MINING AND METALLURGY INSTITUTE BOR

and

TEHNICAL FACULTY BOR, UNIVERSITY OF BELGRADE

IOC 2018

International October Conference

50th International October Conference
on Mining and Metallurgy

PROCEEDINGS

Editors:
Ana Kostov
Milenko Ljubojev

30th September – 3rd October 2018
Hotel "Jezero" Bor Lake, Serbia

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SEPARATION OF THE PS/ABS PLASTICS USING THE FROTH FLOTATION

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Abstract

Flotation is the process of separation based on the different physical-chemical characteristics of surfaces and their ability to wet with water. The process can be used for separation the primary and secondary materials. This paper presents the results of a laboratory study separation of plastic waste. The aim is to extract the PS plastics from the PS/ABS mixture. Experiments were carried out in a Denver cell at the pH 7 in presence of the Tannic acid as a depressant, and MIBC as a frother. The results showed that the PS plastics has a higher flotation rate constant value and high quality value (over 90%). The results indicate that the ABS and PS could be successfully separated by the froth flotation under the certain conditions. The obtained results were represented by the classical model of the first-order trying to describe the kinetics of plastics flotation with a good correlation coefficient.

***Keywords**: flotation, PS, ABS, plastic waste, kinetic model*

1 INTRODUCTION

Flotation is the process of concentration the mineral raw materials based on the different physical-chemical characteristics of mineral surfaces and their ability to wet with water [1]. The application of the flotation process in concentration the metallic minerals [2,3], non-metallic minerals, paper [4,5], plastic materials [6,7] etc., has significantly contributed to the development of various flotation reagents [1]. From the discovery of flotation concentration, the process itself is continuously developed and established in the mineral raw industry as a selective process or process of separation the mineral raw materials. Currently, the processes of plastic separation by the froth flotation are in the early stages of development [8]. The idea to apply the flotation to separate one type of plastic from a mixture of plastic was a logical step as the ore flotation research has showed that the surface properties of different materials can be altered selectively by the surfactant adsorption [9]. The application of froth flotation for plastic separation is challenging due to the similarity in the surfaces properties. All plastic have the naturally hidrophobic surfaces and will readily with the aid of air bubbles, and it is necessary that one of products become a hydrophilic. One of the methods of wetting is the use of wetting agents [10]. In the plastic flotation, the selective adsorption of depressants influences the affinity of air bubbles for different types of plastic [11]. Figure 1 shows the difference of mechanism of forming a bubble aggregate in the ore and plastic particles. In the ore flotation, a small particle is attached to one small air bubble, while in the plastic flotation, numerous small air bubbles are attached to one large plastic particle [7]. Besides the flotation process, the plasticz waste can also be separated by the other methods: magnetic separation, eddy current separation, electrostatic separation, separation in hydrocyclones and others [12].

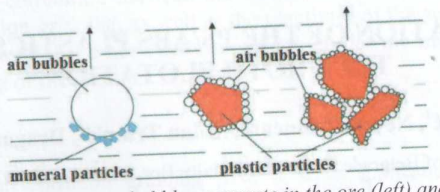

Figure 1 *Mechanism of forming a bubble aggregate in the ore (left) and plastic (right) [7]*

In this paper, the focus is on experimental studies on separation the ABS and PS plastics by the froth flotation, and the classical model of the first-order is used for mathematical interpolation of flotation kinetics

$$\ln\frac{1}{1-I_t} = kt \quad (1)$$

where *It* is flotation recovery, *k* is flotation rate constant, *t* is flotation time. Equation (1) presents the equation of a straight line in a coordinate system [t; $\ln\frac{1}{1-I_t}$].

2 EXPERIMENTAL

2.1 Materials and Methods

The ABS and PS samples were collected from the recycling company in Ćuprija. The plastics differed on shape which facilitated separation through the manual sorting at the end of each flotation test. The samples are shown in Figure 2. The density of both plastics, measured by a picnometer, ranged from 1024 kg/m^3 (PS) to 1034 kg/m^3 (ABS). The both plastics were screened to obtain a size fraction -3.35+2.36 mm. The sample (5g of each polymer) was introduced in the Denver cell with volume of 2.2 l and agitated at rotational speed of 1100 rpm for 5 min with 4,4 ml of solution of tannic acid [7,13] as a wetting agent, and for 5 min with 6.6ml solution of Methyl Isobutyl Carbinol (MIBC) [7,13] as a frothing agent. The pH value in the flotation cell was approximately constant, about 7. In each flotation test, the floated product was collected after a certain time, from 0.5 to 10 min, hence float and the sink products were collected. Both float and sink products are collected, dried, manually separated and weighed.

Figure 2 *Sample of PS (left) and ABS (right)*

3 RESULTS AND DISCUSSION

Table 1 shows the recovery and quality of both polymers in the floated and sink products, obtained in the kinetic tests, carried out under the same conditions.

Table 1 *The results of recovery and quality of the ABS and PS plastics in the foam product after flotation*

pH 7	MIBC 3 ml/l, Tannic acid 2 ml/l			
t (min)	It (%)		k_p (%)	
	ABS	PS	ABS	PS
0.5	2.4	16.2	12.91	87.09
1	3.4	30.0	10.18	89.82
2	5.6	44.6	11.16	88.84
4	6.0	62.4	8.77	91.23
7	7.4	71.2	9.42	90.58
10	**7.4**	**75.4**	**8.94**	**91.06**

The highest values obtained for the recovery and quality of PS plastics in the foam product were after 10 minutes of flotation at a concentration of TA=2 ml/l, and MIBC=3 ml/l, It=75.4 %, 91.06 %, respectively. The recovery and quality of the ABS plastics recovery, at the same concentration and after the same flotation time were It =7.4% and 8.94 %, respectively. Analyzing the obtained results, it can be said that the separation of ABS and PS plastics is possible, since the recovery value were ranged around 75%, however the separated PS product did not have a market quality of 97%. The results of the PS separation from the ABS/PS mixture are graphically described in a coordinate system $\left[t, ln\frac{1}{1-It}\right]$, with the conventional model of flotation kinetics, given by Equation 1.

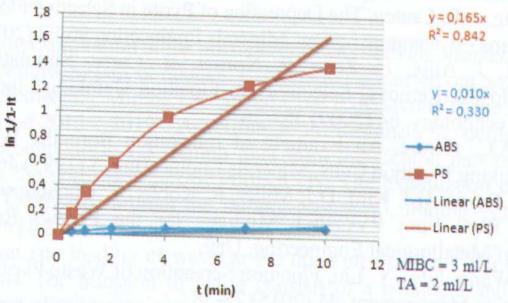

Figure 3 *The influence of flotation time on recovery of the ABS and PS plastics in the foam product*

It can be seen from Figure 3 that the values of the correlation coefficient R^2 for ABS is 0.330 and for PS is 0.842. Considering that the correlation coefficient minimum value R^2_{min} is 0.44 [14], it can be said that this kinetic model can describe the flotation kinetics of PS plastics, but cannot describe the flotation kinetics of ABS plastics. The knowledge on flotation kinetic of the plastic separation is of great importance to evaluate the flotation results and effect of flotation variables with influence on the process.

Table 2 *The values of flotation rate constant k and correlation coefficient R^2*

MIBC 3 ml/l pH 7	PS		ABS	
	k_{PS}	R^2	k_{ABS}	R^2
TA 2 ml/l	0.165	0.842	0.010	0.330

The value shown in Table 2 for the PS flotation rate constant have a higher value compared to the ABS plastics, which suggests a faster separation of the PS plastic particles into the foam layer, or a higher degree of depression the ABS plastics.

4 CONCLUSION

Plastics present a problem on the landfills for decades. In order to reduce the plastic waste, it is necessary to recycle and reuse already used plastics. Flotation is one of the oldest methods used to separate the mineral raw materials. However, a research has shown that flotation can also be used to separate two or more types of plastics that have approximately the same density values. The aim of this experimental work was to examine the possibility of separation the PS plastics from a mixture ABS/PS.

Analyzing the results, it can be concluded that the flotation kinetics of the PS plastics can be described by the classical model of the first order kinetics with a very good correlation coefficient, and flotation rate constant is much higher for the PS plastics than for ABS. Based on the results, it can be said that the PS and ABS plastics can be separated by the flotation, but a further process optimization is necessary and, in that sense, the future research should focus on the second level of flotation, the purify foam products in order to achieve the market product quality of 97%.

REFERENCES

[1] S. Milošević, Flotation Concentration, Technical Faculty in Bor, Bor, 1994, pp. 88-91 (in Serbian)
[2] E.A. Gordon, Flotation of Chalcopyrite, Pentlandite, Pyrrhotite Ore, International Journal of Mineral Processing, 33 (1991) 1-19.
[3] Y. Mu, Y. Peng, A.R. Lauten, The Depression of Pyrite in Selective Flotation by Different Reagent Systems - A literature review, Minerals Engineering 96-97 (2016) 143-156.
[4] D. Beneventi, J. Allix, E. Zeno, P. Nortier, B. Carre, Simulation of Surfactant Contribution to Ink Removal Selectivity in Flotation Deinking Lines, Separation and Purification Technology, 64 (2009) 357-367.
[5] A.J. Finch, A.C. Hardie, An Example of Innovation from the Waste Management Industry: Deinking Flotation Cells, Minerals Engineering, 5 (1999) 467-475.
[6] J. Drelich, T. Payne, H.J. Kim, D.J. Miller, R. Kobler, S. Christiansen, Selective Froth Flotation of PVC from PVC/PET Mixtures for the Plastics Recycling Industry, Department of Metallurgical Engineering, Utah
[7] C Wang, H. Wang, J. Fu, Y. Liu, Flotation Separation of Waste Plastics for Recycling – A review, Waste Management, 41 (2015) 28-38.
[8] R.M. Gent, M. Menendez, J. Torano, S. Torno, Optimization of the Recovery of Plastics for Recycling by Density Media Separation Cyclones, Resources, Conservation and Recycling, 55 (2011) 472-482.
[9] N. Fraunholcz, Separation of Waste Plastics by Froth Flotation - A Review, Part I, Minerals Engineering, Deft University of Technology, 2004.
[10] C. Wang, H. Wang, B. Wu, Q. Liu, Boiling Treatment of ABS and PS Plastics for Flotation Separation, Waste Management, 34 (2014) 1206-1210.
[11] F. Pita, A. Castilho, Separation of Plastics by Froth Flotation, The Role of Size, Shape and Density of the Particles, Waste Management, 2016.
[12] M. Trumić, S.M. Trumić, G. Bogdanović, Recycling Methods of Plastics Waste with a Special Emphasis on Mechanical Treatment, 5 (2012) 39-52 (in Serbian)
[13] M. Censori, F. La Marca, M.T. Carvalho, Separation of Plastics: The Importance of Kinetics Knowledge in the Evaluation of Froth Flotation, Waste Management, 2016.
[14] W. Volk, Statystyka stosowana dla inżynierów, Wydawnictwa Naukowo – Techniczne, Warszawa, 1965.