GOSPODARKA SUROWCAMI MINERALNYMI

Tom 24 2008 Zeszyt 4/1

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A correlation between water content in froth and flotation results of hard coals

Introduction

Water content is one of major parameters characterizing properties of flotation froths. Flotation froths belong to transient foams of low stability and high liquid contents. Low stability of flotation froth is required, because it should rupture quickly when removed from flotation machine together with the collected concentrate. According to Melo and Laskowski (2007) the bubbles carry increasing amount of water and become finer with increasing concentration of frother. The amount of water carried with bubbles into froth layer affects many sub-processes taking place in the froth which can significantly affect the concentrate quality.

In flotation the particles reach the froth layer either by "true flotation", i.e. as the bubble-grain aggregates and/or by "entrainment" (Leja 1982), i.e. as the particles suspended in the solution layers carried with the bubbles in the froth layer. The flotation aggregates are formed when the bubbles collide with grains having hydrophobic surface and the bubbles act as carriers of the hydrophobic grains. The hydrophobic grains are concentrated in the froth and the concentrate is obtained by skimming the top froth layer from the flotation cell. The hydrophilic grains are not attached to the bubbles during collisions. They sink to bottom of the flotation cell and form the cell tailings (Laskowski 1976, 1998). There can be contained also the hydrophobic grains, which were detached from the bubbles, because were too heavy. On the other hand the concentrate contains, besides hydrophobic particles, also the hydrophilic ones which are transported into the froth column via the "entrainment"

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(Ireland et al. 2007; Konopacka 2005), i.e. the hydrophilic (gangue) grains are carried within the liquid layer surrounding the bubbles entering the froth layer. As a result of the entrainment the grade of the froth product is reduced. Ireland et al. (2007) pointed out that it has long been recognised that the mass of entrained solids is related to the recovery of water into the froth product, and the concentration of solids in the pulp remaining in the cell. In general, the entrainment is closely linked to the conditions in the pulp such as solids concentration, grains size distribution, air flow rate and bubble size. The degree of entrainment increases with water contents in froth and decreases with increase in grains size (Zheng et al. 2006).

It was showed in many studies (Laskowski1976; Drzymała 2001; Małysa et al. 1981) that majority of mineral grains shows hydrophilic properties and various chemical reagents are used to modify their surface properties. There are three main groups of the reagents applied, namely: collectors, frothers and modifying agents, which are classified in respect to their action during flotation separation. Collectors are the reagents added to modify, in a selective manner, hydrophilic/hydrophobic properties of various grains to facilitate their flotation separation. Modifying agents are added to help either to keep a hydrophilic character of the selected component grains or to reinforce the action of the given collector and respectively, they are called depressants and activators. Frothers task is to increase a dispersion degree of the air introduced into flotation cell, through diminishing diameters of the bubbles formed and preventing their coalescence. Moreover, a dynamic adsorption layer formed by frothers molecules adsorbed over surface of the floating bubble cause a lowering the bubble velocity (Krzan et al. 2002, 2004). As a result of lowering the bubbles velocity the time of contact of the colliding bubbles and grains is increased and probability of formation the bubble-grain aggregates is higher. Frother main task is to assure formation of a froth layer of a definite stability.

Froth layer formed above the pulp is a zone necessary for concentrating of the grains floated and their separation from the pulp. Amount of liquid contained in froth is related to thickness of water layers surrounding the floating bubbles, when they enter the froth layer, and depends on the structure of the Plateau-Gibbs border and drainage kinetics. It is worthy to underline that the drainage kinetics can be affected in significant degree by amount and size of the solid particles contained in the froth column. Simultaneously, a supplementary segregation of the hydrophilic grains (cleaning action of froth) depends on water contents and distribution in the froth layer. Froth drainage can lead to a removal of particles, which are not strongly attached to bubbles, i.e. gangue grains of having low hydrophobicity. The water content and its distribution along the foam height are important parameters as regards both supplementary separation and amount of solution removed from flotation machine together with the concentrate (Malysa 1998). Thick foam films (high liquid content), especially in bottom part of the froth layer, would be advantageous for the cleaning action occurring in froth column because the larger hydrophilic particles can drain back into the pulp. On the other hand, the amount of liquid contained in the concentrate collected should be as small as possible because it is an additional load for further processing of the concentrate and there are contained hydrophilic gangue grains. The finer the hydrophilic particle is the more likely it remains suspended in the inter-bubble water and to be contained in the concentrate. Similarly, the higher water content in the top froth layer, which is removed from flotation machine together with the concentrate, the larger probability that there will be more hydrophilic grains contained due to the entrainment process. It leads to lowering the selectivity of the flotation separation. Thus, the water contents in froth column are of great importance for selectivity of the flotation separation (Laskowski 1998; Leja 1982; Pugh 1996). Moreover, it was showed recently (Małysa, Surowiak 2006a, b) that the amount of water contained in the flotation concentrate depended on the solids concentration in the pulp and the pulp volume.

The paper is devoted to analysis of the interdependencies between results of the coal flotation and water contents in the froth products. Influence of solids concentration in the pulp and time of flotation on water contents in froth and coal yields was studied.

1. Materials and experimental procedures

The concentrate of the coking coal originating from the benefication process in the jig was used in studies. Ash contents in the concentrate used were low 2.6 %. The contents of the grains of dimensions 0.5–0.045 mm was 96% in the coal slimes used as a feed for the flotation tests carried out. Thus, influence of fine particles on flotation results was eliminated. Thus, influence of fine particles on flotation results was eliminated.

The flotation tests were carried out at room temperature, using the Denver type laboratory machine of ca. 1 dm^3 capacity. The dry weighted samples were kept in water for 15 minutes prior the flotation tests, to assure complete particles wetting. Next, the samples were conditioned in water in the flotation machine (mixing) for 5 minutes. n-hexanol of concentration $1 \cdot 10^{-3}$ mol/dm^3 was applied in the flotation tests to act simultaneously as the collector and frother (Małysa et al. 1987; Małysa 2000). The time of the coal slime samples mixing with n-hexanol solution (in flotation machine) was 1 minute. Two first products of froth flotation were collected every 15 seconds. The following products were collected after time intervals of 30 seconds and 1 minute. The froth products collected were weighted in “wet” and “dry” states, i.e., together with the water contained in (immediately after collection), and after drying the concentrates.

2. Results and discussion

Water content in froth products, collected after three different flotation times, as a function of the pulp volume is presented in Fig. 1. The concentration of solids in the pulp was 80 g/dm^3 in all experiments. As can be seen, the water content increases with increasing volume of the pulp. Moreover, the amount of water increase is of similar degree for all

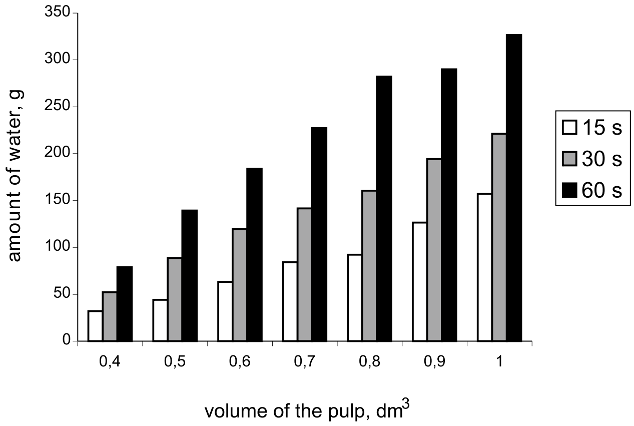

Fig. 1. Dependence of the water contents on volume of the pulp for flotation time of 15, 30 and 60 s

Rys. 1. Zależność zawartości wody w produktach pianowych od objętości zawiesiny dla czasów flotacji: 15, 30 i 60 sekund

flotation times applied. Simultaneously, as one could expect, when the flotation time was prolonged, then the water content in the froth products was higher for each pulp volume. In further studies on influence of the solids content on water recovery in froth product the constant pulp volume of 1 dm^3 was used. Thus, all further data and their analysis refer to the pulp volume of 1 dm^3.

Figures 2 and 3 present the dependences of the concentrate yield and water recovery on flotation time for the pulp with the solids contents of 60, 80,100 and 120 g/dm^3. It is seen that the concentrate yield (Fig. 2) and water recovery (Fig. 3) are increasing with the flotation time. For example at the solids concentration of $60 g/dm^3$ in the pulp the concentrate yields were ca. 80% and 98% after flotation times of 30 and 120 seconds, respectively. Simultaneously, for the same flotation times and pulp density the water recoveries (Fig. 3)

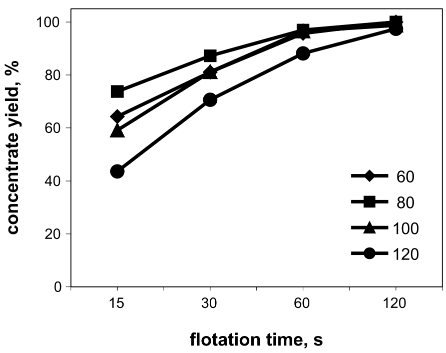

Fig. 2. Yields of the flotation concentrate as a function of flotation time for pulp densities of 60, 80, 100 and 120 g/dm^3

Rys. 2. Wychód koncentratów flotacyjnych w zależności od czasu flotacji dla zawartości części stałych w zawiesinie: 60, 80, 100 i 120 g/dm^3

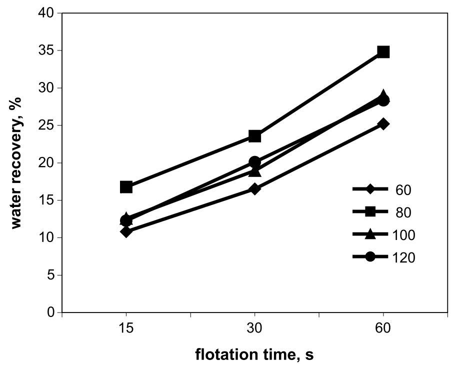

Fig. 3. Water recovery in the froth product as a function of the flotation time for the pulp densities of 60, 80, 100 and 120 g/dm^3

Rys. 3. Uzysk wody w produktach pianowych w zależności od czasu flotacji dla zawartości części stałych w zawiesinie: 60, 80, 100 i 120 g/dm^3

were ca. 16 and 25%, respectively. It can be also noted in Figs. 2 and 3 that the highest values of the concentrate yields and water recoveries were found for the pulp density of 80 g/dm^3.

Variations of water recovery in froth products with the pulp density are presented in Fig. 4 for three different flotation times. It is clearly seen there that for all flotation times the highest value of the water recovery was observed for the solids content in the pulp of 80 g/dm^3. It needs to be underlined here that for other volumes of the flotation pulp the maximum water recovery was also determined for 80 g/dm^3 of the solid content (Małysa, Surowiak 2006b). At lower and higher solids contents in the pulp the water recoveries were smaller. As can be noted in Fig. 5 the variations of yields of the coal concentrates with the solids contents in the pulp were of similar character, i.e. the highest yields were obtained at the solids content of 80 g/dm^3 in the pulp. Thus, there exists a correlation between the water content in the froth products and flotation yield of the coal concentrates (see Figs. 4 and 5).

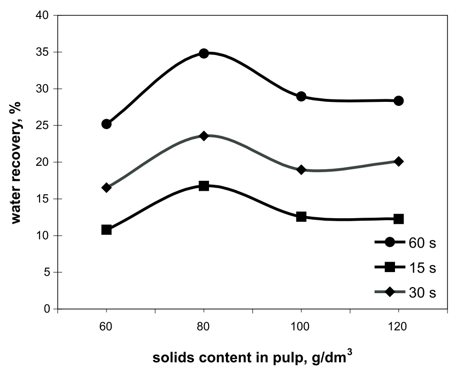

Fig. 4. Dependencies of the water recovery on solids contents in the pulp for flotation times: 15, 30 and 60 s

Rys. 4. Zależność uzysku wody od zawartości części stałych w zawiesinie dla czasów flotacji: 15, 30 i 60 sekund

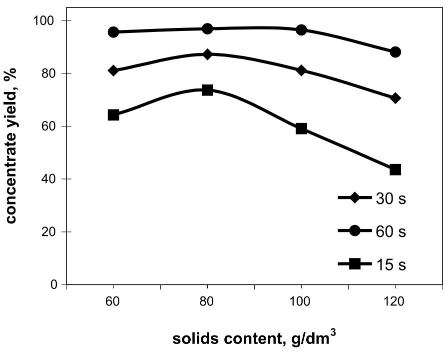

Fig. 5. Dependency of yield of coal concentrates on solids contents in the pulp for flotation times of 15, 30 and 60 s

Rys. 5. Zależność wychodu koncentratów węglowych od zawartości części stałych w zawiesinie dla czasów flotacji: 15, 30 i 60 sekund

Mutual interdependencies between the solids recovery, recovery of water both in froth and the froth products, and contents of the solids in the pulp are illustrated in 3-dimensional plot presented in Fig. 6. As seen the best flotation results were obtained at 80 g/dm^3 solids contents in the pulp. At this solids concentration, the yield of the coal concentrate was 73,7% after 15 s of flotation and the water recovery was 16,8%.

Let's discuss why the best flotation results were obtained for the moderate concentration of solids (80 g/dm^3) and reasons of existence a correlation between the water contents in froth products and the coal concentrate yields. Initial increase of the flotation yields with solids concentration in the pulp is most probably related to an increased probability of

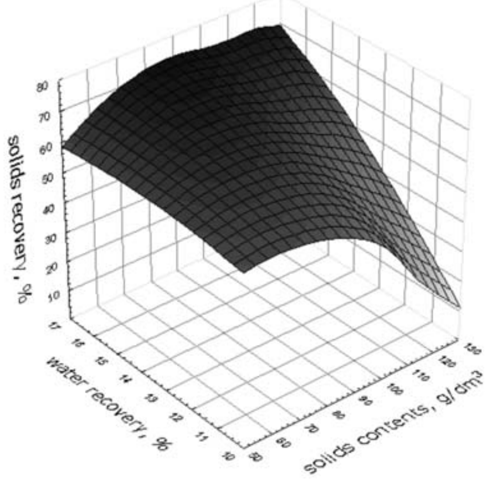

Fig. 6. Yields of the coal concentrate and water recoveries as a function of the solids contents in the pulp at 15 s of flotation

Rys. 6. Wychody koncentratów węglowych i uzysk wody w funkcji zawartości części stałych w zawiesinie po 15 sekundach flotacji collisions between air bubbles and coal grains. The increased probability of the collisions means also a higher probability of formation the stable bubble-grain aggregates, due to which larger amounts of the coal grains are transported to froth layer and collected in the froth products. At high solids concentrations (100 and 120 g/dm^3) there is an increased number of coal grains. Thus, there is also increased probability of collisions of the formed bubble-grain aggregates with the coal grains not attached to bubbles. These collisions can lead to detachment of the coal grains from the aggregates, which have already been formed. As a result of these competitive phenomena the best flotation results were obtained at the moderate solids concentration of 80 g/dm^3. A correctness of this argumentation is confirmed by the correlation found between the yields of the coal concentrates and amounts of water collected in the froth products. The water present in the froth is transported there, as discussed in introduction, mainly in a form of liquid layers surrounding the bubbles. The solid grains attached to the bubbles are also surrounded by similar liquid layers. Thus, when more grains were transported into froth layer they were accompanied by water and therefore the water contents in froth products were higher.

3. Concluding remarks

Mutual interdependences between yields of the coal concentrates and recoveries of water in the froth products were studied for different flotation times and solids contents in the pulp. It was found that there existed a correlation between water contents in the froth products and yields of the coal concentrates. Highest yields of the coal concentrates were obtained when also the water contents in the froth products were the highest ones. This correlation is most probably due to the fact that the water present in the froth is transported there in a form of liquid layers surrounding the bubbles and also grains attached to the bubbles. Thus, when more grains was transported into froth layer they were accompanied by more liquid and therefore the water contents in froth products were higher. Best flotation results were obtained for solids contents of 80 g/dm^3 in the flotation pulp.

The study was carried out within frame of the project: Badania statutowe AGH nr 11.11.100.276.

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KORELACJA MIĘDZY ZAWARTOŚCIĄ WODY W PIANIE A WYNIKAMI FLOTACJI WĘGLA KAMIENNEGO

Słowa kluczowe

Flotacja węgla, uzysk wody, piana, zawartość części stałych, węgiel kamienny

Streszczenie

Istotnym czynnikiem wpływającym na proces flotacji węgla są właściwości piany powstającej w maszynie flotacyjnej. W pianie następuje gromadzenie ziaren składnika użytecznego. Wraz z ziarnami mineralnymi przyczepionymi do pęcherzyków gazowych przechodzi do produktu pianowego również pewna ilość cieczy z zawiesiny flotacyjnej. Zawartość cieczy w pianie jest ważnym czynnikiem zarówno z uwagi na proces dodatkowej separacji w warstwie piany jak też na ilość roztworu usuwaną wraz ze zgarnianą z koncentratem warstwą piany. Dlatego też piana powinna być odpowiednio trwała oraz powinna zawierać odpowiednią ilość roztworu. Zbyt duża ilość cieczy w usuwanej wraz z koncentratem warstwie piany jest niekorzystna, ponieważ stanowi to obciążenie dla dalszych operacji przeróbczych np. filtracji. Ponadto usuwany jest z układu flotacyjnego roztwór wraz z odczynnikami niezbędnymi dla procesu flotacji. Zbyt mała zawartość cieczy jest niekorzystna dla procesu dodatkowej segregacji zachodzącej w warstwie piany.

Celem pracy było określenie korelacji między wynikami flotacji węgla a zawartością wody w pianie. Przeanalizowano wpływ zawartości części stałych w zawiesinie flotacyjnej oraz czasu flotacji na wychody koncentratów węgla i uzyski wody w produktach pianowych. Badania te dotyczyły koncentratu węgla pochodzącego z osadzarki wzbogacającej miał węglowy w jednym z zakładów mechanicznej przeróbki węgla kamiennego. Koncentrat charakteryzował się niską zawartością popiołu, a ponadto węgiel ten był bardzo dobrze flotujący. Na podstawie wyników flotacji zaobserwowano, że ilość wody w pianie zależy od objętości zawiesiny flotacyjnej. Przy stałej zawartości części stałych w zawiesinie ilość wody w produktach pianowych jest wprost proporcjonalna do objętości pulpy. Ponadto stwierdzono, że istnieje korelacja pomiędzy uzyskiem wody w pianie a wychodami koncentratów węglowych. Najwyższe uzyski wody i wychody koncentratów obserwuje się dla tej samej zawartości części stałych w zawiesinie równej 80 g/dm^3 dla wszystkich badanych czasów procesu.

A CORRELATION BETWEEN WATER CONTENT IN FROTH AND FLOTATION RESULTS OF HARD COALS

K e y w o r d s

Coal flotation, water recovery, froth, solids contents, hard coal

A b s t r a c t

Properties of the froth layer formed in a flotation machine can affect significantly the results of coal flotation. Froth is a product of flotation where concentration of particles of a useful component occurs. Water enters into the froth layer by surrounding both the bubbles and particles attached to the bubbles. Water content in the flotation froth is an important parameter because it affects significantly both the additional separation, taking place in the froth layer, and the amount of aqueous solution removed together with the collected particles. Therefore, the flotation froths should have a definite stability and water contents. Too much water in the froth layer removed from the flotation machine together with the collected concentrate is disadvantageous because it is an additional load for further processing operations, for example filtration. Moreover, it means also that solution and flotation reagents needed for the flotation process are being removed from the system. A low solution content in froth is unfavorable for the supplementary segregation process.

The paper aims at finding a correlation between the coal flotation and water contents in the froth products. The influence of solids concentration in the pulp and flotation time on water contents in froth and coal yields was studied. Flotation tests of coal samples obtained from a jig concentrate were carried out in ca. 1 dm^3 laboratory Denver type flotation machine. The coal samples used in the studies were the jig concentrate of hard coal fines obtained from the industrial processing plant. Low ash contents and good floatability were the characteristic features of the coal used. The influence of the solids content in the pulp and flotation time on yield of the coal concentrate and water recovery in the froth products was studied. It was observed that liquid contents in froth were proportional to the pulp volume. Moreover, it was found that there is a correlation between water content in the froth products and the concentrate yields. Highest water recovery and yield of the coal concentrates were observed for the solids contents of 80 g/dm^3 for all flotation times studied.