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INVESTIGATION OF SURFACE PROPERTIES OF PVC FOR SELECTIVE RECOVERY

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ABSTRACT – The selective recovery of PVC as a sink product required an effective plasticizer to enhance its surface properties. In this study, the effects of Triton XL-100N and Gelatine were compared through surface tension, contact angle, and zeta potential measurements, along with microflotation tests using a Hallimond tube. Results showed that Triton XL-100N significantly reduced surface tension and contact angle, increasing PVC hydrophilicity. The isoelectric point shifted to pH 3 with Triton XL-100N and pH 6 with Gelatine. Microflotation tests confirmed that 0.1 M Triton XL-100N optimized PVC depression at pH 4, whereas Gelatine showed limited effectiveness. Therefore, Triton XL-100N was identified as the optimal plasticizer for selective PVC recovery.

Keywords: PVC, Selective Flotation, Surface Chemistry, Triton XL-100N, Gelatine.

INTRODUCTION

Recycling plays a crucial role in minimizing waste generated by human activities. However, the accumulation of polymer waste causes significant environmental challenges. Burning is not a viable recycling method for polymers, as it releases toxic gases. In particular, polyvinyl chloride (PVC) produces hazardous emissions such as hydrogen chloride (HCl) gas and chlorine-containing dioxins, which contribute to air pollution and reduce the lifespan of burning facilities. Additionally, PVC contamination complicates the recycling of other polymers. With a density range of 1.30-1.35 g/cm³, PVC cannot be effectively separated using conventional gravity-based methods. However, due to the natural hydrophobicity of polymers, therefore, froth flotation, a cost-effective and widely used technique in mineral processing, offers a promising alternative for PVC recycling due to its simplicity and efficiency [1]. For instance, collected polyethylene terephthalate (PET) bottles, commonly used for soft drinks, are often mixed with polyvinyl chloride (PVC) bottles, which are used for edible oils, detergents, and shampoos. Generally, different types of plastics cannot be recycled together due to their chemical incompatibility, variations in melting points, and differences in thermal stability [2]. The hydrophobicity of plastics follows the order: PS > ABS > PC > PET > PMMA > PVC

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> POM. Consequently, PET and PVC can be effectively separated from PP, PE, PS, or HDPE using flotation techniques [3]. However, the separation of PET and PVC can be influenced by various parameters, including the type and amount of frother [4], the plasticizer [5] used during column flotation, pH, as well as the treatment time and temperature with reagents such as NaOH or $KMnO_4$ [1, 2, 6, 7]. Typically, PVC is recovered as the sink product, while PET is obtained as the float product [8,9].

This study aims to determine the surface properties of PVC for its selective recovery by comparing two different plasticizers, Triton XL-100N and Gelatine. In this context, surface tension measurements, contact angle analysis on PVC particles, zeta potential measurements, and microflotation experiments were conducted to evaluate their flotation behavior under varying pH conditions and plasticizer concentrations. The objective is to assess the fundamental flotation characteristics of PVC in the presence of these plasticizers and to determine their effectiveness in facilitating selective PVC recovery.

MATERIALS AND METHODS

The representative sample virgin PVC polymers was obtained from Arçelik Company, and the d_{80} particle size of the sample was determined as 200 μm.

The surface properties of PVC were systematically analyzed to enable selective flotation during its recycling process. In this context, particular focus was placed on the plasticizers Triton XL-100N (BDH Chemicals, USA) and Gelatine (Merck KGaA, Germany). Surface tension measurements (Krüss Ring Tensiometer, Krüss GmbH, K6, Germany), contact angle (Goniometer, Rame-Hart Inc., United States) analyses, and zeta potential measurements (Zeta Meter +3.0, Malvern Panalytical, Germany) were conducted at varying concentrations of these chemicals on virgin PVC polymers. Additionally, microflotation experiments were performed under different concentration and pH conditions to assess the effects of both plasticizers on flotation efficiency. Surface tension measurements were conducted using the Du Noüy ring method with a Krüss tensiometer. During these measurements, concentrations from 0.1 to 1.0 M were examined for both plasticizers. For contact angle measurements, the sessile drop method was employed, and experiments were performed using a Rame-Hart goniometer. These measurements were carried out with a solution containing 1% plasticizer concentration, and the same concentration range (0.1–1.0 M) was investigated for both plasticizers. Zeta potential measurements were conducted using a Zetameter based on the principle of microelectrophoresis. These measurements were performed at different pH values of 2, 4, 6, 8, and 10, using both plasticizers at concentrations of 0.1, 0.2, 0.5, 0.7, and 1 M. Sulfuric acid (H_2SO_4) (95-98%) (Isolab Chemicals, Germany) and sodium hydroxide (NaOH) (Extra pure, Technical Grade, granules) (Tekkim, Türkiye) were used as pH regulators. By determining the surface properties, the selective flotation of PVC was investigated using a Hallimond tube as the microflotation cell. The primary objective of these investigations was to obtain PVC as a sinking product. Experiments were conducted with both plasticizers at concentrations from 0.1 to 1.0 M, under pH conditions of 2, 4, 6, 8, and 10.

RESULTS AND DISCUSSION

Surface tension measurements

In the surface tension measurements, Triton XL-100N and Gelatine were used as plasticizers, as specified. Figure 1 presents the measurements conducted with Triton XL-100N at concentrations from 0.1 to 1.0 M, while Figure 2 displayed the measurements performed with Gelatine at the same concentrations. The surface tension experiments revealed that the surface tension of PVC varied between 55 and 63.5 mN/m upon the addition of Gelatine. In contrast, the addition of Triton XL-100N resulted in a reduction of surface tension to the range of 35–38 mN/m. Yet, lower surface tension can enhance flotation efficiency, this condition may improve the flotation of PVC.

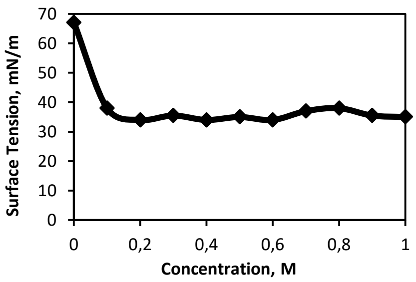

Figure 1 The Surface tension measurements of Triton XL-100N

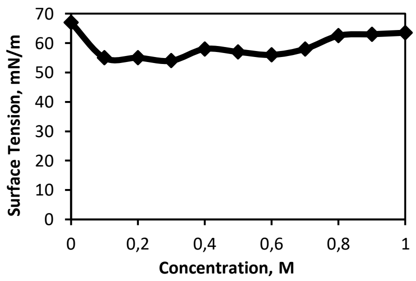

Figure 2 The Surface tension measurements of Gelatine

Contact angle measurements

Contact angle measurements were conducted at the same concentrations examined in the surface tension measurements and performed by Sessile Drop Method. The contact angle values of both plasticizers on PVC particles were determined and evaluated in terms of their impact on selective flotation of PVC. Contact angle measurements of Triton XL-100N and Gelatine were shown in Figure 3 and 4, respectively.

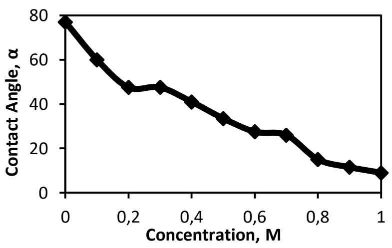

Figure 3 The contact angle measurements by Triton XL-100N

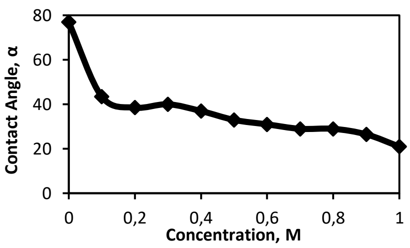

Figure 4 The contact angle measurements by Gelatine

As the concentration of both plasticizers increased, the contact angle measured on PVC particles decreased. However, Triton XL-100N reduced the contact angle significantly more than Gelatine, indicating that the naturally hydrophobic PVC particles underwent a greater degree of surface hydrophilization. The lowest measured contact angle was 10° at a 1.0 M concentration of Triton XL-100N, while the lowest contact angle measured with Gelatine at high concentration was 20°. Considering that the objective in flotation processes was to obtain PVC as a sink product, these results suggested that flotation experiments could be more successful at higher plasticizer concentrations.

Zeta Potential measurements

Zeta potential measurements were conducted using fine-sized PVC particles at pH values of 2, 4, 6, 8, and 10 with both plasticizers at concentrations of 0.1, 0.2, 0.5, 0.7, and 1.0 M. Additionally, measurements were performed using pure water as a reference. The results for Triton XL-100N were presented in Figure 5, while the measurements conducted with Gelatine were shown in Figure 6.

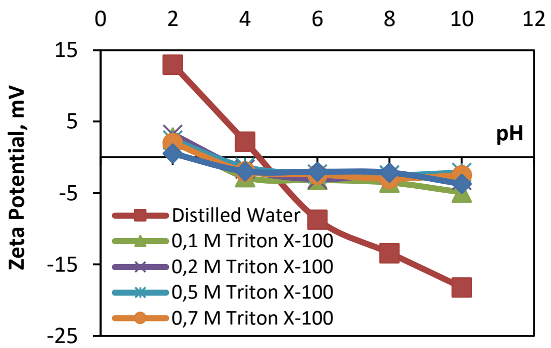

Figure 5 Zeta potential measurements of Triton XL-100 depending on different concentrations and pH values

As seen from the results, the iso-electric point (IEP) of PVC powders in distilled water was determined to be pH 4.2, which was consistent with similar measurements reported in the literature [5]. The iso-electric points in Triton XL-100N and Gelatine were found to be approximately pH 3 and pH 6, respectively. It was evident that the plasticizers could operate within different optimal pH ranges to effectively depress PVC.

Microflotation tests

Microflotation tests were conducted using a Hallimond tube to investigate the effect of Triton XL-100N and Gelatine on the recovery of PVC as a sink product at different concentrations and pH levels. In Figure 7, the effect of different concentrations of Triton XL-100N and in Figure 8, the effect of pH values followed by optimizing the concentration 0.1 M of Triton XL-100N were illustrated.

Microflotation tests showed that PVC was primarily recovered as a sink product at its natural pH when 0.1 M Triton XL-100N was used, with a flotation efficiency of approximately 40% as a float product. Thus, 0.1 M was selected as the optimum concentration for further pH-dependent tests. Flotation experiments at this concentration revealed the lowest flotation efficiency (~20%) at pH 4. Yenial *et al.* [7] demonstrated that Triton XL-100N facilitated PVC recovery as a sink product in batch flotation, while Marques and Tenorio [4] used calcium lignin sulfonate as a plasticizer at pH 4 for PET/PVC flotation in a column system. These findings confirmed that PVC could be recovered as a sink product at pH 4 with 0.1 M Triton XL-100N. To further investigate selective PVC recovery, additional tests were conducted using Gelatine, evaluating flotation efficiency as a function of concentration and pH (Figures 9 and 10).

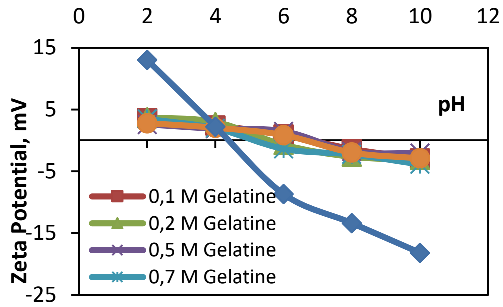

Figure 6 Zeta potential measurements of Gelatine depending on different concentrations and pH values

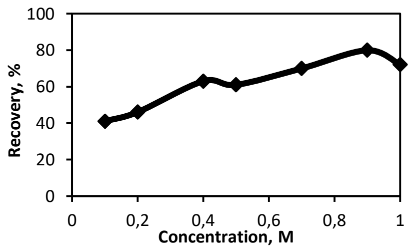

Figure 7 Microflotation tests conducted by different concentrations

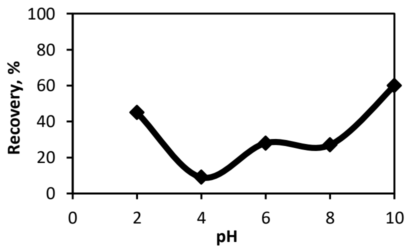

Figure 8 Microflotation tests performed on different pH values

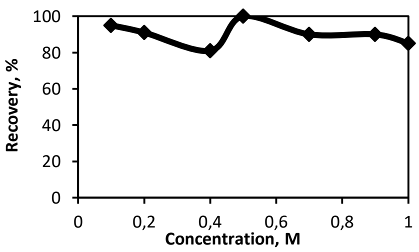

Figure 9 Microflotation tests conducted by different concentrations

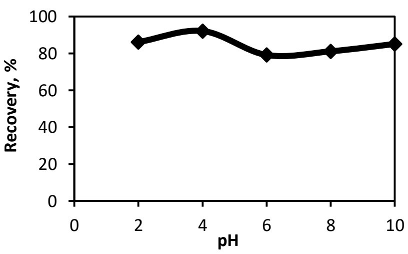

Figure 10 Microflotation tests performed on different pH values

The results indicated that Gelatine had minimal effectiveness in depressing PVC, as it consistently floated at all concentrations with high flotation efficiency. Even at 0.4 M, where the lowest efficiency was observed, the value remained relatively high (~80%). Thus, further tests were conducted at this concentration to examine the effect of pH. As shown in Figure 10, the lowest flotation efficiency was recorded at pH 6, yet it remained significant (~80%), confirming Gelatine's limited ability to facilitate to obtain PVC as sink product.

CONCLUSION

This study examined the selective recovery of PVC as a sink product using Triton XL-100N and Gelatine as plasticizers. Surface tension, contact angle, zeta potential, and microflotation tests were conducted. Triton XL-100N reduced surface tension more effectively, and increased PVC hydrophilicity. At 0.1 M, PVC remained a sink product at natural pH, with flotation efficiency dropping from 40% to 20% at pH 4. In contrast, Gelatine promoted PVC flotation, with the lowest efficiency (~80%) at 0.4 M and pH 6. Triton XL-100N was identified as the optimal plasticizer for selective PVC recovery.

REFERENCES

1. Burat, F., Güney, A., & Kangal, M. O. (2009). Selective separation of virgin and post-consumer polymers (PET and PVC) by flotation method. *Waste Management*, *29*(6), 1807-1813.
2. Wang, C., Wang, H., Liu, Y., & Huang, L. (2016). Optimization of surface treatment for flotation separation of polyvinyl chloride and polyethylene terephthalate waste plastics using response surface methodology. *Journal of Cleaner Production*, *139*, 866-872.
3. Shen, H., Pugh, R. J., & Forssberg, E. (2002). Floatability, selectivity and flotation separation of plastics by using a surfactant. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *196*(1), 63-70.
4. Marques, G. A., & Tenório, J. A. S. (2000). Use of froth flotation to separate PVC/PET mixtures. *Waste Management*, *20*(4), 265-269.
5. Güney, A., Özdilek, C., Kangal, M. O., & Burat, F. (2015). Flotation characterization of PET and PVC in the presence of different plasticizers. *Separation and Purification Technology*, *151*, 47-56.
6. Drelich, J., Payne, T., Kim, J. H., Miller, J. D., Kobler, R., & Christiansen, S. (1998). Selective froth flotation of PVC from PVC/PET mixtures for the plastics recycling industry. *Polymer Engineering & Science*, *38*(9), 1378-1386.
7. Yenial, Ü., Burat, F., Yüce, A. E., Güney, A., & Kangal, M. O. (2013). Separation of PET and PVC by flotation technique without using alkaline treatment. *Mineral Processing and Extractive Metallurgy Review*, *34*(6), 412-421.
8. Buchan, R., & Yarar, B. (1995). Recovering plastics for recycling by mineral processing techniques. *JOM*, *47*, 52-55.
9. Fraunholcz, N. (2004). Separation of waste plastics by froth flotation-a review, part I. *Minerals Engineering*, *17*(2), 261-268.