Water content in froth products depending on the salinity level of pulp flotation

K Tupek-Murowany and A Młynarczykowska
AGH, University of Science and Technology, Faculty of Mining and Geoengineering
Department of Environmental Engineering and mineral Processing, al. Mickiewicza 30, 30-059 Kraków, Poland
ktupek@agh.edu.pl

Abstract. This paper presents the results of the evaluation of the coal flotation efficiency in the presence of an inorganic salt in the pulp. It was shown that change of salt contains (NaCl) in pulp affects to the stability and mineralization degree of floatation foam. These results have confirmed to the effectiveness of enrichment. The quantitative measure of foam quality was the water recovery in this flotation product.

1. Introduction
Flotation is one of the many most complex methods of enrichment. It allows the separation of components useful from gangue in the smallest grades of particles. The effects of the process depend on a number of closely related parameters. The most important aspect for the distribution of foam flotation material is the formation of a float foam layer in the upper part of the pulp.

The foam is formed as a result of floating of particle - gas bubble aggregates to the surface of the pulp surface. Its construction and stability have a significant impact on the quality of the obtained concentrate [1,2].

According to the definition, foam stability is related to the effectiveness of bubbles for foaming, their durability and limited susceptibility to coalescence [2]. The stability of the floatation foam generated in the flotation process depends on type and dose of foaming agents used, gas dispersion, suspension viscosity, size and particles number suspended in the flotation chamber, induction time and the water quality used of the process [1-6]. It turns out that fine particles, mainly grains of gangue have a greater impact on the stability of froth floatation, and thus lead to an increase of water amount in the foam [2,3,6,7]. Similarly, a larger amount of water in the foam means higher content of gangue in concentrate [7,8]. Therefore, very important during floatation it is to drain water from foam, which makes it possible to break off the gangue grains and return back of them to the pulp, thus increasing the quality of concentrate. Greater stability allows better concentrate yield, and its dewatering takes place mainly in lower part of foam, so that the amount of water in froth has been linked to at the speed of receiving the concentrate, depth of its stripping and flotation time [7].

Foam stability is also strongly associated with the salinity of technological water. An addition of electrolyte to the enrichment process results in the production of smaller and more strongly round and dense air bubbles, and also inhibits their coalescence due to the increased repulsive force between them. [3,4,5,6,9,10]. It should be borne in mind, that not all inorganic salts are able to inhibit bubble
coalescence [3,6]. Thanks to the production of fine air bubbles, flotation in saline water leads to better yields of the combustible substance in concentrate. The salt present in the flotation process causes the aggregation of grains, including gangue trapped within the coal grains, thereby increasing its entrainment, which in turn increases the ash content of concentrate and foam stability [2,4,9,11].

In addition, the presence of electrolytes in pulp flotation has a significant impact on the frother. According to Castro et al., 2013 [3], relatively weak surfactants become stronger as a result of increased water salinity, which in the initial stages leads to improved foaming. Nevertheless, at high concentrations of electrolytes, the solubility of frother is blocked. Wei et al., 2016 [5] investigated the effect of common salt in pulp flotation and the frother on foam stability, and they found that salt is a more important stimulus in stabilizing foam.

In summary, it can be concluded that the presence of very stable foam is undesirable, because by mechanical gangue flotation the quality of concentrate is lower [2,12].

The aim of the tests was to determine the impact of salt content in process water on the amount of water in foam products. The relationship between yields and water content in products has been evaluated.

2. Flotation tests

The tests were carried out on a 32.2 type carbon slurry with a particle size below 1 mm, of which almost 50% of grains constituted a particle class below 0.063mm. The average ash content of the examined coal was 26.55%.

The flotation tests were performed in a Denver type pneumatic-mechanical laboratory machine with a working chamber volume of 1 dm$^3$. Both the flotation pulp density and rotor speed for each flotation test was constant and amounted to 80 g / dm$^3$ and 1850 rpm respectively. The RF55 (Reaflot-55) reagent from the glycol group was used as a collector and frother in the flotation process. A variable parameter of experiments was the salt content in process water considered as the content of sodium chloride. One of the test was carried out with mine water taken from one of the Polish mines whose salinity was 0.23M. Water with 0.3 and 0.4M salinity was obtained by adding pure NaCl to mine water. While, the salinity at the level of 0.05M NaCl was obtained by mixing a coal slurry with distilled water. The final salt content (NaCl) expressed by the molar concentrations in process water was: 0.05M, 0.23M, 0.3M and 0.4M. Mixture of distilled water with a coal slurry rinsed from salt was used for flotation test number 5.

3. Kinetics of flotation

Each time, the carbon samples were flooded of saline water (the various salt concentration) and the material was conditioned to moisten it, for 5 minutes. After a set time, the flotation machine was started and mixed feed without air for 1 minute, after which the flotation reagent was added at 1016.21g per ton of dry feed and stirring continued for further 3 minutes. In the next step, the air in flotation chamber was started and the fractional flotation was performed. The total flotation time was 6 minutes except for one case of flotation test (shortening flotation resulted from the absence of mineralization froth flotation and its spontaneous quenched). The concentrates obtained during the flotation tests were weighed with water and after drying. The measurements were carried out in various time steps.

4. Results

The paper evaluates the impact of salinity pulp flotation on water content in the foam. In table 1 presented results obtained from the flotation tests for concentrates and water content in grams for individual flotation concentrates from experiments carried out with variable NaCl content in the pulp.
Table 1. Yields of concentrates and water content in concentrates at a variable salinity level of the flotation pulp, depending on the duration of the process.

| Concentrate number | Flotation time t(s) | F1, salinity of the water 0,4M NaCl | F2, salinity of the water 0,3M NaCl | F3, salinity of the water 0,23M NaCl | F4, salinity of the water 0,05M NaCl | F5, flotation without salt |
|--------------------|--------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------|
|                    |                    | Mass of water in the froth (g) | Yield (%) | Mass of water in the froth (g) | Yield (%) | Mass of water in the froth (g) | Yield (%) | Mass of water in the froth (g) | Yield (%) |
| K1                 | 30                 | 302.6                           | 72.54    | 379.8                           | 71.76    | 274.3                           | 66.54    | 239.6                           | 62.57    |
| K2                 | 60                 | 158.0                           | 8.03     | 169.8                           | 6.92     | 191.0                           | 12.23    | 188.7                           | 14.11    |
| K3                 | 120                | 187.6                           | 4.40     | 233.8                           | 4.90     | 176.1                           | 6.62     | 140.2                           | 8.38     |
| K4                 | 180                | 212.6                           | 3.11     | 224.4                           | 2.59     | 149.7                           | 3.87     | 87.8                            | 3.35     |
| K5                 | 240                | 105.4                           | 1.30     | 151.8                           | 1.15     | 61.4                            | 0.75     | 66.6                            | 1.40     |
| K6                 | 300                | 96.4                            | 1.04     | 102.6                           | 0.86     | 60.5                            | 0.62     | 45.1                            | 0.70     |
| K7                 | 360                | 115.2                           | 1.04     | 111.0                           | 1.15     | 78.5                            | 0.37     | 30.8                            | 0.28     |

In order to visualize the results, the graph showing the dependence of water content in individual foam products for flotation time was presented in figure 1, while figure 2 illustrates the changes of water content in each flotation concentrates depending on the salinity of the process water and reaction time.

Figure 1. The water content in the float foam as a function of the process progress, for the variable salinity level of flotation pulp. F1- F5 – number of the flotation test.
Figure 2. The water content in froth products for individual concentrate in relationship on the concentration of NaCl in flotation pulp. K1-K7 – concentrate number; F1-F5 – number of the flotation test.

The analysis of each of the floatation tests (table 1 and table 2) we may notice that the usual amount of water in the received floatation foam decreases overtime during the process. The highest amounts of water are present in the first floatation concentrates (K1) which reflect the acquired yield values. As the floatation process progresses yield values significantly drop over time along with the amounts of water in the foam. One exception is the example which shows an increase in the amount of water in the foam product of the third (K3) and fourth (K4) concentrate bearing the highest salinity level of the floatation pulp (F1 and F2) - see fig. 2. We can also noticed a minute increase in water amount for the last concentrates in floatations F1, F2, and F3 which does not thoroughly correlate with the increase in yields of these products. The probable cause might be a mechanical elevation of gangue towards the concentrate which raises the density of solid particles in the foam (decreases concentrate quality) and thus the amount of water in the foam.

Taking into account the amount of water in the foam products depending on floatation time for various concentrations of NaCl in floatation pulps (table 1 and figure 1), we can observe a gradual decrease of water in the foam of the first concentrate (K1) for floatations F2 through F4. The correlation does not apply to concentrate K1 for floatation F1 where the water amount in the foam is 77,2 grams less than in K1 floatation F2. However, the yield acquired in F1 is larger than in floatation F2 even though the quality of the concentrate is lower. In concentrate K1 for floatation F1 the ash content is 17,56% whereas in concentrate K1 for floatation F2 equals 16,53%. This tendency might be caused by insufficient solubility of the frother (foaming factor) accompanied by higher levels of inorganic salt and the mechanic elevation of gangue towards the concentrate due to particle aggregation [3], thus we observe a decrease in the amount of water in the foam. Relating to the other floatation concentrates we may observe a descent of water amount in the foam starting with floatation F2 and successively floatations F1, F3, and F4. The trend is inverted for K2 and ranks the floatations respectively F3, F4, F2, and F1. Single derogations occur for K1 F5 where the lack of salt in the water caused a production of a wet foam which correlates with the highest yield for K1. We may assume that a significant salinity of the water adversely impacts the flotation reagent. We must highlight, however, that not only the presence of NaCl but also the amount of salt in the flotation pulp directly affects the enrichment outcomes, because yields for K1 increase along with the salinity of the flotation pulp. For experiments F3 and F4 the quality of the concentrate is also increasing (the amount of ash is F3: $\lambda_A = 14.82\%$ and F4: $\lambda_A = 15.19\%$) compared to the results obtained for F1, F2, and F5 (F1: $\lambda_A = 17.56\%$; F2: $\lambda_A = 16.53\%$ and F5: $\lambda_A = 16.46\%$). Furthermore, we need to highlight the fact that
a large yield does not always correspond with producing a better quality concentrate. Literary sources [2,4,9,11,13] support the theory that a large amount of water in the foam might be the stimulus of raising the hydrophilic particles towards the foam layer. Similar to the aforementioned case, despite higher figures of yield the quality for concentrate K1 in flotation F5 ($\lambda_A = 16.46\%$) has decreased in comparison with the results of flotation F3 ($\lambda_A = 14.82\%$) and F4 ($\lambda_A = 15.19\%$).

5. Summary
The article is an analysis of the effects of salt in the form of sodium chloride in water on the amounts of water in flotation foam. The analysis of water in the foam has been correlated with yield amount and quality of concentrates. On the basis of the presented results of experiments carried out we may assume that:

- increased wetness of the flotation foam allows to obtain higher yield concentrates compared to the first enrichment products, although they are of lower quality,
- usually the amount of water in the flotation foam increases with the growth of water salinity
- on average water amount in flotation foams drop as the process progresses over time,
- in the event of a lack of salt in the flotation pulp, but also with higher levels of salinity, there is correlation between the increase of yield in first concentrates, which is caused by the presence of hydrophilic particles, and the increased amount of water in the flotation foam,
- raising the level of inorganic electrolytes in the flotation pulp leads to mechanical elevation of gangue towards the concentrate.

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