Analysis of the Gas Phase in Flotation Process. Part 2 Empirical Functions of Occurrence Frequency of Tested Parameters

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Abstract

Mineralization of air bubbles, the most important part of the froth flotation process, depends on a number of factors which affect the conditions in the flotation chamber's work space. They can be defined as physico-chemical parameters and hydrodynamic parameters. The latter depend on the operating conditions of the floatation machine during the enrichment process. The process of forming of durable flotation aggregates is preceded by generation and dispersion of gas bubbles in the flotation machine tank which also depend on the aforementioned parameters. The paper presents the results of experimental analyses of changes of selected values which define the size of air bubbles generated in the flotation chamber.

Keywords: cell flotation, air bubbles distribution, empirical verification of the theoretical model

Introduction

Elementary flotation actions can be described quantitatively as probabilities used to measure the effectiveness of individual sub-processes. A collision of a particle with an air bubble is one of such probabilities and it determines the air bubble mineralization rate during flotation.

There are probabilistic models of the particle-air bubble collision or probability distribution models in the function of quotient of random variables: particle size and bubble size which also are subject to distribution (Brożek 2010). There are mathematical descriptions which account for energy dissipation in the flotation chambers with mechanical agitation of the suspension which treat the bubble surface as an elastic body (Woodburn et al. 1971), or empirical models which verify and modify the earlier descriptions (Brożek and Młynarczykowska 2010).

Dispersion of bubbles in the flotation machine's work space and changes of energy at phase boundaries can be connected starting from the Boltzmann distribution because the air supplied to the flotation chamber is dispersed in turbulent vortices of the liquid. Brożek and Młynarczykowska (2012) expressed the bubble size distribution by means of the Rayleigh distribution, belonging to the gamma distributions family, obtained on the basis of heuristic considerations. The bubble size distribution and mean bubble diameter are overtly expressed by the number of rotor revolutions, air consumption in a unit of time, method of air supply to the flotation chamber, surface tension of the solution depending on the surfactant addition.

Taking into account the type and amount of flotation reagent used, the flotation chamber aeration degree, forces acting on the forming flotation aggregate, the formula for the minimum bubble size is as follows: (1),

$$D_{b\min} = \frac{\pi(\rho_s - \rho_c)\,D_p}{\rho_c} \qquad (1),$$

where: D_p – particle diameter, D_b – bubble diameter, ρ_c - liquid density, ρ_s – grain density.

Hence, the minimum bubble size depends on the density and size of floated particles. For example, for coal with particle density ρ_s = 1.5 Mg/m^3 and ρ_c = 1.0 Mg/m^3, $D_{b\min}$ = 1.57 D_p (Brozek and Młynarczykowska 2012). In addition, while calculating the most probable value of D_p/D_b random variable quotient, Brożek (2010) obtained the formula for the probability of the bubble-particle collision in the flotation chamber with mechanical pulp agitation. This probability depends on the surface tension of the solution, air consumption, degree of pulp aeration, energy dissipation and average feed particle size. It is described by the following relationship (Brożek, 2010):

$$P_c = a_c\left(\frac{d_p}{d_b}\right)^2 = \frac{1}{3\lambda_p}a_c\lambda_b = \frac{a_c}{3\lambda_p} = \left[\frac{\left(36\,\sigma^2 V_g{}^3 \rho_l g\right)^{\frac{1}{3}} + N_o N^3 D^3 \rho_l \sqrt[3]{d_i}}{6,77\,V_g \sigma \sqrt[3]{d_i}}\right]^2 \qquad (2)$$

where: a_c – coefficients factor, λ_p – distribution parameter of the particles size, D – diameter of a large (dispersed) bubble, entering the flotation chamber [m], V_g – gas flow-rate [m^3/s], σ – surface tension [N/m], ρ_l – liquid density [kg/m^3], N_o – power number assuming the constatnt value for given type of flotation chamber, N – rotational speed of the rotor, d_i – diameter of the pipe (capillary) [m], g – acceleration due to gravity [m/s^2].

It is clear that determination and description of air bubbles in the flotation chamber by relevant dispersion

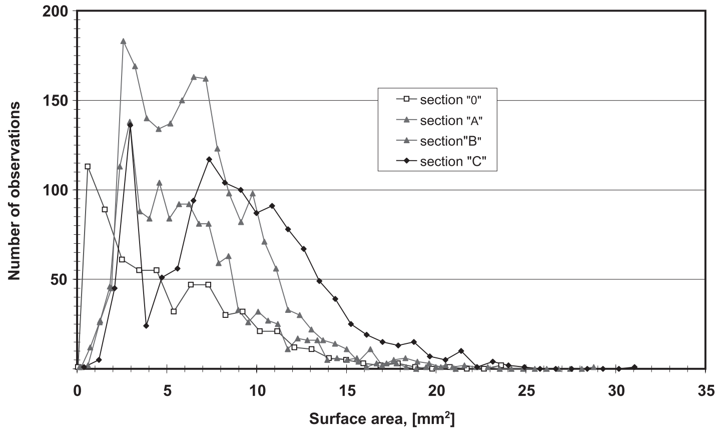

Fig. 1 Changes of gas bubble surface area for the 240 dm³/h airflow

Rys. 1 Zmiany powierzchni pęcherzyka powietrza dla przepływu powietrza 240 dm³/h

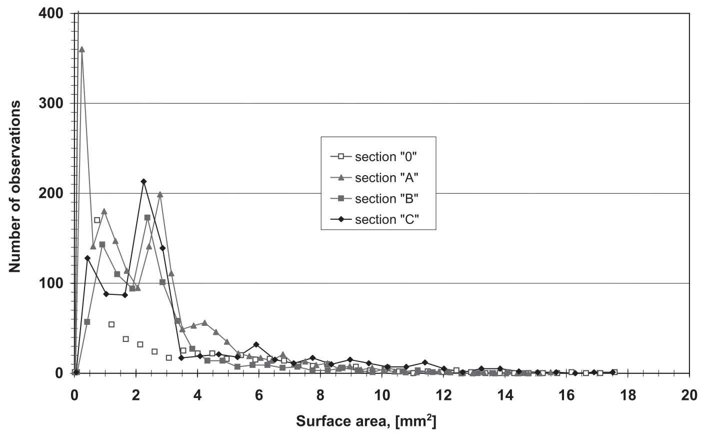

Fig. 2 Changes of gas bubble surface area for the 24 dm³/h airflow

Rys. 2 Zmiany powierzchni pęcherzyka powietrza dla przepływu powietrza 24 dm³/h

parameters will facilitate the analysis of enrichment of a raw material in specific physico-chemical parameters and hydrodynamic parameters.

Measurement Methodology

The measurements were performed on the test stand equipped with a pneumatic-mechanical flotation machine with the automatic control system, aeration system, and image recording system (Młynarczykowska, Nyrek, Oleksik 2015).

Firstly, individual photographs were extracted from the film showing the air bubbles flowing in the flotation chamber. The best quality photos were selected and were processed in order to determine the values (Feret diameter, bubble perimeter, bubble surface area). Professional software was used for the quantitative and qualitative analysis of the recorded images of the bubbles. The analysis was performed for images recorded during the actual operation of the flotation machine: t_0 = 1 s, t_1 = 5 s, t_2 = 10, etc., i.e. for the 5-second time interval.

Empirical Functions of Occurrence Frequency of Tested Parameters

The values in the result tables (Młynarczykowska, Nyrek, Oleksik 2015) do not show the variation of determined values within the entire population of analysed stream of air bubbles from the indicated flotation chamber section.

The tests were conducted with two airflow levels (Q) equal to 24 dm³/h and 240 dm³/h, at specified rotor speed (ω) of 1350 rpm and 1000 rpm for section 0 and sections A, B, C respectively. The reason for using higher rotor speed in cell 0 was the results of previous experiments.

A detailed analysis in accordance with the measurement methodology was performed for each space at specific operating parameters of the flotation machine.

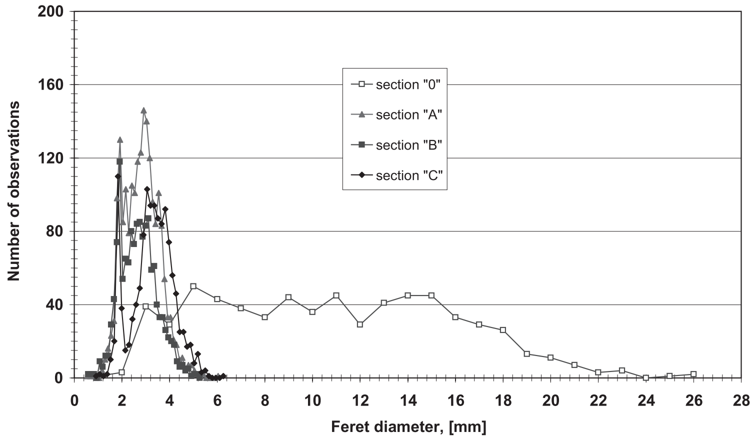

Fig. 3 Changes of air bubble Feret diameter for the 240 dm³/h gas flow

Rys. 3 Zmiana średnicy Fereta pęcherzyka powietrza dla przepływu gazu 240 dm³/h

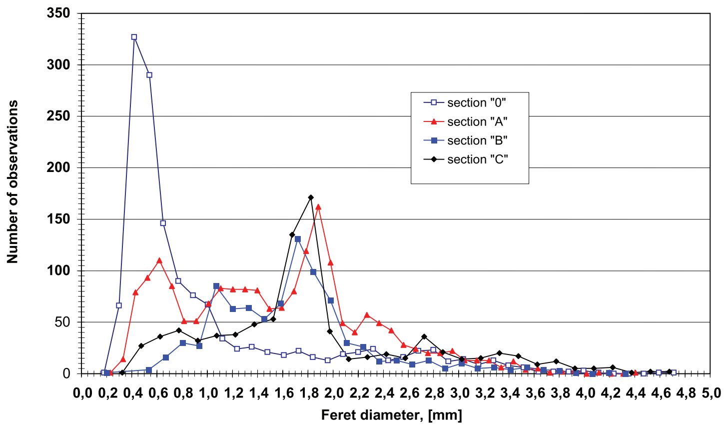

Fig. 4 Changes of air bubble Feret diameter for the 24 dm³/h gas flow

Rys. 4 Zmiana średnicy Fereta pęcherzyka powietrza dla przepływu gazu 24 dm³/h

This allowed to determine the number and size of air bubbles formed in the flotation machine chamber.

The full picture of average values of Feret diameter, perimeter, and surface area of bubbles is presented in Figures 4–9.

The graphs are grouped for individual determined values, according to the variable process parameters, to show the impact of rotor speed and supplied air on the obtained results.

The analysis of the distribution of values of individual measurement fields indicates that the surface area of bubbles dispersed at maximum aeration in the flotation cell is in the 3–12 mm². Under identical conditions, the largest population was determined for section A, and the least population for cell 0. With reduced airflow (24 dm³/h), the mean bubble surface area varies from 0.2 to 3.5 mm². Please note that for the stream of bubbles analysed in section 0 and A the number of observations was large, 360 and 905 respectively, which means that exactly that number of bubbles had indicated size. The results prove that under given conditions of measurement a lot of micro-bubbles are generated which potentially do not have an opportunity to form durable flotation aggregates but can be subject to the coalescence process.

The other measured values, Feret diameter and the gas bubble perimeter, correspond to the surface area.

At conditions of maximum tank aeration and maximum rotor speed, the majority of bubbles have the size in the 1.8–4.0 mm range, which means that the generated bubbles are durable and similar to spherical in shape. The largest spread of values at small population size was achieved for bubbles from cell 0, meaning that a small portion of poorly dispersed air was supplied to this sector.

The results obtained for the minimum airflow at specified rotor speed indicate the dispersion of two separated groups of the population in relation to the bubble

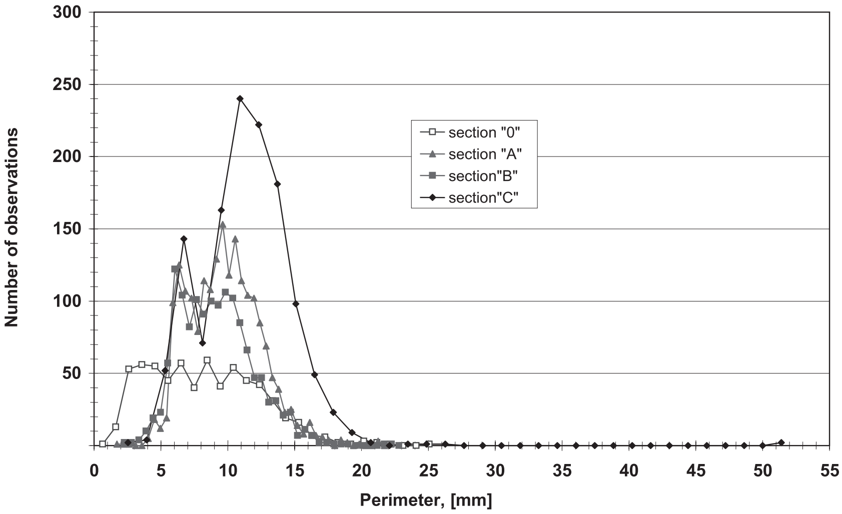

Fig. 5 Changes of air bubble circumference for the 240 dm³/h gas flow

Rys. 5 Zmiany rozmiarów pęcherzyka powietrza przy przepływie gazu 240 dm³/h

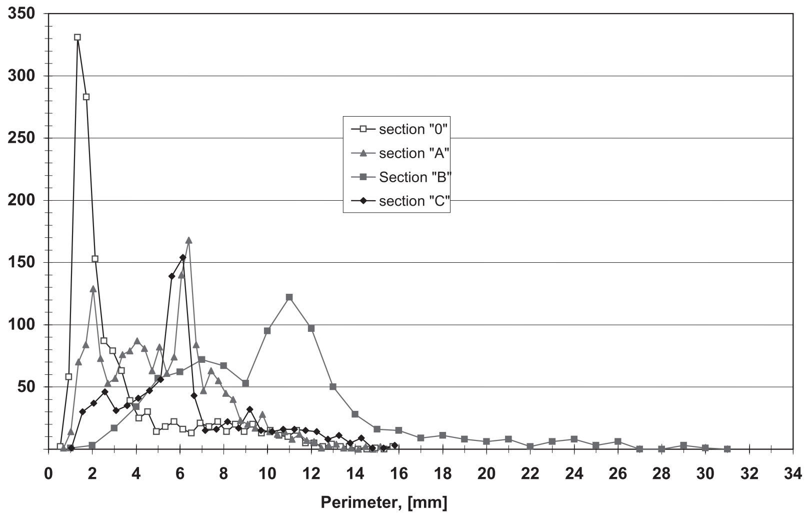

Fig. 6 Changes of air bubble circumference for the 24 dm³/h gas flow

Rys. 6 Zmiany rozmiarów pęcherzyka powietrza przy przepływie gazu 24 dm³/h

surface area which is shown in the graphs as peaks. A large number of micro-bubbles with Feret diameter in the 0.2–0.8 mm range were formed, and half the number of micro-bubbles with Feret diameter from 1.5 to 2.1 mm.

Fig. 8. showing the distribution of air bubble perimeter values for the specified flotation machine operating conditions, indicates analogous patterns as in the previous cases. At maximum rotor speed and maximum tank aeration (240 dm³/h) the air bubble circumference is in the 5–14 mm range, with the least number of bubbles in section 0 and the greatest number in section A as proved by the population size.

At conditions of reduced airflow, the most numerous population was recorded in section 0, with dominating micro-bubbles however. In remaining sections, the number of air bubbles was two times less and their mean perimeter was in the 4–12mm range.

It should be emphasized that all calculated values which describe the physical properties of gaseous phase are interconnected by fundamental mathematical relationships. Thus, it is possible to calculate their theoretical values, for instance the air bubble surface area, using only the measurements of the Feret diameter. These considerations will be described in a separate paper.

Summary

Taking into account the presented and discussed experimental results and additionally analysing the relationships on graphs (Fig. 4–9) for population of air bubbles generated in the flotation tank and sent to its individual sectors as oriented streams, the following observations can be made:

1. The most numerous populations are formed at conditions of maximum rotor speed and reduced airflow.
2. The largest number of qualitatively homogenous populations for this type of flotation machine is obtained at high rotor speed and reduced aeration.
3. The most homogenous, stable in terms of shape, and durable bubble streams are generated in the corner spaces of flotation tank, sectios A and B.
4. The least values of air bubble surface area, circumference and Feret diameter were obtained in section 0, accompanied by a small bubble population.

Acknowledgements
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Analiza fazy gazowej w procesie flotacji.
Część 2. Funkcje empiryczne częstotliwości występowania badanych parametrów

Mineralizacja pęcherzyków powietrza jest najważniejszym etapem procesu flotacji pianowej. Zależy on od szeregu czynników wpływających na warunki panujące w przestrzeni roboczej komory flotacyjnej. Można je określić jako parametry fizykochemiczne oraz hydrodynamiczne. Te ostanie są zdeterminowane warunkami pracy maszyny flotacyjnej podczas procesu wzbogacania. Procesem poprzedzającym tworzenie trwałych agregatów flotacyjnych jest generowanie i dyspersja pęcherzyków gazu w komorze maszyny flotacyjnej, które są również zależne od wymienionych parametrów. W artykule przedstawiono wyniki analiz doświadczalnych zmiany wybranych wielkości opisujących rozmiary pęcherzyków powietrza generowanych w komorze flotacyjnej.

Słowa kluczowe: flotacja komórek, rozkład pęcherzyków powietrza, empiryczna weryfikacja modelu teoretycznego