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Jerzy SABLIK*

# CONTACT ANGLE, ISOELECTRIC POINT AND STANDARD FLOATABILITY AS FUNCTIONS OF OXYGEN CONTENT IN COAL

The paper presents investigations of contact angle, isoelectric point and standard floatability as functions of oxygen content of hard coal representing the whole metamorphism range. Significant correlation of the parameters was observed for the tested coals. Four types of coal surface have been distinguished, featuring different structure as well as physical and chemical properties and conditioning different floatability.

## 1. Introduction

Among all minerals beneficiated by flotation, both of hydrophylic and hydrophobic surface properties, hard coal features surface properties most complex and most difficult to define. This is due primarily to the fact that different from other minerals, hard coal substance is a mixture of numerous organic coal compounds and as solid features no crystalline structure. Crucial differences in properties determining flotation performance appear not only between coal and other minerals but between different types of coal as well. Both, chemical and physical structure of coal surface, determining the natural and induced flotation response, depend on the coal metamorphism degree. Surface properties may be also influenced by mineral substance dispersed in coal. Generalization and definig of principles for properties of the given coal type to be floated must therefore employ approximate values from several coal samples of similar physical and chemical parameters. The paper presents data for variable values of contact angle, isoelectric point and standard floatability as function of oxygen content of coal. Analysis of data obtained points to four types of coal surface which may be distinguished from the viewpoint of flotation properties.

* Główny Instytut Górnictwa, 40-951 Katowice

## 2. Experimental

### Coal samples

Specifications for coal samples tested are included in Table 1. According to the coalification value tested coal was divided into 10 groups of similar carbon and oxygen content, covering the whole hard - coal metamorphism range. Table 1 provides approximate values for each group. A detailed description of sample selection procedure may be found in [1,2].

Table 1

Characteristics of the tested coals

| Coal No | Number of Samples | Mean content, % | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ash $A^a$ | Volatile matter $V^{daf}$ | Carbon $C^{daf}$ | Hydrogen $H^{daf}$ | Oxygen $O^{daf}$ | Sulphur $S_t^a$ |
| 1 | 4 | 5,68 | 37,95 | 78,59 | 4,69 | 13,5 | 1,16 |
| 2 | 4 | 3,60 | 36,70 | 80,44 | 5,22 | 12,5 | 0,89 |
| 3 | 4 | 3,07 | 35,94 | 81,41 | 4,84 | 12,2 | 0,69 |
| 4 | 4 | 3,64 | 34,81 | 84,01 | 5,03 | 8,7 | 0,55 |
| 5 | 5 | 5,93 | 33,12 | 85,78 | 5,12 | 6,6 | 0,78 |
| 6 | 4 | 4,75 | 36,36 | 85,49 | 5,26 | 6,7 | 0,84 |
| 7 | 4 | 2,89 | 28,05 | 87,42 | 5,01 | 5,1 | 0,78 |
| 8 | 4 | 7,46 | 21,84 | 89,68 | 4,38 | 3,0 | 1,00 |
| 9 | 2 | 9,09 | 13,59 | 90,57 | 4,03 | 2,3 | 1,51 |
| 10 | 1 | 8,64 | 9,36 | 91,95 | 3,04 | 1,3 | 1,70 |

### Contact angle evaluation

The contact angle was evaluated on the basis of capillary pressure of the wetting and non-wetting liquid for the given coal surface, following Bartell's [3] procedure. Coal samples were prepared as pellets of 0.1-0.06 mm grade tested in a special design unit [4]. Contact angle was calculated following the equation:

$$\cos\Theta = \frac{P_{Lo}\,\gamma_L}{\gamma_{Lo}\,P_L}$$

where: $P_{Lo}$, $P_L$ - capillary pressure of water and wetting liquid

$\gamma_{Lo}$, $\gamma_L$ - free surface energy of wetting liquid and water

The wetting liquid used here / $\Theta = 0^o$/ was benzene.

Determination of $pH_{iep}$

Isoelectric points of the tested coals were determined by using electroosmosis technique. Measurements of electrokinetic potential employed Gortikov's [5] device. Electrokinetic potential was calculated using the equation of Helmholtz and Smoluchowski:

$$\zeta = \frac{4\pi\eta V \varkappa}{D I t}$$

where: $\eta$ - liquid viscosity
V - volume of liquid transferred
$\varkappa$ - specific conductivity
D - diaelectric constans
I - current intensity
t - transfer time for liquid of V volume.

Standard floatability evaluation

Floatability [1,2] of the tested coals was determined in a laboratory flotation machine of 0.25 $dm^3$ cell capacity using 0.5-0.0 mm size coal. The flotation agent was the collector /90%/ and froth generating substance /10%/ mixture of 1 g • 1 $kg^{-1}$ amount. Concentration of solids in the suspension was 100 g • $dm^{-3}$; flotation time was 120 sec.

3. Test results

Test results are illustrated by Fig. 1. Contact angle /a curve /, $pH_{iep}$ /b curve/ and standard floatability /c curve/ have been presented as function oxygen content of coal.

Contact angle values are highest for coal containing approx. 3 to 6% oxygen, reaching nearly $90^0$. Contact angle is similar for coal of higher or lower metamorphism degree /oxygen content below 3% or above 6%/. The lowest contact angle value was observed for coal of oxygen content higher than approx. 12.5%. It is claimed that the phenomenon effects from the occurrence, apart from hydroxyl groups, of ionogenic carboxyl groups [6] increasing considerably the surface polarity. The results obtained are comparable to data by other authors [7,8,9], however their reports usually lack information on the chemical structure of the tested coal; it is therefore difficult to draw detailed conclusions.

Isoelectric point /$pH_{iep}$/ features variability practically identical to the contact angle of the tested coals. For coal of the lowest metamorphism degree /oxygen content above 12.5%/ $pH_{iep}$ ranged between 2.5 and 3.0 and reached 7 for coal of high metamorphism degree. For

coal of maximum coalification /oxygen content below 3%/ the value of iep was lower than the maximum one obtained for coals of medium grade of metamorphism. The values of $pH_{iep}$ presented on Fig. 1 /b curve / agree with those reported by other authors [10,11, 12, 13].

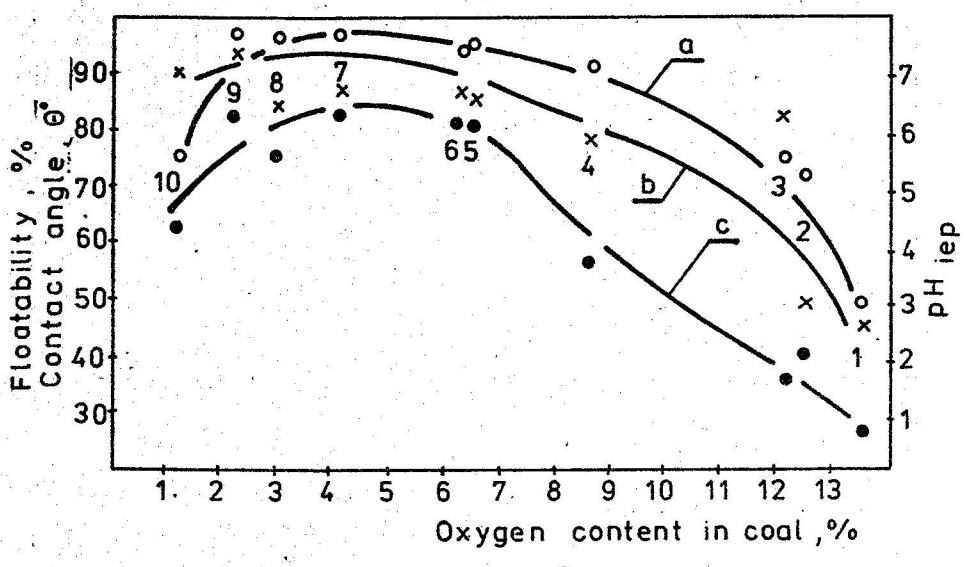


Fig. 1. Dependence of values of contact angle /a/ $pH_{iep}$ /b/ and standard floatability /c/ on oxygen content in coal

The shape of the curve for standard floatability of the tested coals /Fig. 1/ c curve/ is close to the curves $\Theta = f$ /oxygen content / and $pH_{iep} = f$ /oxygen content/. Decrease of the oxygen content of coal points however to higher floatability decrease than it would be deduced from the decrease in contact angle and $pH_{iep}$ values. It is claimed that this is the consequence of the increased specific surface of low coalification coals [14] resulting in the reduced amount of flotation agent per unit surface.

4. Discusion

The data presented show high correlation between contact angle and isoelectric point values and coal flotation response. These parameters depend to a great extent on oxygen content of coal as well as the degree of aromatization and the internal structure. It may be assumed that the flotation response of coal is function of the same surface properties as contact angle or $pH_{iep}$. Models of coal surface constructed on

the basis contact angle and $pH_{iep}$ may then be employed to interpret the mechanism of flotation agent's activity.

The investigations carried out allowed to distinguish four types of coal surface.

Coal of lowest oxygen content features high aromatization and highest order of the internal structure [15], which effects in the appearance of $\pi$ electrones [16] and consequently, in easy polarization of the surface. Such structure results in the values of contact angle, $pH_{iep}$ and standard floatability values /Fig. 1, coal No. 10/ lower than the maximum ones. The carbon content exceeds 90% in this case.

The next group includes coal of maximum values of the evaluated parameters /Fig. 1, coal No. 5,6,7,8,9/. In this coal, oxygen content is lower than the value required for oxygen occurrence in hydroxyl group /5-6%/; carbon content ranges between 85 and 90%. The degree of coal structure order and of aromatization are comparatively low, therefore $\pi$ electrons cause no surface polarization. Such coal features the highest hydrophobic properties and flotation response.

The increase of oxygen content of coal above 5% results in the occurrence of functional oxygen as hydroxyl groups [6] on the coal surface. Test data presented in Fig. 1 /coal No.2,3,4/ indicate that under such conditions the value of contact angle and $pH_{iep}$ is reduced which points to the reduced hydrophobic properties of the surface and decrease in flotation response.

If oxygen content of coal exceeds approx. 12.5% then ionogenic carboxyl groups appear in the coal structure [6]. Their presence results in considerable decrease of contact angle values /down to $50^{0}$/ and shifting of $pH_{iep}$ to the range 2.5-3.0. The effect is nearly absolute decay of flotation response under standard conditions /Fig. 1, coal No. 1/. Such coal contains less than 80% of carbon and feastures the lowest metamorphism degree among hard coal types.

The division of coals presented above was based on surface properties important for their flotation response and was different to the well known technical classification which was often used for characterization of coals predestined for floatability testing.

x Discussion and generation of the issues of flotation of the given coal type under different conditions should be preceded by detailed information on the type of surface. This will facilitate application of test data dor coal flotation provided by different authors.

## 5. Conclusions

The research work performed on samples of different types of subbituminous, bituminous and anthracite coals showed that the values of isoelectric point, contact angle and standard floatability as a function of oxygen content of coal represented very similar mutability.

The shapes of the curves illustrating the studied dependence between isoelectric point, contact angle and standard floatability and the oxygen content of coal, as well as the knowledge concerning physical and chemical structure of coals of different coalification enabled the distinction of four types of coal surfaces depending on their flotation response:

1° Surfaces of coals containing oxygen in organic compounds only; the lower values of the tested parameters than the maximum ones were caused by easy polarization of surface as an effect of $\pi$ electrons action.

2° Surfaces of coals containing oxygen in organic compounds only and representing the maximum values of the tested parameters, due to lower degree of coal structure order the action of $\pi$ electrons disappeared.

3° Surfaces of coals containing oxygen not only in organic compounds, but in an increasing number of hydroxylic groups as well; the presence of hydroxylic groups caused the decrease of the values of the tested parameters.

4° Surfaces of coals containing oxygen in organic compounds, hydroxylic groups and in carboxylic groups; the values of the tested parameters were the lowest and the flotation response in standard condition disappeared almost completely.

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Streszczenie

J.Sablik, 1990. Graniczny kąt zwilżania i punkt izoelektryczny oraz flotowalność standardowa jako funkcja zawartości tlenu w węglu. Fizykochemiczne Problemy Mineralurgii. 22; 119-126.

Przedstawiono wyniki badań zależności granicznego kąta zwilżania, punktu izoelektrycznego oraz flotowalności standardowej od zawartości tlenu w węglu. Przedmiotem badań były próbki węgli kamiennych o różnym stopniu zmetamorfizowania i antracytu od najniżej uwęglonych /typ 31.1 wg polskiej klasyfikacji/ do najwyżej uwęglonych /typ 42/. Stwierdzono, że kierunki zmian wartości badanych parametrów uwarunkowane zmianami zawartości tlenu w węglu są dla tych parametrów jednakowe i wskazują

na istnienie dużej korelacji między odpowiednimi wartościami. Uwzględniając uzyskane wyniki badań i niektóre dane o strukturze badanych węgli dokonano klasyfikacji tych węgli na cztery grupy różniące się własnościami powierzchniowymi i aktywnością flotacyjną.

СОДЕРЖАНИЕ

Е. Саблик, 1990. Краевой угол смачивания, изоэлектрическая точка и стандартная флотируемость как функция содержания кислорода в угле. Физикохимические вопросы обогащения, 22; 119-126.

Представлены результаты исследований зависимости: краевого угла смачивания, изоэлектрической точки и стандартной флотируемости от содержания кислорода в углях различных стадий метаморфизма. Обнаружено существование большой корреляции между исследуемыми параметрами. Эти результаты использованы для классификации углей на четыре группы, отличающиеся поверхностными свойствами и флотационной активностью.