Improving the odour removal from flexible packaging waste by optimizing the water management in plastic recycling plants

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1. Introduction

Unwanted odours, primarily attributed to volatile organic compounds (VOCs), impact the recycling of post-consumer flexible packaging. Mechanical upcycling is hindered by these odours, and the cost of recycled plastics is constrained by virgin plastic prices and the quality of recyclates. The key focus in this work is on optimizing the washing process of polyethylene films. This includes enhancing the removal of these VOCs, while maintaining a low cost, since water consumption is a huge cost factor. Given the polarity mismatch between these VOCs and washing media, such as water and caustic soda (Roosen *et al.,* 2021) the use of detergent (CTAB) was also evaluated, considering its potential influence on subsequent wastewater treatment.

To mitigate odour, VOCs must be desorbed from the polymer to the washing medium. Roosen *et al.* (2021) and De Somer *et al.* (2022) observed in a kinetic study re-adsorption of these compounds from the medium to the polymer. Based on lab experiments and comparing different model types, they found the reversed first order (RFO) model most suitable to describe this mechanism. Interestingly, they noted a preference for re-adsorption over desorption. This highlights the importance of frequent renewal of the washing medium to enable effective VOC-removal. However, according to the authors knowledge, no comparable study has explored the behavior of organic pollutants that contribute to chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP). Currently, industrial washing lines do not have substantial knowledge on how much tons of plastic can be treated before their washing medium should be renewed. Therefore, in this work, a new washing line was proposed and simulated in Aspen Plus for an optimized quality of the recyclates, considering potential wastewater treatment and reuse.

2. Materials & Methods

A post-consumer polyethylene film bale was used for all experiments and provided by a sorting site of SUEZ SA (Belgium). Shredded PE-bale (Universal Cutting Mill) was mixed with various washing media for 10 minutes in different S/L-ratios for the washing experiments, following established methodologies (Roosen *et al.*, 2021) (Figure 1). Water, 2% w/w NaOH in water (Chem-Lab >99%) and 9.2 mM CTAB (Sigma-Aldrich, >98%) were tested media. When multiple washing steps were performed, the plastics were filtered and fresh washing medium was added, repeating the process (Figure 1). Water samples were analyzed on COD, TN and TP using Hach Lange cuvette test kits (LCK114, LCK138 LATON and LCK348, respectively) and plastics were analyzed on VOCs by GC-MS. Kinetic tests with tap water and reused water were performed, supported by equilibrium tests by 15 consecutive washes with 3 g of new dirty plastic waste with the same washing water in order to implement the removal behaviour of COD, TN and TP in Aspen Plus version 14.

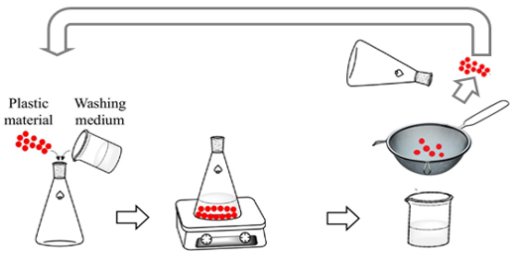

Figure 1. Schematical methodology of the washing procedure, based on Roosen *et al.* (2021).

Different wastewater treatment techniques were tested before reuse. Coagulation with ferric chloride (Chem-Lab, >98%) included optimization with jar tests (0.116 g Fe^{3+}/g COD removed). Granular activated carbon (GAC) adsorption (ORGANOSORB 10-AA; 0.60-2.36 mm, Desotec) utilized 40 g pre-treated GAC in a 100 mL column. Finally, membrane filtration with a cellulose acetate membrane (Porafil, Macherey-Nagel, 0.45 mm) was

performed on the supernatant post-coagulation. All techniques were evaluated for their effectiveness in removing COD, TN, TP and VOCs.

3. Results & Discussion

Several washing steps were conducted, showing that fewer contaminants (COD, TN, TP, VOCs) are removed from the plastics with each washing cycle. The removal behavior of COD, TN and TP can be described by the reversed first order model taking into account desorption and re-adsorption. The influence of the S/L ratio was investigated and results revealed that lower S/L ratios yield higher removal efficiencies. With a S/L ratio of 0.03 kg plastics/L water, 78% VOC removal could be reached. Simulations in Aspen Plus compared two and three washing steps with S/L ratio 0.03, demonstrating that a three-step process achieved 91%, 75% , 89% and 78% for COD, TN, TP and VOCs, respectively, compared to 80%, 72%, 79% and 60% for two steps. The three-step process included a final polishing wash using CTAB, two water treatment steps and three recirculation cycles. Using washing media should improve washing efficiencies but requires further investigation due to its impact on subsequent treatment (increased COD, TN and pH).

From kinetic tests, it could be observed that it takes a longer time to reach the same level of contaminant removal when the wash was performed with reused water (Figure 2). The concentration in the reused water (W1+2) was corrected for the concentration in the reused water itself. Moreover, the input stream's contamination level is crucial for washing process performance. Higher contamination requires more frequent water replacement or advanced treatment. Key parameters to monitor include COD, TN, and VOCs, with COD and TN showing different removal behaviours, necessitating measurement of both for accurate performance assessment. Coagulation with ferric chloride, combined with GAC or MF, showed promising results for (partial) wastewater treatment before reuse, achieving 99% and 91% COD, 87% and 69% TN removal and 100% TP, respectively.

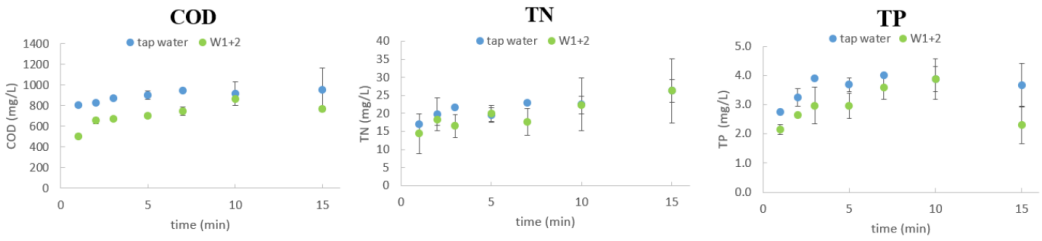

Figure 2. COD, TN and TP removal kinetics, W1+2 = wastewater after one and two wash steps (n=2).

4. Conclusion

Enhancing the quality of secondary materials in terms of their VOC content involves implementing a washing process that is subdivided into several steps, each with their own water quality requirements and management. It is proposed to apply three washing steps to optimize the balance between the number of washing steps, and related to this the overall cost, and the VOC removal that can be achieved. The first two washing steps remove the biggest dirt, while the third washing step is mainly for removing more recalcitrant components, mainly VOCs. In this step, using only water as a washing medium will not create the highest quality and other washing media might be considered. The integration of wastewater treatment techniques can enhance the economic feasibility of the washing process and mitigate drought or discharge problems by reusing the washing water. Coagulation with $FeCl_3$, GAC adsorption and membrane filtration, showed their ability to remove certain contaminants from the water and can be employed in the process to reuse the wastewater.

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