

PRELIMINARY RESEARCH ON SEPARATION OF ALUMINIUM FROM PLASTICS FROM FOOD PACKAGING WASTE

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Abstract: Packaging is a huge problem in waste management, and food packaging stands out in particular. This article presents the results of preliminary research on the separation between aluminium and plastic from yogurt cup wastes as a sample of food packaging waste. Two different separation methods were used: eddy current and electrostatic separation. It has been shown that an eddy-current separator can be used for the separation of larger particles, where it is possible to obtain a concentrate with an aluminium content of 65.5% and recovery of 92.3%, while an electrostatic separator is more appropriate for the separation of finer particles, whereby a concentrate with an aluminium content can be obtained of 73.3% with recovery of 96.9%.

Keywords: Waste Management, Eddy-Current Separation, Electrostatic Separation, Aluminium Recycling, Food Packaging Waste

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Preliminary report

1. INTRODUCTION

The increasing volume of food packaging waste presents a significant environmental challenge, both due to resource depletion and environmental contamination (Antonopoulos, Faraca, & Tonini 2021; Dahlbo et al. 2018). These composite materials, while effective for food preservation by enabling foods to travel safely for long distances (Marsh & Bugusu 2007), pose substantial recycling difficulties due to the intimate bonding between different materials, as many recycling systems require materials to be separated (Marsh & Bugusu, 2007; Antonopoulos, Faraca, & Tonini 2021). Among these, yogurt packaging represents a common yet complex waste stream, typically consisting of polypropylene (PP) cups with aluminium foil lids (Kostic et al. 2022), which require efficient separation methods for effective recycling.

The separation of aluminium from plastic in food packaging is crucial for several reasons. First, aluminium is a valuable material with significant energy savings when recycled compared to primary production, offering the largest reduction potential in energy use and greenhouse gas (GHG) emissions through recycling of post-consumer scrap (Niero & Olsen 2016). Second, the quality of recycled plastics improves substantially when metal contaminants are removed, as demonstrated by issues with ultraviolet protective additives and other contaminants affecting recycled material quality (Dahlbo et al. 2018). However, the thin nature of aluminium foils and their attachment to plastic substrates make traditional separation methods challenging, particularly for thin foils (Niero & Olsen, 2016).

Current recycling technologies offer various approaches for separating different materials, with physical separation methods showing particular promise due to their ability to provide optimum protection of product quality and safety (Marsh & Bugusu 2007). Among these, eddy current separation (ECS) and electrostatic (EST) separation stand out as potential solutions, each exploiting different physical properties of the materials.

This study aims to evaluate and compare the effectiveness of eddy current and electrostatic separation methods for recovering aluminium from yogurt packaging waste. The research specifically focuses on: determining optimal operational parameters for both separation methods (rotor/drum speed, voltage, splitter position, belt speed) and assessing the grade and recovery of aluminium concentrate achieved through each process to evaluate their effectiveness for food packaging recycling.

Through systematic experimentation with varying values of operational parameters, this study seeks to establish the most effective approach for separating aluminium from plastic in food packaging waste, contributing to the development of more efficient recycling processes for composite packaging materials.

2. MATERIALS AND METHODS

2.1. Materials

The feed sample used in these experiments were from yogurt packaging that consisted of polymer cup (polypropylene, PP) and aluminium lid. PP is a lightweight (density between 0.895 and 0.93 g/cm³) and nonpermeable plastic that are commonly used for packaging for cosmetics, food and drinks, and other industrial and consumer goods. Polypropylene, on the first instance, is used primarily for food items. Once it is recycled, it cannot be considered as virgin material or has food grade quality. However, recycled polypropylene could maintain its properties, making it one of ecologically responsible materials (Hossain et al. 2023).

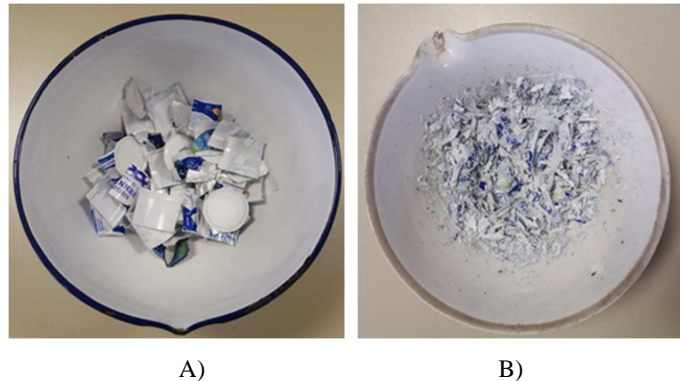


Figure 1. Feed of A) Eddy Current Separator and B) Electrostatic Separator

Aluminium lids are used on many dairy and food products to extend the product's shelf-life, it has excellent durability and protection against corrosion (Barukčić, et al. 2021). Density of aluminium is about 2.7 g/cm³. In this study, sample size for eddy current and electrostatic separator is different as shown in **Figure 1**. Feed mass fraction of polypropylene was 96 % and aluminium 4 %.

Sample was prepared by reducing its size before performing separation test. The size of samples for those two separation methods is different. Samples for eddy current separator were cut manually with average size of 48.4 × 42.5 mm. On the other side, samples for electrostatic separator are smaller and cut using automatic cutting device to obtain particle size <8 mm. Shredding process of PP and aluminium was performed separately. After that, the sample mass of PP and aluminium measured separately to get material fraction for each type in a feed sample.

2.2. Methods

Eddy current and electrostatic separation processes were two physical separation methods that were used to determine the recovery rate of aluminium and polymer in yogurt cups. Eddy current separation is performed to separate non-ferrous metals from non-metals material due to different conductivities and densities (Shan et al. 2025). Eddy currents are a manifestation of electromagnetic induction occurring when a magnetic field is applied to a conductor. When magnetic flux density changes, eddy currents are induced in a conductor, creating a magnetic field that opposes or reinforces the applied field, as described by Lenz's law (Rao 2006). This technology has proven effective for larger metal particles but faces challenges with thin foils. The separation efficiency depends on various operational parameters, including belt speed, splitter position, and rotor speed (Niero & Olsen 2016).

Electrostatic separation, alternatively, relies on differences in electrical conductivity among materials (Niero & Olsen, 2016). This method has shown promise for separating fine particles, with separation efficiency influenced by factors such as applied voltage, drum rotational speed, and splitter position (Antonopoulos, Faraca, & Tonini, 2021). The technology's effectiveness for thin aluminium foils from food packaging, however, requires further investigation.

Before testing, the samples were washed of food residues in hot tap water and cut to the appropriate grain size for eddy-current separation or in the case of electrostatic separation, shredded in a Retsch 2000 cutting mill, as seen in **Figure 2a**. Each separation process yields a metallic and a non-metallic material fraction. The proportions of plastic and aluminium within these fractions were manually calculated and separated by visual inspection to determine its recovery.

2.3. Equipments

Size reduction process for electrostatic separation sample was done by using cutting mills from Retsch SM2000 (Fig 2a) with a mesh size of 8 mm. Separation process was conducted with two different methods. Eddy current

separator produced by Magnapower and electrostatic separator from Eirez. All equipment used in the experiment is shown on **Figure 2**.

An eddy current separator Magnapower model ECS 300 (**Figure 2b**) was used for eddy current separation tests. There are three working parameters which govern the separation process. Belt speed could be adjusted in range from 25 Hz to 50 Hz which corresponds belt velocity from 1.32 m/s to 2.67 m/s. Rotor speed also could be changed and the supplier recommend to run it at 70% of the maximum speed. Third parameter is splitter position which can be adjusted between -5 (farthest away from the belt) and 4 (the closest to the belt).

The laboratory electrostatic separator was manufactured by Eriez Magnetics. High tension model HT-150 (**Figure 2c**) was used and has several adjustable working parameters, such as position of two splitter plates, H.T. voltages (up to 30 kV), and roll speed (up to 105 m/min). Through this type of separator, three fractions of the result are possible to achieve. It is magnetic, middlings, and non-magnetic materials. However, this paper only calculates and evaluates the recovery of plastic (PP) and aluminium from the magnetic and non-magnetic fractions.



A)

B)



C)

Figure 2. Equipment used in the research: A) shredder, B) eddy current separator, and C) electrostatic separator

2.4. Testing Plan

Eddy current separation test was carried out 11 tests with variation of setting in splitter position and belt speed as seen on **Table 1**, while rotor speed was constant at 70 % (by the producer recommendation). Sample from separator setting with the optimal test condition was going through scavenging process to increase aluminium content and recovery in the concentrate with the same settings.

Table 1. Test plan, eddy current separator

| Test | Rotor speed, (%) | Splitter position, (-) | Belt speed, (Hz) |
|--------|------------------|------------------------|------------------|
| ECS-1 | 70 | 3 | 25 |
| ECS-2 | 70 | -3 | 50 |
| ECS-3 | 70 | 0 | 35 |
| ECS-4 | 70 | 0 | 50 |
| ECS-5 | 70 | 3 | 50 |
| ECS-6 | 70 | 3 | 35 |
| ECS-7 | 70 | -3 | 35 |
| ECS-8 | 70 | 0 | 25 |
| ECS-9 | 70 | -3 | 25 |
| ECS-10 | 70 | 4 | 25 |
| ECS-11 | 70 | 4 | 30 |

For electrostatic separation process, three settings from the machine were being adjusted. Different voltages, number of drum rotations, and splitter positions were tested to obtain the optimal settings. All electrostatic testing was conducted with single splitter, resulting only two discharges to be analysed. Test was performed 6 times with variations of testing device settings as described in **Table 2**.

Table 2. Test plan, electrostatic separator

| Test | Voltage, (V) | Drum rotational speed, (Hz) | Splitter position, (°) |
|-------|--------------|-----------------------------|------------------------|
| EST-1 | 20000 | 35 | 120 |
| EST-2 | 25000 | 35 | 130 |
| EST-3 | 25000 | 55 | 130 |
| EST-4 | 20000 | 35 | 130 |
| EST-5 | 30000 | 35 | 120 |
| EST-6 | 30000 | 65 | 120 |

3. RESULTS AND DISCUSSION

3.1. Eddy Current Separation

The belt speed and splitter position affected the grade and recovery for the eddy current separation. At a lower belt speed of 25 Hz, aluminium content was high (72.2 % in Met -1), with a recovery of 34.0 %. At a higher speed of 50 Hz, the aluminium content dropped significantly to 25.6 % in Met - 4, with a lower recovery of 32.5 %.

Met -1 and Met - 5 tests conducted with the splitter's flap closer to the drum (positive angle) yielded 34.2 % and 91.9 % aluminium recovery, respectively. However, with the splitter flap farther from the drum (negative angle) in Met - 7, the recovery dropped to 23.7 %. The results for the eddy current separation are illustrated in **Table 3**.

Table 3 Results of Eddy Current Separation

| Fraction | Al content, (%) | Al recovery, (%) | Fraction | PP content, (%) | PP recovery, (%) |
|----------|-----------------|------------------|-----------|-----------------|------------------|
| Met-1 | 72.2 | 34.2 | NonMet-1 | 96.8 | 99.3 |
| Met-2 | 37.5 | 23.7 | NonMet-2 | 96.3 | 98.0 |
| Met-3 | 25.6 | 26.3 | NonMet-3 | 96.3 | 96.2 |
| Met-4 | 6.1 | 60.5 | NonMet-4 | 96.5 | 53.6 |
| Met-5 | 4.4 | 91.9 | NonMet-5 | 89.3 | 3.3 |
| Met-6 | 9.2 | 71.1 | NonMet-6 | 97.8 | 65.0 |
| Met-7 | 60.0 | 23.7 | NonMet-7 | 96.3 | 99.2 |
| Met-8 | 100.0 | 21.1 | NonMet-8 | 96.2 | 100.0 |
| Met-9 | 100.0 | 13.2 | NonMet-9 | 95.9 | 100.0 |
| Met-10 | 49.0 | 63.2 | NonMet-10 | 98.2 | 96.7 |
| Met-11 | 10.1 | 63.2 | NonMet-11 | 97.5 | 72.2 |

For the eddy current separation, the recovery of aluminium was decreased at a higher belt speed. This may be because higher speed lowers the residence time of the ECS. However, it was observed that the closer the splitter position is to the drum, the better the recovery. The optimal test condition for the eddy current separation was first achieved in Met – 10. The belt speed was set at 25 Hz and the splitter position at +4 with the aluminium recovery of 63.2%. Met – 10 was further taken through rougher and scavenging tests to improve the recovery and grade of the aluminium maintaining the splitter position and the belt speed at +4 and 25 Hz. The optimal result was achieved at the third scavenging (Scv) stage, Scv-3 (**Table 4**) with aluminium grade and recovery of 65.45% and 92.31%, respectively.

Table 4. Eddy current separation process with scavenging, mass balance

| | Al, (g) | PP, (g) | Mass, (g) | Al, (%) | PP, (%) | Al recovery | PP recovery |
|-----------|---------|---------|-----------|---------|---------|-------------|-------------|
| Feed | 3.9 | 76.7 | 80.6 | 4.84 | 95.16 | 100.00 % | 100.00 % |
| Rougher | 2.0 | 0.9 | 2.9 | 68.97 | 31.03 | 51.28 % | 1.17 % |
| Scv-1 | 2.8 | 1.9 | 4.7 | 59.57 | 40.43 | 71.79 % | 2.48 % |
| Scv-2 | 3.3 | 1.9 | 5.2 | 63.46 | 36.54 | 84.62 % | 2.48 % |
| Scv-3 | 3.6 | 1.9 | 5.5 | 65.45 | 34.55 | 92.31 % | 2.48 % |
| Reject | 0.3 | 74.8 | 75.1 | 0.40 | 99.60 | 7.69 % | 97.52 % |
| Feed cum. | 3.9 | 76.7 | 80.6 | 4.84 | 95.16 | 100.00 % | 100.00 % |

3.2. Electrostatic Separation

Three parameters; voltage, drum speed and splitter position influence the grade and recovery of aluminium using the electrostatic separation. The splitter position was set at 120 and 130 degrees respectively while varying voltage and the drum rotational speed.

3.2.1. Effect of drum rotational speed on aluminium grade and recovery

The effect of drum rotational speed on aluminium grade and aluminium recovery was analysed using the following pairs of tests:

- EST-2 vs. EST-3: Voltage at 25 kV, splitter position at 130°
- EST-5 vs. EST-6: Voltage at 30 kV, splitter position at 120°

In both pairs, the primary variable was the drum rotation speed. At the same time, the voltage and splitter position remained constant, allowing us to isolate and observe the effect of drum speed on grade and recovery. Considering the EST – 2 and EST – 3 (**Figure 4**), with an increase in the drum rotation speed from 35 rpm to 55 rpm, the aluminium grade dropped significantly from 27.50% to 15.24% with an increase in the recovery from 55.00% to 73.53%. A sharper decrease in the aluminium grade was discovered (from 73.33% to 12.05%) when the rotation speed was increased from 35 rpm to 65 rpm (EST – 5 and EST – 6) with a slight change in the recovery from 96.91% to 96.79%. It can be established that an increase in drum speed rotation resulted in a decrease in aluminium grade. Also, the observed changes in recovery was not only dependent on the drum rotation speed.

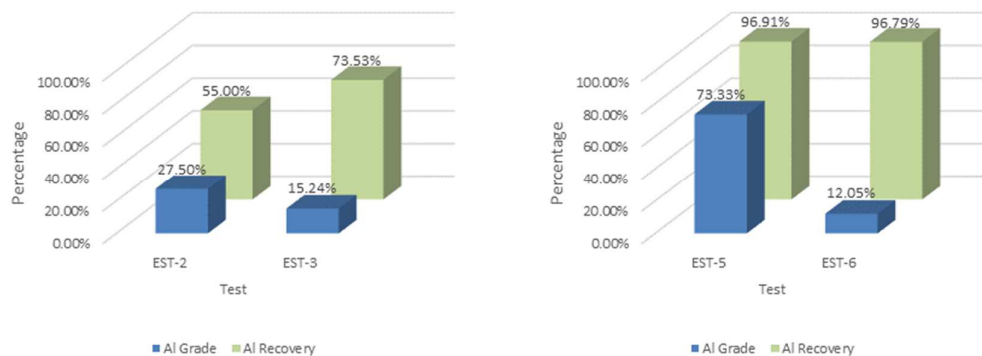


Figure 3. Grade and recovery variation with the varying drum rotation speed

3.2.2. Effect of voltage on aluminium grade and recovery

The effect of voltage on aluminium grade and aluminium recovery was analysed by comparing two test pairs:

- EST-2 vs. EST-4: Drum rotation speed at 35 Hz, splitter position 130°
- EST-1 vs. EST-5: Drum rotation speed at 35 Hz, splitter position 120°

Decreasing the voltage from 25 kV (EST-2) to 20 kV (EST-4) significantly diminished the aluminium grade from 27.50% to 13.79 % (Figure 5). However, aluminium recovery was only marginally affected by the change in voltage, decreasing from 55.00% at 25 kV (EST-2) to 53.33% at 20 kV (EST-4). A significant improvement in aluminium grade was observed when the voltage increased from 20 kV (EST-1) to 30 kV (EST-5). The grade increased from 14.40% to 73.33% with a slight decrease in the recovery dropping from 100% at 20 kV (EST-1) to 96.91% at 30 kV (EST-5).

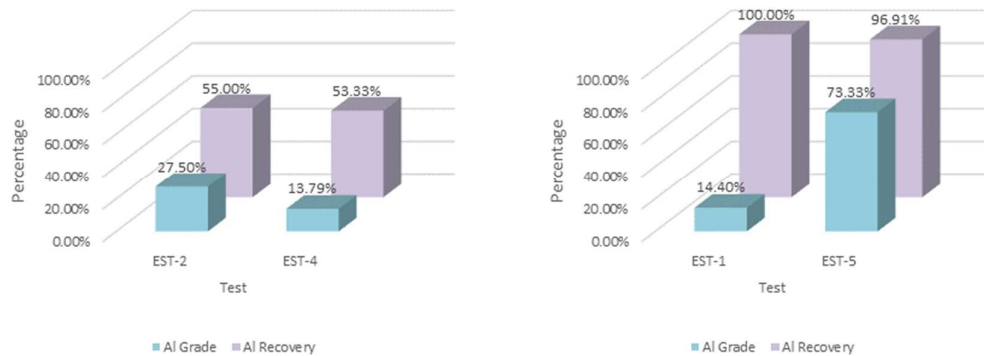


Figure 4. Grade and recovery variation with the varying voltage

In both test pairs, increasing the voltage results in a significant improvement in aluminium grade. This is due to the stronger electric field at higher voltages, which enhances the ability of the high-tension separator to pull out conductive aluminium particles more effectively, leaving behind plastics.

3.2.3. Aluminium grade and recovery optimization

In the Eddy Current separation, the optimal result was achieved in Sev – 3 with aluminium grade of 65.45% and recovery of 92.31%, setting the belt speed at 25 Hz and the splitter position at +4. This indicates that a slower belt speed, combined with a splitter flap positioned closer to the drum gives the optimum result.

Grade and recovery optimization in aluminium separation using electrostatic separation was a delicate balance between drum speed, voltage, and splitter position. Lower drum speeds and higher voltages result in a higher grade with improved selectivity, but recovery may be slightly impacted. An optimal result was achieved during EST – 5 with 73.33% and 96.91% of aluminium grade and recovery respectively. The drum rotation speed was set at 35 rpm, voltage at 30, and the splitter position at 120°. In this study, the splitter position was kept at two different positions but lacks data to predict the behaviour of grade against the splitter arrangement. It is suggested to conduct more tests to establish the optimization with the splitter position.

4. CONCLUSION

In the Eddy Current Separation process, the optimal test condition was observed when the belt speed was set at 25 Hz and the splitter position was adjusted to +4 position. This combination led to an aluminium grade and recovery of 65.45% resp. 92.31%. These results indicate that a slower belt speed, coupled with a splitter flap positioned closer to the drum, enhances both aluminium recovery and grade. Although ECS is effectively separated aluminium from the plastics, tiny fractions of plastics were attached to the aluminium, especially at the lid. This can be observed in the lowest recovery of aluminium at Met – 9, hence further separation is required.

In Electrostatic Separation, optimizing the aluminium grade is a delicate balance between drum speed, voltage, and splitter position. Lower drum speeds and higher voltages typically result in higher aluminium grade by improving the selectivity of the separation process, although this can come at the cost of slightly reduced recovery. While the study effectively examined the effects of drum speed and voltage, it was limited in the exploration of splitter position, which was only tested in two settings. Further testing is recommended to fully understand the impact of splitter position on aluminium grade and recovery and to establish the optimal configuration for maximizing separation efficiency.

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