating minerals and other substances which contaminate the environment in the course of their utilisation. The coal slurry, to fulfil the principles of the "clean coal" programme [Sablik 2002], should be processed. The finest coal is basically prepared using physical-chemical methods, and most frequently the flotation method. The principal condition of flotation response of coal is low surface energy of the particles, which causes their surface to be hydrophobic. A measure of coal hydrophobic is the contact angle, and the surfaces of coal particles is considered hydrophobic when the contact angle is greater than zero. A measure of the energy state of the surface of coal particles can also be the critical surface tension of wetting, which can be determined using the film flotation method (Fuerstenau et al. 1991, Diao, Fuerstenau 1991). This is a parameter

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enabling to give the surface energy characteristics of particles in the entire population, to draw up the probability curve of surface energy distribution and to determine the value of mean critical surface tension of wetting for a given collection of particles (Fuerstenau et al. 1991, Sablik, Wierzchowski 2001). The results of tests using this method enable also to determine the energy nonhomogeneity of particle surfaces in a specified population (Fuerstenau et al. 1991, Sablik 2000).

The film flotation method enables to determine the effect of chemical reagents on the state of surface energy of coal particles. The technique of particle surface coating outside the technological environment was developed by Sablik and Wierzchowski (1992, 1994, 1995), which made it possible to evaluate the effect of those reagents on the energy state of particle surface. It has been additionally shown that the particles that were upgraded within the flotation process have a similar surface energy to that of particles coated with a reagent outside the technological environment (Wierzchowski et al. 2000).

The development of research methods and determination of empirical relationships between some quantities characterising the surface of coal provide the possibility of a deeper analysis of the preparation process using physical-chemical methods.

METHODOLOGICAL GROUNDS FOR INVESTIGATION OF SURFACE ENERGY PROPERTIES OF FINEST SIZE PARTICLES

The information concerning the energy state of fine coal particles can be obtained using several methods (Sablik, 2007). To do this, one most often applies the measurement of the contact angle θ, while since the eighties of the last century, the measurement of the critical tension of wetting γ_c (Fuerstenau et al., 1991, Diao and Fuerstenau 1991). A relationship was found between the two parameters mentioned above describing the energy state of the surface of coal particles (Neumann and Good 1972; Neumann et al., 1972; Fuerstenau et al. 1970; Li and Neumann 1992; Sablik 2003). The empirical relationship cos θ = f(γ_c), graphically presented in Fig.1, is described with the regression equation (Sablik 2003):

$$100 \cos \theta = 0{,}0012 \exp 0.1959 \quad \bar{\gamma}_c \tag{1}$$

where θ – contact angle,

$\bar{\gamma}_c$ – mean critical surface tension of wetting,

while the correlation coefficient between these variables is 0.90.

In the case when cos θ = 1, the contact angle equals to zero, and the value of mean critical surface tension of wetting calculated with the use of Eq. 1, $\gamma_{c(\theta=0)}$, is equal to 57.83 mJ/m^2. The particles whose surface tension of wetting is equal or greater than $\gamma_{c(\theta=0)}$ have hydrophilic surfaces. Such particles do not show any flotation response. This is proved by the results of tests on natural floatability F_n (Wierzchowski and

Sablik, 1993) and standard floatability (Sablik, 1998). The dependence on natural floatability F_n on the mean critical surface tension of wetting $\bar{\gamma}_c$ $\{F_n = f(\bar{\gamma}_c)\}$ can be described with the regression equation (Sablik, 2004):

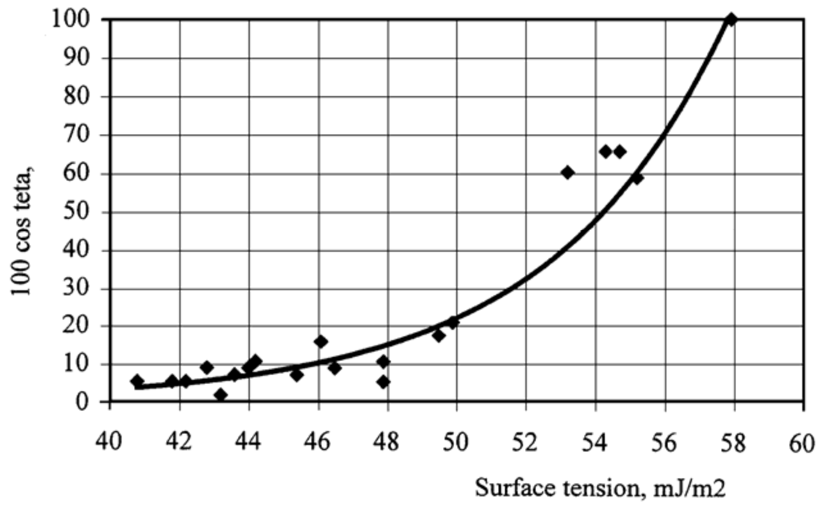

Fig. 1. Dependence between contact angle and mean critical surface tension of wetting for coals of different rank

$$F_n = 2\cdot 10^7 \exp(-\ 0.2903\ \bar{\gamma}_c) \quad (2)$$

The correlation coefficient of these variables is - 0.92. The value of critical surface tension of wetting, when calculated using equation (2) F_n=0 is $\gamma_{c\ (Fn=0)}$ = 57.90 mJ/m^2. The standard floatability is the floatation response of various types of coal determined in identical experimental conditions. The measure of the standard floatability can be the yield of combustible in the concentrate ε, that is $\varepsilon = \gamma B_K/B_N$, where γ is the yield of the concentrate, B_K the content of combustible in concentrate, B_N the content of combustible in the feed. The relationship $\varepsilon = f(\bar{\gamma}_c)$ is described by the regression equation (Sablik, 2004):

$$\varepsilon = 3\cdot 10^9 \exp(-\ 0.3915\ \bar{\gamma}_c) \quad (3)$$

and the coefficient of correlation between these variables is - 0.95. The value of critical surface tension of wetting calculated from equation (3) for ε = 0 is $\bar{\gamma}_{c(\varepsilon=0)}$ = 55.73 mJ/m^2 . The values $\gamma_{c(Fn=0)}$ and $\gamma_{c(\varepsilon=0)}$ prove the conclusion resulting from the relationship cos θ = f($\bar{\gamma}_c$) on the total disappearance of hydrophobicity of coal particles when $\bar{\gamma}_c \geq$ 57.83 mJ/m^2.

The value $\gamma_{c(\theta=0)}$ and that of the distribution function of critical surface tension of wetting of coal particles enable to determine the contents of hydrophilic particles in a given collection of finest particles (Sablik, 2003, 2004, Sablik and Wierzchowski, 2004). Figure 2 shows the distribution functions of surface tension of wetting, determined using the film flotation method, obtained after disintegration of coal lump with the content of C^{daf} = 77.46 % and of ash 3.42%, not covered and covered with an apolar reagent, while Fig. 3 those of coal with C^{daf} = 82.80 % and ash content 2.30% not covered and covered with an nonpolar reagent or mixture of nonpolar (80 %) and polar (20%) reagents. In order to determine the content of hydrophilic particles in the analysed collections of particles, the point of intersection of the abscissa $\gamma_{c(\theta=0)}$ = 57.83 mJ/m^2 with the distribution function of the tension of wetting is projected on the axis of the content of lyophobic fraction.

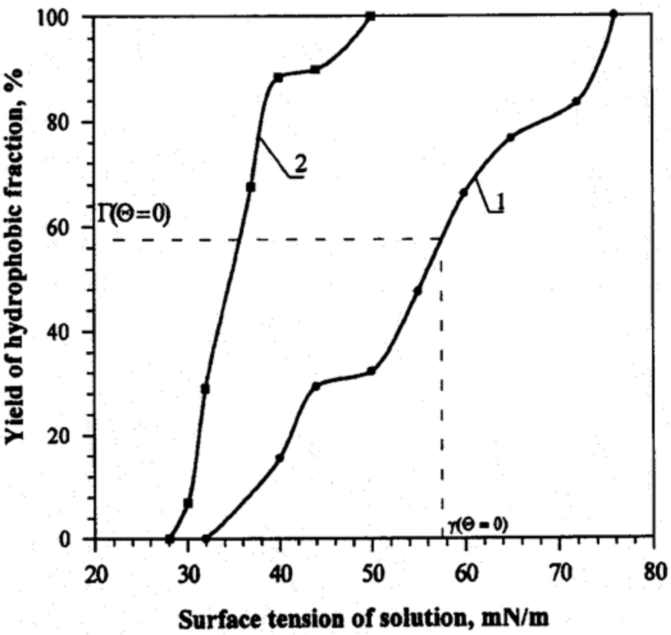

Fig. 2. Distribution functions of the surface tension of wetting of coal particles with a low degree of coalification, not coated (curve 1) and coateded with an nonpolar reagent (curve 2). There has been marked the contribution of particles (ca. 42 %) whose value of the contact angle is zero degrees

The point $\Gamma_{(\theta=0)}$ found this way defines the content of particles with hydrophilic surfaces. This content is equal to 100 - $\Gamma_{(\theta=0)}$. In the case of a very low coalification of coal (Fig.2), the content of hydrophilic particles in the collection obtained after disintegration of the coal lump with low ash content is about 42 %. In the population of particles obtained after disintegration of the lump of more coalificated coal (Fig.3), the content of hydrophilic particles is about 22 %. Because of a low content of ash-producing mineral substances (ash) in all tested lumps, one can draw a conclusion that the particles with hydrophilic surfaces are those of organic coal substance with a high content of reactive oxygen complexes. In the case of weakly coalificated coal, the content of such complexes is greater, which causes that the content of hydrophilic particles in the population is higher.

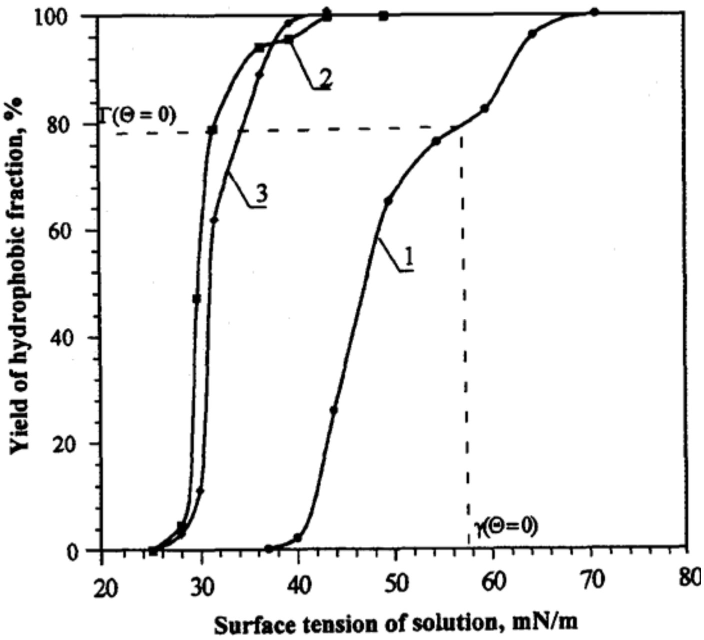

Fig. 3. Distribution functions of the surface tension of wetting of coal particles with medium degree of coalification not coated (curve 1) and coated with nonpolar reagent (curve 2) or reagent being a mixture of nonpolar (80 %) and polar (20 %) reagents (curve 3). There has been marked the contribution of particles (ca. 22 %) whose value of the contact angle is zero degrees

The surfaces of hydrophilic coal particles can be hydrophobised with an action of appropriate chemical reagents. Figures 2 and 3 present the curves of the distribution of surface tension of wetting of examined coals, after their surface has been coated outside the technological environment (Sablik and Wierzchowski, 992, 1994, 1995) using a polar reagent or mixture of nonpolar and polar reagents.

Table 1. Surface tension of wetting (mJ/m^2) of coal particle populations of non-coated with reagents, coated out of flotation environment and coated in flotation process

Carbon content C^{daf}, %	Particles non-coated with reagents		Particles coated with reagents out of flotation environment		Particles coated with reagents in flotation process	
	Surface tension of wetting mJ/m^2	Energetic nonhomogeneity mJ/m^2	Surface tension of wetting mJ/m^2	Energetic nonhomogeneity mJ/m^2	Surface tension of wetting mJ/m^2	Energetic nonhomogeneity mJ/m^2
79.2	49.7	11.9	41.6	6.7	41.9	9.2
80.8	44.0	8.4	33.0	5.0	35.3	5.8
87.5	40.8	5.4	29.6	3.0	31.8	5.0

In the cases of both tested coals, coating of the particle surfaces with the reagents resulted in the hydrophobisation of all the particles in the populations. This means that surface tension of wetting of those particles is lower than $\gamma_{c(\theta=0)}$= 57.83 mJ/m^2, and contact angle is greater than zero.

Using the film flotation method in the investigations, the hydrophobisation of the particles of different types of coal in the flotation process has been evaluated (Wierzchowski et al., 2000].

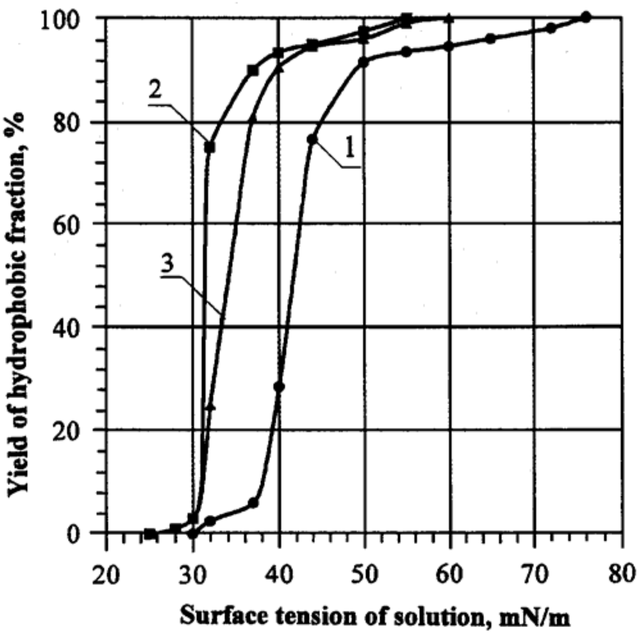

Fig. 4. Distribution functions of the surface tension of wetting of coal with C^{daf} = 80.8 %; 1 - "clean" particles, 2 - particles coated outside the flotation environment, 3- particles coated in the flotation process

Presented in Table 1 and Fig. 4 are the results of tests of surface tension of wetting in the populations of coal particles not coated with a reagent, coated with a reagent outside the flotation environment, and those coated in the process of flotation. It has been experimentally shown that the particles of coal undergo hydrophobisation in the process of flotation, and the energy state of the surface, reached as a consequence of action of reagents, does not change in the course of dewatering and drying of those particles. The distribution of surface tension values of particles coated with reagents in the process of flotation is very close to the distribution on the surface of particles coated in ideal conditions outside the flotation environment (Fig.4). The differences in the values of evaluated energy parameters characterising the surfaces of particles result, first of all, from the differences in coalification of the investigated coals.

Table 2. Characteristics and selected properties of coals with the use of different relationships ($\cos\theta = f(\bar{\gamma}_c)$ (1) and (Sablik and Wierzchowski 2001; Sablik, 2000, Sablik and Makula 1984), and minimal and maximal contact angles in the collection of fine coal particles, calculated on the basis of Eq. (1) and conditioned by energy nonhomogeneity of their surface

Carbon content, C^{daf}, %	Ash content A^a, %	Contact angle θ, deg	Mean critical surface tension, * $\bar{\gamma}_c$,mJ/m^2	Energetic surface nonhomo-geneity ** $\sigma_{\gamma c}$ mJ/m^2	$\bar{\gamma}_c + \sigma_{\gamma c}$ mJ/m^2	Minimal contact angle, deg	$\bar{\gamma}_c - \sigma_{\gamma c}$ mJ/m^2	Maximal contact angle, deg
78.48	6.41	49	54.7	12.1	66.8	0	42.6	86
77.46	3.42	54	55.2	11.9	67.1	0	43.3	86
79.19	6.28	49	54.3	7.3	61.6	0	47.0	82
80.90	6.60	53	53.2	11.9	65.1	0	41.3	87
82.80	2.30	78	49.9	8.0	57.9	0	41.9	87
81.91	9.70	81	46.1	8.9	55.0	53	37.2	89
80.70	4.72	80	49.5	7.3	56.8	57	42.2	87
82.23	7.70	84	47.9	7.6	55.5	49	40.3	88
84.76	5.26	85	46.5	7.5	54.0	60	39.0	88
86.47	2.36	87	47.9	10.2	58.1	0	37,7	88
84.45	12.63	85	44.0	6.7	50.7	75	37.3	88
84.50	3.80	84	44.2	6.7	50.9	74	37.5	88
85.00	4.61	85	42.8	6.1	48.9	79	36.7	89
85.80	3.80	86	45.4	5.9	51.3	73	39.5	88
87.10	2.30	87	42.2	5.6	47.8	81	36.6	89
87.36	3.28	88	43.2	6.9	50.1	77	36.3	89
87.10	2.40	87	42.2	6.0	48.2	81	36.2	89
87.11	4.20	86	43.6	5.9	49.5	78	37.7	88
88.73	2.61	87	41.8	5.4	47.2	82	36.4	89
89.60	8.10	87	40.8	8.1	48.9	79	32.7	89

*Calculated according to relation

$$\bar{\gamma}_c = \int_{\gamma_{c\min}}^{\gamma_{c\max}} \gamma_c f(\gamma_c) d\gamma_c$$

** Calculated according to relation

$$\sigma_{\gamma c} = \sqrt{\int_{\gamma_{c\min}}^{\gamma_{c\max}} (\gamma_c - \bar{\gamma}_c)^2 f(\gamma_c) d\gamma_c}$$

CONTACT ANGLES OF FINEST COAL PARTICLES

In the collections of finest coal particles with different coalification one observes the energetic nonhomogeneity of surface $\sigma_{\gamma c}$ (Sablik 2000). The values of the energy nonhomogeneity are, for all types of coal, confined in the range $\bar{\gamma}_c \pm \sigma_{\gamma c}$. By using empirical relationship (1) and the values of energy nonhomogeneity of the surface of particles in a specified collection, one can determine the limits of the ranges corresponding with these values, in which the values of contact angles are confined (Sablik and Wierzchowski, 2004). Specified in Table 2 are the characteristics of coals with different degrees of coalification, and the limits of ranges within which the values of contact angles of the surfaces of particles of a given population are confined. In the case of hard coals with the lowest coalification, the ranges of those values are very wide (0^o- 87^o), and the surfaces of a part of particles have the contact angle equal to zero (hydrophilic particles). With the increasing coalification of coal, the decrease of the ranges of contact angle values takes place, and in the case of hard coals with the highest coalification, up to several degrees (Table 2).

Table 3. Characteristics of tested coal samples and the influence of reagents on contact angles of slime particles

No.	Characteristics of coal samples				Characteristics of coal surfaces coated with reagents					
	Carbon content C^{daf}, %	Ash content A^a, %	$\bar{\gamma}_c$, mJ/m^2	Share of hydrophilic particlesn $\gamma_{c\ (\theta=0)}$, %	Reagent	$\bar{\gamma}_c$, mJ/m^2	$\sigma_{\gamma c}$ mJ/m^2	Angle $\theta_{(\gamma c)}$ deg	$\theta_{(\gamma c + \sigma\gamma c)}$ deg	$\theta_{(\gamma c - \sigma\gamma c)}$ deg
1	78.48	6.41	54.7	~ 55	A A +20%P	48.3 42.9	9.5 9.2	81 86	7 71	88 84
2	77.46	3.42	55.2	~ 35	A A +20%P	38.1 40.3	5.8 12.2	88 88	86 69	89 89
3	79.19	6.28	54.3	~ 23	A A +20%P	39.3 40.7	9.4 13.4	88 88	80 61	89 89(90)
4	80.90	6.60	53.2	~ 40	A A +20%P	40.5 41.6	11.5 9.4	88 87	71 75	89(90) 89
5	82.80	2.30	49.9	~ 15	A A +20%P	31.1 31.4	3.4 4.4	89 89	89 88	90 89(90)
6	80.70	4.72	49.5	~ 20	A A +20%P	30.2 31.4	4.1 4.1	89 89	89(90) 89	90 89(90)

A – nonpolar reagent, *P* – polar reagent

The particles built of the organic substance of coal, but containing numerous oxygen complexes and mineral intrusions can have hydrophilic surfaces, that is contact angles equal to zero. Such particles do not show the flotation response. The energy state of the surface of those particles can be changed by means of adequate chemical reagents. Presented in Table 3 is the effect of chemical reagents on the contact angles of six low- coalificated coals with low content of mineral substances (low ash content). The populations of finest particles of these coals contained a great number of particles with hydrophilic surfaces, having the surface tension values greater than $\gamma_{c(\theta=0)}$= 57.83 mJ/m^2, and contact angle equal to zero. After coating the surfaces of these particles with a nonpolar reagent or mixture of nonpolar (80%) and polar (20%) reagents, the surfaces of all particles revealed the hydrophobic properties that is the contact angle greater than zero. The results presented in Figures 2 and 3 and in Tables 1 and 3 prove that after contact with proper reagents, the hydrophilic surfaces of the particles of low-coalificated coals undergo hydrophobisation ($\theta > 0$, $\bar{\gamma}_c$ < 57.83 mJ/m^2), and coal should reveal flotation response.

ENERGY STATE OF THE SURFACES OF COAL PARTICLES IN THE FEED AND PRODUCTS OF INDUSTRIAL FLOTATION

In order to determine the energy state of the surface of coal particles in the course of industrial flotation, there were tested the feed and flotation products obtained in pneumatic-mechanical flotation machines type IZ with the capacity of 140 t/Mg (Sablik, 1998), concentrating under real conditions the slimes of coking and steam coals (Lenartowicz and Sablik, 2006; Lenartowicz 2007).

Table 4. Physicochemical characteristics of feed, concentrates and tailings of the tested coals and the share of particles with hydrophilic surfaces

Sample	Surface tension of wetting, $\bar{\gamma}_c$ mJ/m^2		Energetic nonhomogeneity, $\sigma_{\gamma c}$, mJ/m^2		Ash content, %		Share of hydrophilic particles, %	
	Coking coal	Power coal	Coking coal	Power coal	Coking coal	Power coal	Coking coal	Power coal
Feed	48.90	62.40	13.69	17.37	15.88	33.87	~ 18	~ 65
Concentrate I	40.74	42.42	8.25	9.21	4.92	8.55	~ 3	~ 6.5
Concentrate II	40.90	47.26	8.27	12.03	5.63	16.02	~ 5	~ 16.5
Concentrate III	47.46	49.50	10.51	13.68	9.81	18.22	~ 19	~ 20
Tailings	67.34	65.58	17,25	17.87	63.02	52.28	~ 73.5	~ 70

The flotation machines were constructed of three two-impeller sections with two-sided collection of the concentrate. The concentrates were collected from each section, and the tailings from the tailings bin. The results of tests are compiled in Table 4, and graphically presented in Figs. 5 and 6. The use of the film flotation method to evaluate flotation concentration of coal slimes in the industrial conditions enables to obtain better understanding of this process in the IZ-type pneumatic-mechanical concentrators. The suspension of cocking coal (feed) had relatively high surface tension of wetting (48.90 mJ/m^2), and about18% of the content of particles with hydrophilic surfaces, while the ash content was 15.88%. In successive impeller compartments, the concentrates containing 3%, 5% and 19% of hydrophilic particles were obtained, and the ashes in these compartments equalled 4.92, 5.63 and 9.81 %, respectively. The mean critical surface tension of wetting of particles in the concentrates is lower than the mean surface tension of wetting of particles in the feed, and much lower than this tension in the tailings (Fig. 6). A high content of hydrophobic particles in the tailings (26.5 %) indicates, however, that the analysed technology needs improving, aimed at decreasing the number of hydrophobic particles (combustible particles) that pass into tailings, and, consequently, increasing the ash content in the tailings.

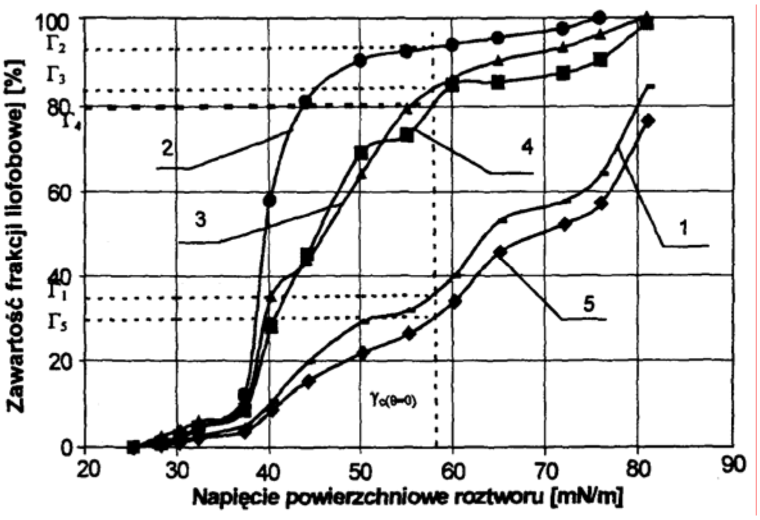

Fig. 5. Distribution curves of surface tension of wetting power coal particles in feed and products obtained in the IZ flotation machine, 1- feed, 2- concentrate I, 3 – concentrate II, 4 – concentrate III, 5 – tailings (100 - Γ_n) – yield =of hydrophilic particles

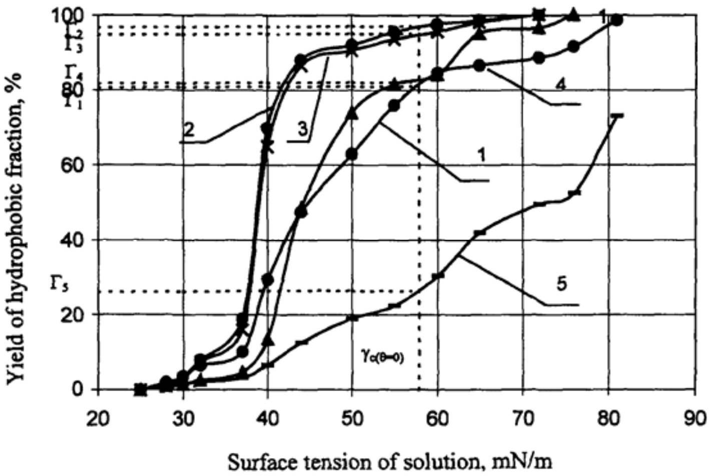

Fig. 6. Distribution curves of surface tension of wetting the coking coal particles in a feed and products obtained in the IZ flotation machine 1 - feed, 2- concentrate I, 3 – concentrate II, 4 – concentrate III, 5 – tailings (100 - Γ_n) – yield of hydrophilic particles

Steam coal has a substantially lower, as compared to coking coal, degree of coalification, and contains in its structure a relatively high number of oxygen-containing complexes, which causes that its surface is, to a great extent, hydrophilic. Such coal reveals a low flotation response. The mean critical surface tension of wetting of slime particles of the analysed coal was high (64.4 %), and the proportion of hydrophilic particles was 65 % (Table 4, Fig. 5). Concentrating of coal slimes of such a type using the flotation method needs very accurate adjustment of technological parameters. The presented results prove that, particularly in this case, the technology needs improving. A considerable part of particles with hydrophilic surfaces in the feed was hydrophobised during the process of flotation and passed to the concentrate, while a considerable amount of hydrophobic particles (ca. 30%) passed into the tailings. This resulted in a too low ash content in the product and loss of combustible matter.

The imperfection, in this case, of the flotation process is illustrated by the distribution curves of surface energy of particles in the feed and in the tailings (Fig. 5, curves 1 and 5). The differences in surface tension of wetting of particles in the feed and tailings are too small for the process of concentration of steam slimes to be found correct.

From the considerations above, it follows that the energy characteristics of the surfaces of finest coal, including the particles in the feeds and flotation products, can be used to perform deepened assessment of the course of physical – chemical concentration (flotation) of coal slimes. The film flotation method is the one that enables to make energy characteristics of the surface for the population of the finest coal particles.

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Przedstawiono wybrane wyniki badań energetycznych właściwości powierzchni ziaren węglowych w populacji węgli najdrobniej uziarnionych oraz metodologiczne podstawy prowadzenia takich badań. Informacje o stanie energetycznym powierzchni drobnych ziaren węglowych uzyskać można kilkoma metodami. Najczęściej w tym celu stosuje się pomiar kąta zwilżania θ, a od lat osiemdziesiątych ubiegłego stulecia pomiar krytycznego napięcia powierzchniowego zwilżania γ_c Określona została zależność między powyższymi dwoma parametrami. Zależność ta jako funkcja (cos θ = f($\bar{\gamma}_c$).) przedstawiona została graficznie na rysunku 1 i opisana równaniem regresji (1) W przypadku kiedy cos θ = 1 graniczny kąt zwilżania θ równy jest zero, a wartość średniego krytycznego napięcia powierzchniowego zwilżania zerowego kąta zwilżania obliczona z wykorzystaniem równania (1) $\gamma_{c(\theta=0)}$ wynosi 57,83 mJ/m^2. Ziarna, których napięcie powierzchniowe zwilżania jest równe lub większe od $\gamma_{c(\theta=0)}$, mają powierzchnie hydrofilowe. Ziarna takie nie wykazują aktywności flotacyjnej. Potwierdzają to wyniki badań flotowalności naturalnej F_n i flotowalności standardowej, której miarą może być uzysk substancji palnej w koncentracie ε. Obliczona z wykorzystaniem równania (2) wartość krytycznego napięcia powierzchniowego zwilżania kiedy F_n = 0 wynosi $\gamma_{c(Fn=0)}$ = 57,90 mJ/m^2. Wartość krytycznego napięcia powierzchniowego zwilżania obliczona z równania (3) dla ε = 0, wynosi $\gamma_{c(\varepsilon=0)}$ = 55,73 mJ/m^2. Wartości $\gamma_{c(Fn=0)}$ oraz $\gamma_{c(\varepsilon=0)}$ potwierdzają wniosek wynikający z zależności cos θ = f($\bar{\gamma}_c$).) o całkowitym zaniku hydrofobowości ziaren węglowych kiedy $\bar{\gamma}_c \geq$ 57,83 mJ/m^2. Wykorzystując omówione wyżej zależności obliczono kąty zwilżania ziaren węglowych o różnym stopniu uwęglenia w obszarze wyznaczonym przez niejednorodność energetyczną powierzchni w danym zbiorze. Przedstawiono sposób wyznaczania i określono wychód ziaren hydrofilowych w badanych zbiorach ziaren oraz zmiany wartości granicznych kątów zwilżania ziaren węglowych o powierzchniach hydrofobowych i hydrofilowych po zwilżeniu odczynnikami apolarnym i polarnym (rys. 2 i 3, tabele 2. i 3.). Wykazano, że rozkład napięć powierzchniowych zwilżonych odczynnikami w procesie flotacji jest bardzo zbliżony do rozkładu na powierzchni ziaren zwilżonych w warunkach idealnych poza środowiskiem flotacji. Przedstawiono wyniki badań procesu flotacji w korytowej pneumomechanicznej maszynie flotacyjnej typu IZ z zastosowaniem frakcjonowanej flotacji powierzchniowej. Określono stan energetyczny powierzchni ziaren węglowych w nadawach, koncentratach z poszczególnych przedziałów wirnikowych i odpadach (Rys. 5. i 6.), co umożliwiło analizę przebiegu i ocenę tego procesu.