Separation of Pet from Other Plastics by Froth Flotation Combined with Alkaline Pretreatment

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Abstract

Plastics are naturally hydrophobic materials so, in order to employ flotation for the separation of plastic mixtures, the use of appropriate wetting agents is mandatory. In this work, the effect of pretreatment with alkaline solutions of sodium hydroxide on the floatability of four plastics (PET, PS, PMMA and PVC) was studied. The influence of NaOH concentration, treatment time and temperature of the alkaline solution, and influence of particle size was analyzed.

Results showed that alkaline treatment had a strong effect on PET floatability, some effect on floatability of PMMA and PVC and no effect on floatability of PS. Plastics floatability decreased with the increase of NaOH concentration, temperature and treatment time of the alkaline solution. Based on flotation behavior of simple plastics, flotation separation after alkaline treatment of bi-component mixtures of PET with PS and PVC was achieved efficiently. The best separation was obtained for PET/PS mixture, a floated with a grade of 98% in PS and a sunk with a grade of 100% in PET. PET/PMMA mixture led to the worst separation. For PET/PMMA and PET/PVC mixtures, flotation separation improved with the decrease of the particles size.

Keywords: plastic; froth flotation; alkaline treatment; particle size.

1. Introduction

Since the discovery of plastic in the 50's of last century, its global production has been continuously rising, gradually replacing materials, like glass and metal. In the last decade, the world production of plastics has been grown around 3.5% per year, increasing from 230 million tonnes in 2005 to 359 million tonnes in 2017 [1]. Global plastics consumption is predicted to continue to grow, reaching 400 million tonnes a year by 2025.

Despite the constant increase in plastic consumption, as a result of its versatility and excellent properties, over time plastic has acquired a negative reputation and there is some public pressure on the use of plastics, due to its difficult decomposition, since none of the commonly used plastics are biodegradable. Recently, the public pressure has worsened with information about the enormous quantity of plastic waste dumped into the oceans and with the images of marine animals wrapped in plastic or caught with items, like straws in their noses. About 8 million tonnes of plastic enters the sea every year, and if we do not change the way we produce and use plastics, there will be more plastics than fish in our oceans by 2050.

It is noted that landfills is the main final destination of plastic waste, and also the main source of plastic pollution. Of the plastic waste produced between 1950 and 2015, only 9% was recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment. It is estimated that in 2015, around 55% of global plastic waste was discarded, 25% was incinerated, and 20% was recycled [2]. However, it should be noted that in Europe, in 2017, 32.5% of plastic waste was recycled, 42.6% was recovered through energy recovery processes and 24.9% was landfilled [1]. The vast majority of plastic waste ends up in landfills or the natural environment, or are incinerated, causing serious environmental problems. Thus, it is urgent to substantially reduce our use of plastics, reduce plastic waste by recycling and reusing as much as possible. However, in order to recycle plastic waste it is necessary to separate the plastic mixtures into individual plastics, because different plastics cannot be recycled together due to chemical incompatibilities, differences in melting point and thermal stabilities [3,4]. Froth flotation, the most common separation process used by the mineral industry, is a possible alternative for separating plastic mixtures. Froth flotation allows the separation of hydrophobic from hydrophilic material. However, since most plastics are naturally hydrophobic, selective wetting components are required, which can be achieved by adsorption of wetting agents or surface modification.

Several wetting agents, such as methyl cellulose, polyvinyl alcohol, polyethylene glycol, gelatin, tannic acid, saponin, terpineol, triton X-100, calcium lignin sulfonate and sodium lignin sulfonate have been successfully used by several authors [5-10]. Surface modification of plastics by treatment with alkaline solutions followed by froth flotation were developed [3,11-22]. Plastic flotation is controlled not only by hydrophobicity, but also by the size of the plastic particles [13,19,23-24].

In this study, an alkaline treatment of PET, PVC, PS and PMMA particles with sodium hydroxide (NaOH) solutions followed by froth flotation was performed. The parameters analysed were the NaOH concentration, temperature and treatment time of alkaline solution, and particle size.

2. Experimental

2.1 Materials

Four different kinds of post-consumer plastics were used: Polyethylene Terephthalate (PET, transparent), Polyvinyl Chloride (PVC, light green), Polystyrene (PS, black) and Polymethyl methacrylate (PMMA, white). The samples were previously ground and the sieve size fractions used in this study were 2.8-2 mm and 4-2.8 mm.

The density of these plastics, measured by an Ultra Pycnometer (AccuPyc 1330), are as follows: PET: 1.364 g/cm^3; PVC: 1.326 g/cm^3; PS: 1.047 g/cm^3; and PMMA: 1.204 g/cm^3.

Sodium hydroxide was used in the alkaline treatment as wetting agent, and Methyl isobutyl carbinol (MIBC) (109916 Sigma Aldrich) was used as frothing reagent.

2.2. Alkaline pretreatment

Plastic samples were treated with NaOH solutions, using a Denver stirrer (400 rpm) with a plot plate. The treatment was done in a 1 L glass beaker using 40 g of plastic at a solids concentration of 20 wt%. The beaker was placed on a hot plate in order to adjust and control the temperature. The alkaline treatment was controlled by the operating parameters: NaOH concentration, temperature and treatment time (Table 1). Plastic samples were treated in alkaline solutions at NaOH concentrations of 2%, 6% and 10%, at a temperature range between 20 ºC and 80 ºC, and a treatment time between 2.5 min and 30 min (Table 1). After alkaline pretreatment, the plastics were taken out from alkaline solutions and rinsed in a stream of tap water to remove the treatment solution, and used to conduct flotation tests.

Table 1 – Experimental range and levels of the independent variables for the alkaline treatment.

Parameters	Symbol	Range values and coded level ()				
NaOH concentration (%)	A	2	6	10		
		(-1)	(0)	(+1)		
Temperature (ºC)	B	20	40	70	80	
		(-1)	(-0.333)	(+0.666)	(+1)	
Treatment time (min)	C	2.5	5	10	20	30
		(-1)	(-0.818)	(-0.455)	(+0.273)	(+1)

-1: factor at low level; 0: factor at medium level; +1: factor at high level.

2.3 Flotation experiments

The froth flotation experiments were performed in a Denver cell, with a capacity of 3 dm^3, at a low rotational speed of 600 rpm. Each flotation test used 40 g of plastics previously treated with an alkaline solution and rinsed, that was conditioned with the frother (MIBC) for about 2 minutes before the flotation tests. MIBC was added at a constant concentration of 30×10^{-3} g/L in all experiments. After conditioning, the air valve was opened and the floated product was collected over 6 minutes. Both the floated and the sunk (non-floated) were dried and weighed. Tap water was used in the flotation tests.

The pH in the flotation cell was not adjusted, but it was measured periodically along the experiment. The pH remained approximately constant, in the range of 7.0-7.3.

Firstly, flotation tests were carried out with one-component plastic samples previously treated with an alkaline solution. According to the floatability of plastics, it was possible to separate the four plastics into two groups: the first group constituted only by PET, which has low floatability, and the second group that includes the other three plastics (PS, PMMA and PVC), which have similar floatability. Then, flotation separation of binary plastic mixtures was performed using three bi-component mixtures: PET/PS, PE/PMMA and PET/PVC. Plastic mixtures were previously treated with an alkaline solution, and each plastic contributed with 50% (20 g) for the total mixture weight.

The effectiveness of the flotation tests was evaluated by the grade and recovery of each type of plastic in the floated and in the sunk products, and by the separation efficiency, defined by Schulz [25]. In the flotation tests of the plastic mixtures, the plastics type presented in the floated and the sunk were separated from each other by manual sorting, weighed, and flotation recovery and grade were calculated based on mass balance. This was possible due to differences in colours and shapes of the plastics particles. Experiments were done three times under similar operating conditions.

A second order polynomial equation was chosen to investigate the effect of different operating parameters of the alkaline treatment on the floatability of the plastics (Equation (1)):

$$Y = b_0 + b_1A + b_2B + b_3C + b_{12}AB + b_{13}AC + b_{23}BC + b_{11}A^2 + b_{22}B^2 + b_{33}C^2 \qquad (1)$$

where, Y is the predicted response, b_0 is model constant; b_1, b_2 and b_3 are linear coefficients; b_{12}, b_{13} and b_{23} are the interaction coefficients; and b_{11}, b_{22} and b_{33} are the quadratic coefficients. This model represents the effect of NaOH concentration (A), temperature (B), treatment time (C) and their interactions on the plastics floatability. The list of the independent variables (A, B and C) with their coded and levels are presented in Table 1. The significance of model equation, individual parameters, and factor interactions were evaluated by analysis of variance (ANOVA) at the confidence intervals of 95% ($\alpha = 0.05$).

3. Results and discussion

3.1. Effect of alkaline pretreatment on PET floatability

Two size fractions (2-2.8 mm and 2.8-4 mm) of the four plastics were treated with different concentrations of NaOH solutions, at different temperature and treatment time. Figure 1 shows the effect of NaOH concentration, temperature and treatment time of the alkaline solution on the flotation recovery of PET of the two fractions. The floatability of PET was strongly influenced by the NaOH concentration, temperature and treatment time. The flotation recovery of PET decreased with increasing NaOH concentration, temperature and treatment time, of alkaline solution. Also, Kangal et al. [3], Drelich et al. [11], Burat et al. [13], Nagy et al. [15], Wang et al. [10,19], Guo et al. [20], verified that recovery of PET in the floated decreased with increasing NaOH concentration, temperature and treatment time of alkaline solution. They found that alkaline treatment rendered the PET surface more hydrophilic, which may be a result of the hydrolysis of ester bonds in PET chains.

The two size fractions showed similar results. This means that the effect of particle size was minimal. The effect of NaOH concentration depended on the values of temperature and treatment time, and the effect of treatment time depended on the values of NaOH concentration and temperature and vice versa (Figure 1). At higher temperature, the NaOH concentration or treatment time needed to make PET hydrophilic was low. Also, at higher NaOH concentration, the temperature or treatment time needed to make PET hydrophilic was low. The lowest recovery of PET in the floated (2.5% for fraction 2.8-4 mm and 2.8% for fraction 2-2.8 mm) was obtained with the highest NaOH concentration (10%), the highest treatment time (30 min) and the highest temperature (80 ºC).

When temperature was at the lowest value (20º C), a change in NaOH concentration or treatment time had a low effect in PET recovery. PET is naturally hydrophobic since alkaline treatment with low NaOH concentration solutions and at a temperature of 20 ºC, the flotation recovery of PET was about 100%. At a temperature of 20 ºC and low NaOH concentration (2% and 6%), there was no hydrophilization of PET (Figure 1a).

At a temperature of 40 ºC temperature, when NaOH concentration was 2%, a change in treatment time had low effect in PET recovery (Figure 1b). But when NaOH concentration was at 6% or 10%, flotation recovery of PET decreased significantly with increasing treatment time.

At temperatures of 70 ºC and 80 ºC (Figure 1c and 1d), flotation recovery of PET decreased with increasing treatment time. At a temperature of 80 ºC and for fraction 2.8-4 mm, the flotation recovery dropped from 98.6% to 34.5%, when the treatment time increased from 2.5 min to 30 min for a NaOH concentration of 2%. However, for a higher concentration of NaOH (10%), the hydrophilization of PET was achieved for low treatment time.

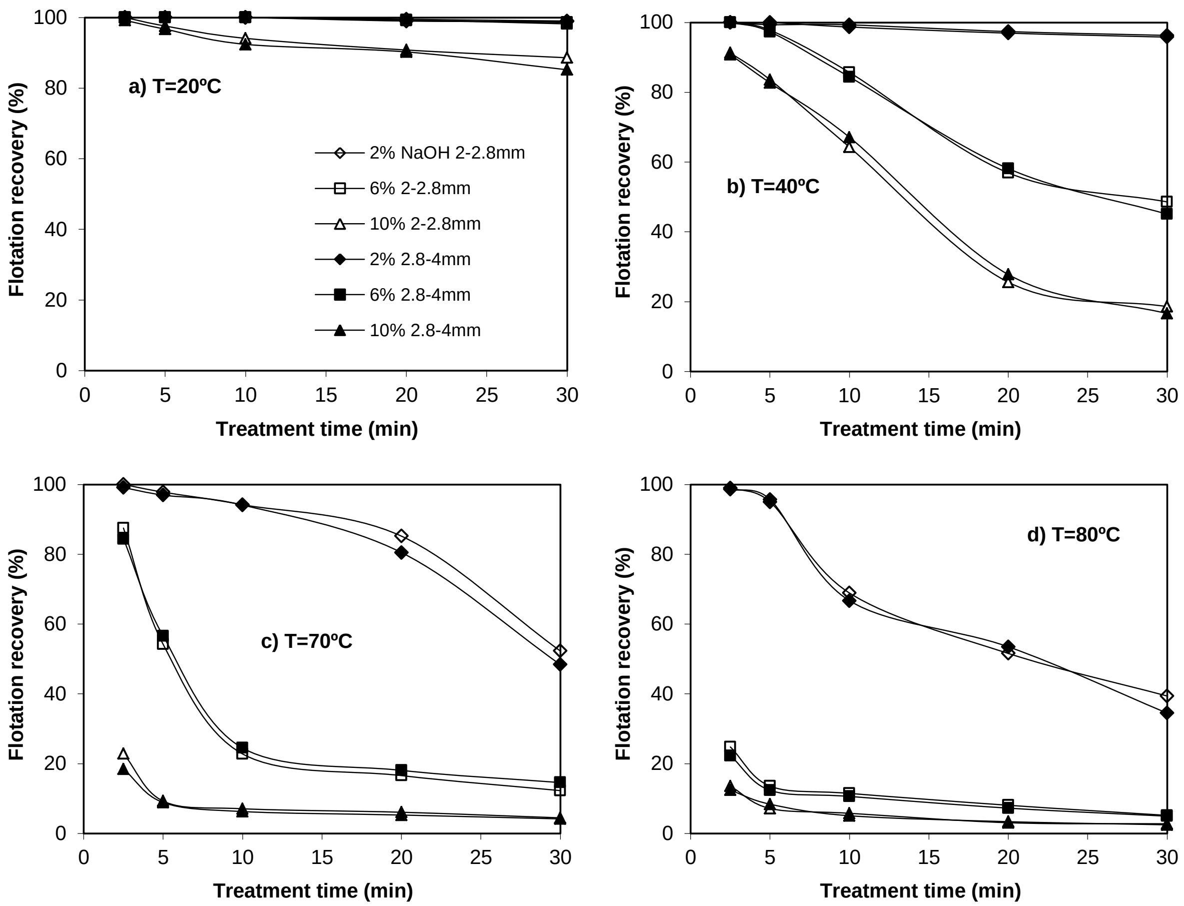


Figure 1 - Influence of NaOH concentration, temperature and treatment time of the alkaline solution on floatability of PET for fractions 2-2.8 mm and 2.8-4 mm.

To find the effect of the NaOH concentration, temperature and treatment time in PET recovery, statistical analysis of the experimental data was done and models were developed for optimization of the parameters. A quadratic relationship was shown to describe the dependence of the plastic floatability on the three operating variables of the alkaline treatment. The equations presented are in terms of coded levels: the low levels of the parameters were coded as -1 and the high levels as +1 (Table 1). Therefore, the relative impact of the NaOH concentration, temperature and treatment time in PET recovery can be identified by comparing the coefficients of the equation.

The analysis of variance (ANOVA) for the PET recovery model of the two size fractions is shown in Table 2. Based on all statistical analysis, the model presented was considered adequate to the prediction of PET floatability after alkaline treatment. The coefficients of determination (R^2) obtained for the PET recovery of size fraction 2-2.8 mm and 2.8-4 mm were 0.8885 and 0.8881 respectively, showing that the fit was good. The significance level of each independent variable, as well as their quadratic terms and interaction between the variables was evaluated based on corresponding F-values and p-values. For the two size fractions the model F-value was about 44 at 99.99% confidence level and the model Prob > F value is less than 0.05, shows that the model is significant.

Table 2 - Analysis of Variance (ANOVA) of the response surface quadratic model for PET recovery of the two size fractions.

		model	A	B	C	AB	AC	BC	A^2	B^2	C^2
2-2.8 mm	p-value Prob>F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.9635	0.1169	0.0588	0.4583	0.1557
	Sum of Square=79831; Mean of square= 8870; degree of freedom=9; F_{model}=44.3; R^2=0.8885; Ajusted R^2=0.8680										
2.8-4 mm	p-value Prob>F	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.8789	0.1242	0.0667	0.4283	0.2593
	Sum of Square=79999; Mean of square=8889; degree of freedom=9; F_{model}=44.1; R^2=0.8881; Ajusted R^2=0.8680										

The quadratic effect of the three variables and the interaction between NaOH concentration and time treatment and between temperature and treatment time had no statistical significance, and hence can be neglected. The variables that influenced PET floatability were the linear terms of NaOH concentration, temperature and time treatment, and the linear term of interaction between NaOH concentration and temperature. For fraction +2-2.8 mm and +2.8-4 mm, the model developed using these factors and their interaction is given in Eqs. (2) and (3), respectively.

$$\text{PET recovery (\%)} = 62.46 - 22.12A - 33.38B - 14.83C - 15.88AB \quad (2)$$

$$\text{PET recovery (\%)} = 61.83 - 22.10A - 33.70B - 15.10C - 15.27AB \quad (3)$$

where A is the NaOH concentration (%), B the temperature (ºC), and C the treatment time (min). The coefficients of the three parameters were negative values indicating a negative correlation between PET floatability and parameter levels. For both size fractions, PET recovery presented an equal order of relative impact of the operating parameters. The equation coefficients clearly showed that PET recovery was mainly affected by temperature, followed by NaOH concentration, treatment time and interaction between the NaOH concentration and temperature. The quadratic effect of the three variables was not significant, and therefore it was not considered.

3.2. Effect of alkaline pretreatment on PS floatability

Figure 2 shows the effect of NaOH concentration, temperature and treatment time of the alkaline solution on the flotation recovery of PS, for fractions 2-2.8 mm and 2.8-4 mm. The floatability of PS was not influenced by alkaline pretreatment, since for all tests the recovery in the float was 100%. For all tests of alkaline pretreatment, there was no hydrophilization of PS.

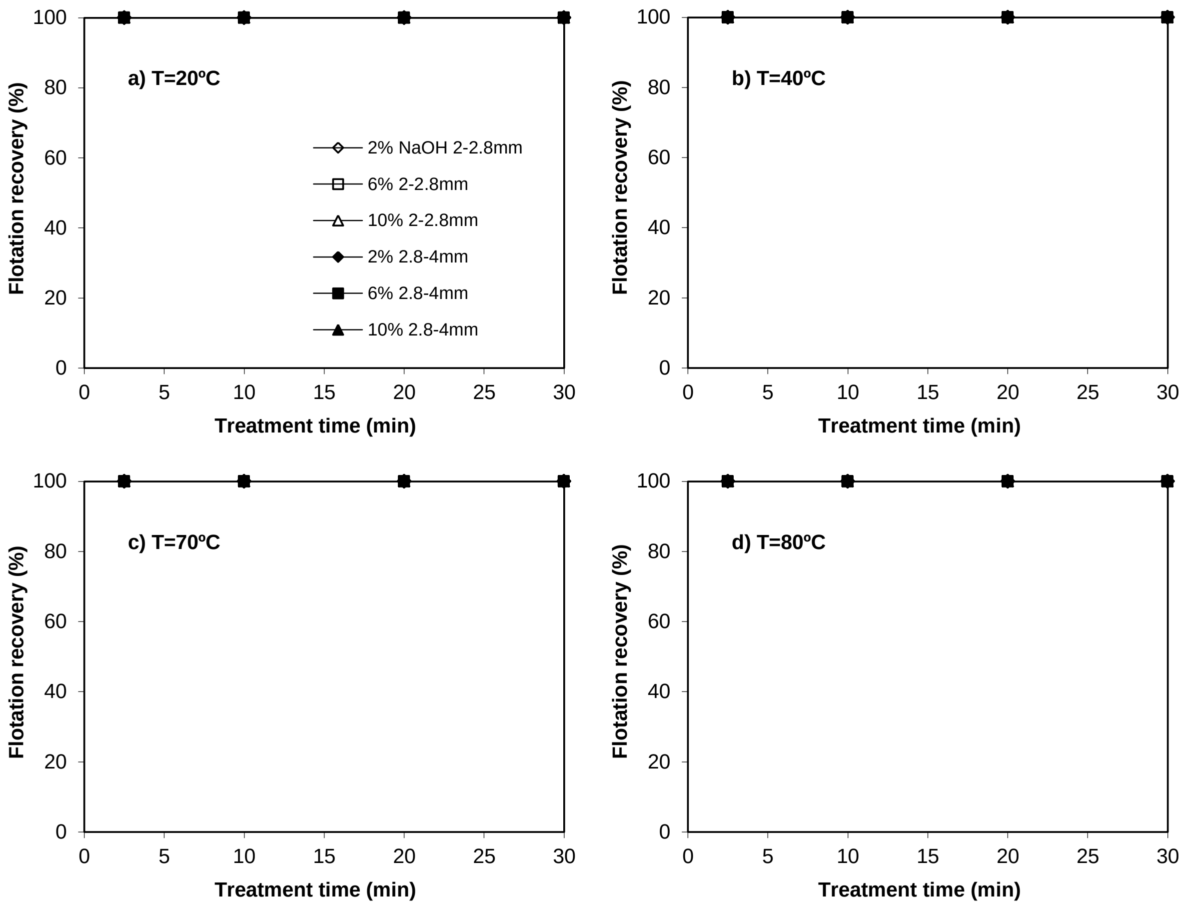


Figure 2 - Influence of NaOH concentration, temperature and treatment time of the alkaline solution on floatability of PS, for fractions 2-2.8m and 2.8-4 mm.

3.3. Effect of alkaline pretreatment on PMMA floatability

Flotation recovery of PMMA decreased slightly with increasing NaOH concentration, temperature and treatment time (Figure 3). However, the effect of these three parameters on PMMA recovery was smaller than that observed for PET. Temperature had a considerable effect on alkaline pretreatment of PMMA. At 20 ºC, for the three NaOH concentrations and for all treatment times, there was no hydrophilization of PMMA, since PMMA recovery was about 100%. The effect of NaOH concentration, temperature and treatment time of the alkaline solution on the flotation recovery of PMMA for the two fractions (2-2.8 mm and 2.8-4 mm) was similar. However, PMMA recovery of fraction 2.8-4 mm was lower than that observed for fraction 2-2.8 mm. Also, Shen et al. [5,23], Fraunholcz [12], Wang et al. [19,21], Pita and Castilho [24], Marques and Tenório [26], found that large plastic particles were more difficult to float than smaller ones.

The lowest recovery of PMMA in the floated was obtained with the highest NaOH concentration (10%), the highest temperature (80 ºC) and the highest treatment time (30 min), with 67.6% recovery for fraction 2-2.8mm and 56.5% recovery for fraction 2.8-4 mm.

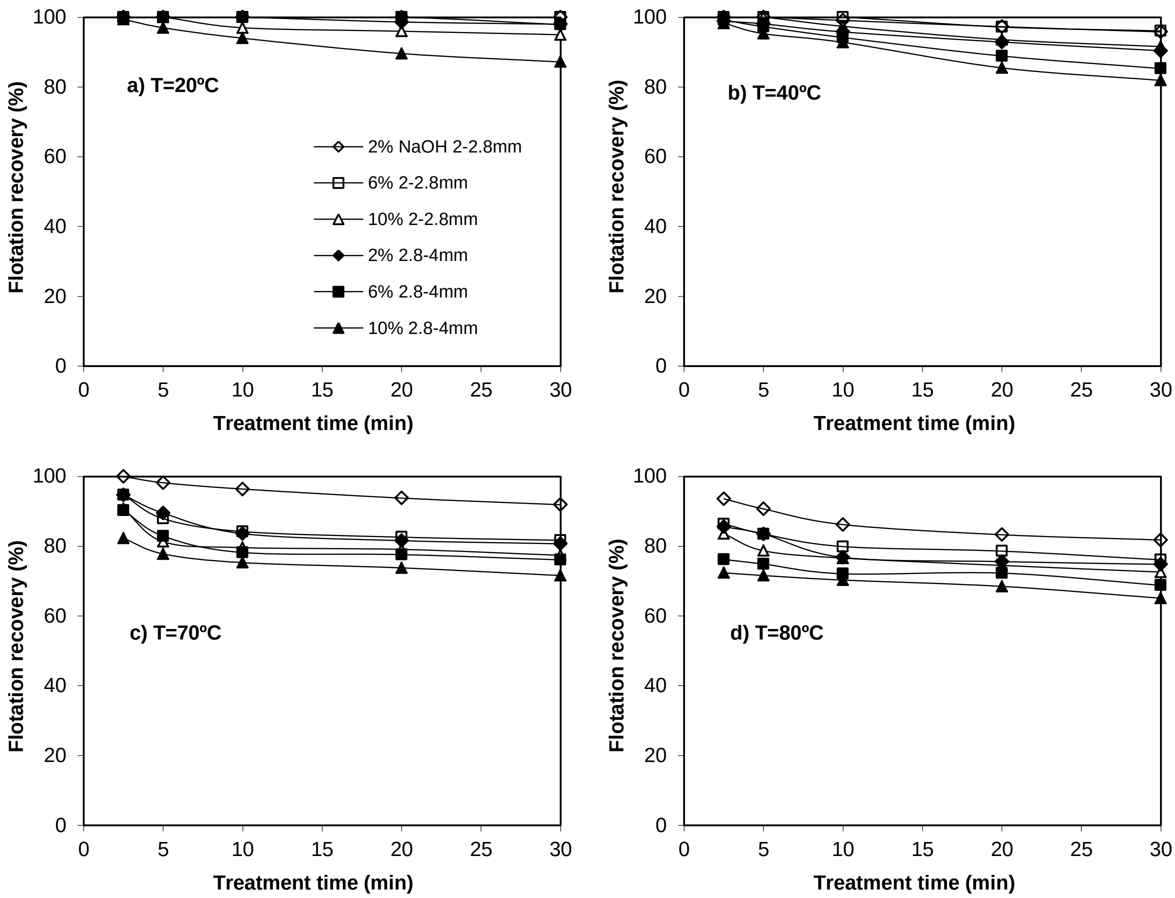


Figure 3 - Influence of NaOH concentration, temperature and treatment time of the alkaline solution on floatability of PMMA, for fractions 2-2.8m and 2.8-4 mm.

A second order polynomial equation was chosen to describe the dependence of the PMMA floatability on the three operating variables of the alkaline treatment. The analysis of variance (ANOVA) for PMMA recovery model of the two size fraction is shown in Table 3. For size fractions of 2-2.8 and 2.8-4 mm, the R^2 values of 0.9485 and 0.9584 respectively, implies that the model fit was good. For the two size fractions, the F-value at 99.99% confidence level and the Prob > *F* value was less than 0.05, showing that the model was significant.

Table 3 - Analysis of Variance (ANOVA) of the response surface quadratic model for PMMA recovery of the two size fractions.

		model	A	B	C	AB	AC	BC	A^2	B^2	C^2
2-2.8 mm	p-value Prob>F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.2060	0.0001	0.3750	<0.0001	0.086
	Sum of Square=4316; Mean of square= 480; degree of freedom=9; F_{model}=102.4; R^2=0.9485; Ajusted R^2=0.9393										
2.8-4 mm	p-value Prob>F	<0.0001	<0.0001	<0.0001	0.0002	0.0088	0.1793	0.3509	0.5321	<0.0001	0.088
	Sum of Square=6645; Mean of square= 738; degree of freedom=9; F_{model}=128.0; R^2=0.9584; Ajusted R^2=0.9509										

For fractions +2-2.8 mm and +2.8-4 mm, the equations (4) and (5), respectively, dictate that linear terms of the NaOH concentration, temperature and treatment time, linear term of interaction between NaOH concentration and temperature, and quadratic term of the temperature had a negative effect on PMMA floatability of the two size fractions. Interaction between temperature and treatment time had a negative effect on PMMA floatability for the size fraction +2.8-4 mm. The linear term of interaction between NaOH concentration and treatment time, and the quadratic effect of NaOH concentration and treatment time had no statistical significance, and hence were not considered.

$$\text{PMMA recovery (\%)} = 95.12 - 3.35A - 9.01B - 3.17C - 2.79AB - 1.98BC - 5.23B^2 \quad (4)$$

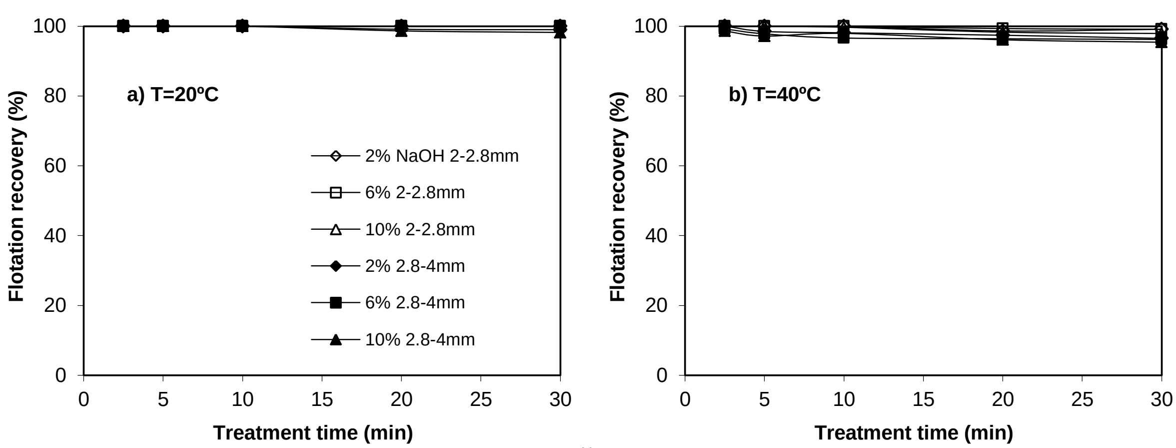
$$\text{PMMA recovery (\%)} = 89.08 - 3.65A - 11.63B - 4.64C - 1.30AB - 4.25B^2 \quad (5)$$

For both size fractions, PMMA recovery presented an equal order of relative impact of the three independent variables. PMMA recovery was mainly affected by temperature, followed by NaOH concentration (A), treatment time (C) and interaction between the NaOH concentration and temperature (AB).

3.4. Effect of alkaline pretreatment on PVC floatability

Floatability of PVC was influenced by NaOH concentration, temperature and treatment time (Figure 4). However, this effect was very smaller than that observed for PET, and slightly smaller than that observed for PMMA. PVC recovery for fraction 2-2.8 mm was greater than for fraction 2.8-4 mm. Flotation recovery of PVC decreased slightly with increasing NaOH concentration, temperature and treatment time. Thus, the lowest recovery of PVC in the floated was obtained with the highest NaOH concentration (10%), the highest temperature (80 ºC) and the highest treatment time (30 min), with 87.8% recovery for fraction 2-2.8mm and 76.4% recovery for fraction 2.8-4 mm.

At a temperature of 20 ºC, for three NaOH concentrations and all treatment times, there was no hydrophilization of PVC, since PVC recovery was about 100%. Also, at 40 °C, the hydrophilization of the PVC was small, since the PVC recovery was close to 100%.



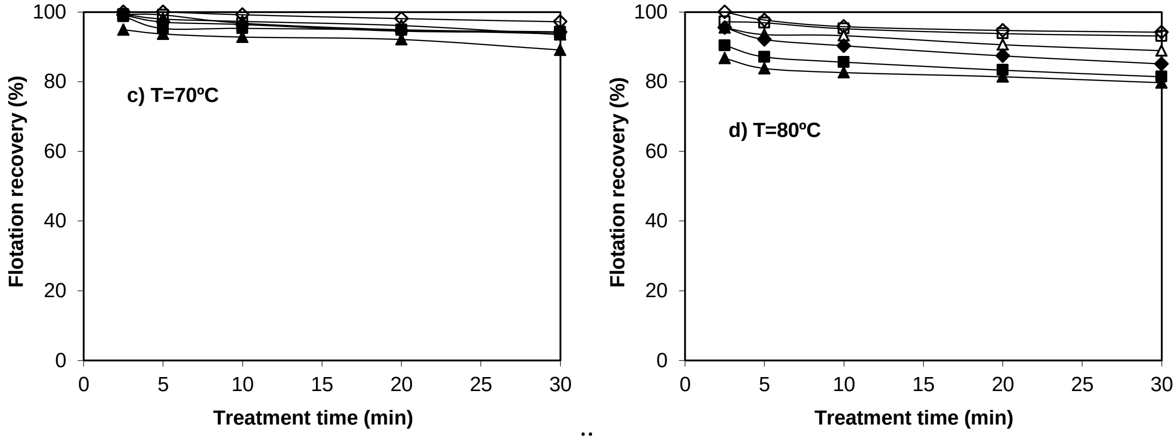


Figure 4 - Influence of NaOH concentration, temperature and treatment time of the alkaline solution on floatability of PVC, for fractions 2-2.8m and 2.8-4 mm.

The analysis of variance (ANOVA) for PVC recovery model of the two size fractions is shown in Table 4. For size fractions of 2-2.8 mm and 2.8-4 mm, the R^2 values of 0.9282 and 0.8720 respectively, implies that the model fit was good. Model F-value of size fractions 2-2.8 mm and 2.8-4 mm was 71.8 and 38.0, respectively, with a 99.99% confidence level and the Prob > *F* value lower than 0.05, showing that the model was significant.

Table 4 - Analysis of Variance (ANOVA) of the response surface quadratic model for PVC recovery of the two size fractions.

		model	A	B	C	AB	AC	BC	A^2	B^2	C^2
2-2.8 mm	p-value Prob>F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1006	<0.0001	0.8151	<0.0001	0.0651
	Sum of Square=406; Mean of square= 45.1; degree of freedom=9; F_{model}=71.8; R^2=0.9282; Ajusted R^2=0.9153										
2.8-4 mm	p-value Prob>F	<0.0001	0.0005	<0.0001	<0.0001	0.0088	0.7543	0.0051	0.8912	<0.0001	0.3082
	Sum of Square=1695; Mean of square= 188; degree of freedom=9; F_{model}=38.0; R^2=0.8720; Ajusted R^2=0.8495										

The linear term of interaction between NaOH concentration and treatment time and the quadratic term of NaOH concentration and treatment time had no statistical significance, and hence were neglected. For fractions +2-2.8 mm and +2.8-4 mm, the equations (6) and (7), respectively, dictate that NaOH concentration, temperature, and treatment time of alkaline pretreatment had a negative effect on PVC floatability of the two size fractions. Also, the interaction between NaOH concentration and temperature, interaction between temperature and treatment time, and quadratic term of temperature had a negative effect on the PVC floatability.

$$\text{PVC recovery (\%)} = 99.01 - 0.75A - 2.64B - 1.29C - 0.97AB - 1.33BC - 1.81B^2 \quad (6)$$

$$\text{PVC recovery (\%)} = 97.37 - 1.38A - 5.84B - 1.85C - 1.57AB - 1.42BC - 4.30B^2 \quad (7)$$

The three independent variables presented an equal order relative impact on PVC recovery for both size fractions. PVC recovery was mainly affected by temperature (B). The three independent variables presented less impact on PVC recovery than on PET recovery.

3.5 Separation of bi-component mixtures of PET with PS, PMMA and PVC

Previous results illustrated that alkaline treatment had a strong effect on PET floatability, some effect on floatability of PMMA and PVC, but no effect on PS floatability. Thus, floatability of PET can be significantly reduced in hot alkaline solutions, showing smaller floatability than the other three plastics, particularly than PS. So, one can assume that the alkaline treatment is not efficient to separate PS, PMMA and PVC plastics from each other, but may allow the separation of PET from PS, PMMA and PVC. In face of these results, further alkaline treatment and flotation tests were developed using bi-component plastic mixtures of PET with PS, PMMA and PVC, in equal proportions, for two size fractions (2-2.8 mm and 2.8-4 mm), in order to render the PET hydrophilic and maintain the other component in a hydrophobic state. The alkaline treatment conditions chosen for each of the three bi-component mixtures (PET/PS, PET/PMMA and PET/PVC) were those that led to maximum differences between PET floatability and floatability of the other plastics, to obtain a selective separation.

For PET/PS mixture, alkaline treatment conditions that led to the maximum difference between floatability of PS and floatability of PET were: NaOH concentration of 10%, temperature at 80 ºC and treatment time of 30 min. In these conditions, PET floatability was minimized, while PS floated recovery was 100%. These were the conditions used in the alkaline treatment of PET/PS mixture. The results of froth flotation tests are presented in Table 5.

For PET/PMMA and PET/PVC mixtures, alkaline treatment conditions that led to the most efficient separation were: NaOH concentration of 10%, temperature at 70 ºC and treatment time of 20 min. Thus, these were the conditions used in the alkaline treatment of plastic mixtures subsequently subject to flotation separation, whose results are shown in Table 5.

The best result was obtained in the PET/PS mixture separation, having the highest separation efficiency (near 98%) and a sunk with a grade of 100% in PET and a floated with a grade of 98% in PS. On the other side, PET/PMMA mixture had the lowest separation efficiency. These results were consistent with the floatability of plastics observed in the mono-component tests (Figure 1, 2, 3 and 4).

The influence of the particle size on separation quality of the PET/PS mixture was not evident, since the two size fractions presented similar results (Table 5). The effect of particle size on PET floatability was minimal, and PS floatability was not influenced by particle size, since all PS particles floated.

Coarse fraction of PET/PMMA mixture had the worst results. The difference between floatability of PMMA and floatability of PET was smaller for the coarse size fraction. The separation was more efficient for the fine fraction because there was a great amount of PMMA recovered in the floated, leading to a sunk with a grade of 82.8% in PET and a floated with a grade of 92.8% in PMMA.

For the PET/PVC mixture, the quality of separation worsened slightly with the increase of the particles size (Table 5). PVC recovery in the floated decreased with the increase of the particles size, and PET recovery in the floated was not affected by particles size. For the fine fraction, PET recovery in the sunk was 94.3%, with a grade of 97.0%; and PVC recovery in the floated was 97.1% with a grade of 94.5%.

Floatability of PS, PMMA and PVC increased with decreasing particle size, because their particles presented regular shapes, while the effect of the particle size on PET floatability was minimal because their particles presented lamellar shape and low weight. For the mixtures of PET/PMMA and PET/PVC, the worst results for coarse fraction can be explained by the more regular shape of PMMA and PVC and by the higher weight of these particles that hinders flotation. Thus, the particles size control is important for flotation separation of plastic mixtures.

Table 5 - Results of the flotation tests on the mixtures of PET with PS, PMMA and PVC for two size fractions.

Plastic Mixtures	Fraction (mm)	Products	Recovery (%)		Grade (%)		Separation Efficiency (SE) (%)
			PET	OP*	PET	OP*	
PET/PS	2-2.8	Floated	1.9	100	1.9	98.1	98.1
		Sunk	98.1	0	100	0	
	2.8-4	Floated	2.2	100	2.2	97.8	97.8
		Sunk	97.8	0	100	0	
PET/PMMA	2-2.8	Floated	6.2	80.5	7.2	92.8	74.3
		Sunk	93.8	19.5	82.8	17.2	
	2.8-4	Floated	5.5	73.8	6.9	93.1	68.3
		Sunk	94.5	26.2	78.3	21.7	
PET/PVC	2-2.8	Floated	5.7	97.1	5.5	94.5	91.4
		Sunk	94.3	2.9	97.0	3.0	
	2.8-4	Floated	5.2	92.6	5.3	94.7	87.4
		Sunk	94.8	7.4	92.8	7.2	

OP* denotes the other plastics, namely PS, PMMA or PVC.

Conclusions

The four plastics (PET, PS, PMMA and PVC) are naturally floatable and thus, it was necessary a selective wetting component to achieve a selective flotation separation of plastic mixtures. The effect of treatment of plastics with alkaline solutions of NaOH on the floatability of the four plastics was studied. It was verified that alkaline solutions had a strong influence on PET floatability, medium influence on PVC and PMMA floatability and no effect on PS floatability. The flotation recovery of PET, PMMA and PVC decreased with increasing NaOH concentration, temperature and treatment time of alkaline solution. From the statistical data analysis, the most significant factor with respect to alkaline pretreatment on plastics floatability was temperature, followed by NaOH concentration, and treatment time. Also, the interaction between NaOH concentration and temperature had a significant negative effect on the plastics floatability.

After alkaline treatment of the plastics under optimal conditions, flotation separation of PET from PS, PMMA or PVC was successfully achieved. The best result was obtained in the PET/PS mixture separation. PET recovery in the sunk was about 98%, with a grade of 100%; and PS recovery in the floated was 100% with a grade of about 98%, with the following pretreatment conditions: 10% NaOH concentration, temperature at 80 ºC, and treatment time of 30 min. For this mixture, the two size fractions (2-2.8 mm and 2.8-4 mm) presented similar results.

PET/PMMA mixture had the worst separation. For PET/PVC, a good separation was obtained. For these two mixtures, the quality of separation worsened slightly with the increase of the particles size as a consequence of the decrease of the recovery of PMMA and PVC in the floated for the coarser particles.

Acknowledgements: This work was supported by the Portuguese Foundation for Science and Technology (FCT-MEC) through national funds and, when applicable, co-financed by FEDER in the ambit of the partnership PT2020, through the following research projects: UID/Multi/00073/2013 of the Geosciences Center of the University of Coimbra.

Conflicts of Interest: The author declares no conflict of interest.

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