Development of an axial gap rotary shear for the sampling of sorted food waste sub-category

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Abstract. Extended Producer Responsibility (EPR) is an important regulatory instrument under which producers are required to pay a fee to cover the end-of-life management and treatment of their products. The Institute of Raw Materials Preparation and Environmental Technologies at the University of Miskolc developed an EPR related municipal solid wastes (MSW) sampling methodology based on the simultaneous application of manual sorting and sieving. A key principle of this methodology is that each particle must be classified in its as-found state according to the material component representing the largest mass fraction. Since food waste is typically present in a highly heterogeneous and contaminated form, it must be sorted in this condition into the appropriate category. This raised the question of how much EPR-relevant material is embedded in the food waste sub-category sorted in this way; therefore, a new methodology was developed to address this issue. The first step of the new procedure is liberation by means of an appropriate comminution device. Fundamental comminution tests were carried out using a cutting mill, a hammer crusher, an axial-gap rotary shear, and a radial-gap rotary shear. Based on the evaluation of the results, a new axial-gap rotary shear was designed and constructed. This paper presents the relevant sampling aspects, the fundamental comminution experiments performed on food waste using four different machines, the design and construction of the new axial-gap rotary shear, and the systematic mechanical and biological investigation of two particle-size fractions obtained from the sorted food waste sub-category of an average residual municipal solid waste average sample.

1. Introduction

Extended Producer Responsibility (EPR) has become an increasingly important policy instrument in modern waste management systems, as it shifts part of the financial and organizational responsibility for end-of-life products from municipalities to producers. In parallel with EPR, deposit return systems (DRS) also play a growing role in improving the separate collection and recovery of valuable material streams. The introduction of these regulatory frameworks requires reliable information on the material composition of municipal solid waste (MSW), including the occurrence and distribution of EPR- and DRS-related components.

In Hungary, the EPR system was introduced in 14th March 2023 by Government Decree 80/2023, creating a strong need for practical and scientifically sound methodologies for the characterization of relevant waste streams. In response, the Institute of Raw Materials Preparation and Environmental Technologies at the University of Miskolc developed a sampling and sorting methodology based on the combined application of manual sorting and sieving (Faitli et. al., 2024; Jaber et. al., 2026). A fundamental principle of this approach is that each particle is classified in its original, as-found state according to the material component representing the largest mass fraction.

However, this principle raises specific challenges in the case of food waste sorted by the developed sampling methodology, which is typically highly heterogeneous and often contains adherent packaging residues and other EPR-relevant materials. According to Hungarian sampling standards the sorted food waste “fraction” is called waste sub-category. As a result, the apparent classification of food waste may mask the actual presence of recoverable material components. To address this problem, a new methodology was developed based on the liberation of the sorted food waste sub-category by comminution. The present study investigates the sampling-related aspects of this problem, compares the performance of different comminution devices, and presents the design of a newly developed axial-gap rotary shear. Figure 1 shows the technological flowsheet of the developed test protocol to examine the material composition of the sorted food waste sub-category. After the liberation by comminution and splitting, a subsample

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was soaked in water, where it split into three parts. Light particles floated up, heavy particles settled and biomaterials typically went into the suspension. This soaking served as a washing also and that facilitated further manual sorting and biological examinations not described here.

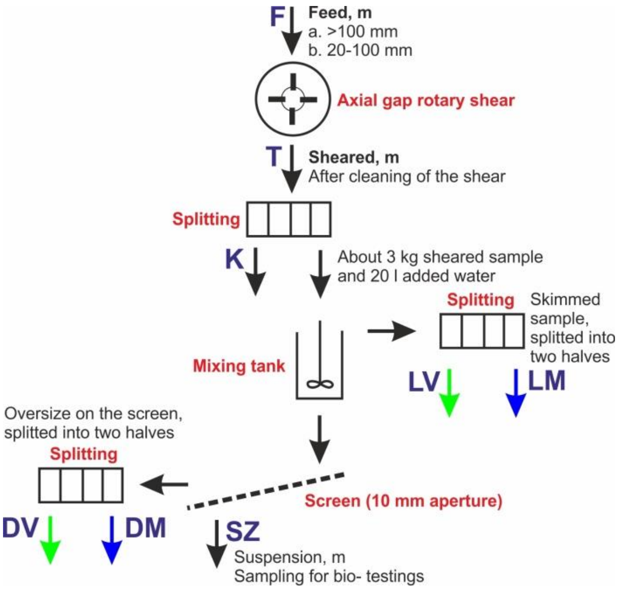

Figure 1. Technological flowsheet of the developed test protocol to examine the material composition of sorted food waste sub-category.

2. Development of the comminution machine

2.1. Preliminary comminution tests

Preliminary tests were carried out using packaged food products and vegetables to select the most suitable type of comminution equipment. The model materials were selected based on photographs of the real food waste sub-categories obtained during previous sampling campaigns. During the preliminary experiments, packaged bread rolls, packaged sliced cold cuts, and lettuce were processed in an axial-gap rotary shear, a hammer crusher (Figure 2), a radial-gap rotary shear, and a cutting mill. The results were evaluated and described based on photographs taken of both the products and the interior of the machines. In the axial-gap rotary shear the plastic-packaged food products were successfully liberated and the food separated from the plastic packaging. However, the plastic remained largely intact, which can be explained by the 0.5 mm shear gap applied in the machine. The food fraction itself was only moderately size-reduced, which can be attributed to the low rotor circumferential speed of 0.5 m/s. In the hammer crusher, liberation of the food material was achieved effectively, and all three materials were finely comminuted due to the high rotor circumferential speed (~40 m/s) and the combined action of impact and shear stresses. The plastic components, however, remained largely intact, and a considerable part of them stayed inside the machine (Figure 2). This can primarily be explained by the small amount of feed material used. At the same time, small sample quantities may also occur during the operation of the final target equipment; therefore, this was identified as a disadvantage of the hammer crusher. In the radial-gap rotary shear, the vegetable material adhered to the inner wall of the machine, and only a minimal amount left the equipment.

Figure 2. Test comminution in a hammer crusher.

The bread roll was comminuted without difficulty; however, due to electrostatic charging, most of the plastic film also adhered to the interior of the machine. In this case, the film itself was comminuted effectively. The cutting mill successfully liberated the individual food products, but the packaging of the sliced cold cuts, similarly to the hammer crusher, did not leave the machine and remained inside. The thin plastic bag, on the other hand, passed through the machine without undergoing effective size reduction.

Based on the experience gained during these tests, and considering the required machine size and cleanability, the two-rotor type axial-gap rotary shear was finally selected for the task.

2.2. Design and construction of the axial-gap rotary shear

In the two-rotor axial-gap rotary shear, the feed material is drawn into the shearing zone by two counter-rotating shafts equipped with disc cutters. Comminution is achieved in the narrow axial gaps formed between the rotating discs and the opposing elements, resulting in efficient liberation and controlled size reduction of heterogeneous waste materials.

The process design of the equipment was performed according to the methodology originally proposed by Csőke et al. (1997), followed by the mechanical design and construction of the machine. For technological design calculations, the following approximate relationships can be derived. The maximum shearing force is given by

$$F_{\max} = kA\tau_m [\mathrm{N}] \quad (1)$$

The maximum torque is

$$M_{\max} = bF_{\max} = kA\tau_m b [\mathrm{Nm}] \quad (2)$$

where, the shear cross-sectional area can be approximated as

$$A = \frac{w^2}{2\tan\alpha} \quad (3)$$

In these equations, A is the cross-sectional area of the material being sheared, τ_m is the shearing resistance of the material, approximated by its shear strength, b is the lever arm, and k is a correction factor accounting for the differences between the conditions under which τ_m is determined and the actual shearing conditions, such as blade wear, cutting speed, and shear gap. In most cases, k lies in the range of 1.0 to 1.3.

By substituting the sheared cross-section into the torque equation, and considering that in a machine of working length L and disc width y, the number of discs mounted on one shaft is

$$N = \frac{L}{2y} \quad (4)$$

The total torque demand of the two-rotor machine, i.e. the combined torque demand of both shafts, can be expressed as

$$M = \frac{kLs^2\tau_m(D-t)}{4y} \quad (5)$$

The useful power demand of the machine drive is then

$$P_h = \frac{kL\pi ns^2\tau_m(D-t)}{2y} \quad (6)$$

In practice, the actual motor power demand is higher because of deformation-fracture effects associated with the front knives and due to friction losses. Therefore, the required motor power can be estimated as $P \approx cP_h$ where, $c = 1.5$–1.9. The rated motor power is then taken as $P_\mathrm{r} = 1.2P$ (Csőke et. al., 1997).

The machine width was set to 0.25 m, considering the largest items expected in the feed material. Liquid-filled soft drink bottles were considered as the reference objects representing the upper size limit of possible feed pieces. Owing to the large feed size, the diameter of the shearing discs was selected as 0.20 m. The rotor circumferential speed was set to 0.5 m/s.

For the determination of torque and power demand, an extreme operating case was assumed in which the machine would be required to shear a 1.5 mm thick metal sheet. This intentionally conservative design approach was adopted because sorted food waste may contain a wide range of foreign materials, including bones and canned food products. Considering the losses in the reduction gearbox, two 4 kW geared motors were selected to drive the machine.

Figure 3. The constructed axial-gap rotary shear and its main units: (a) electrical control box, (b) feed hopper, (c) shearing chamber, (d) product collection container, (e) drive motor, and (f) supporting frame.

The shearing discs and spacers were surface-ground, making it possible to set a shear gap of 0.08 mm to ensure the effective comminution of plastic films. The completed equipment is shown in Figure 1 together with its main units. To improve cleanability, the machine was equipped with a partially rotatable comb assembly, which allows sample material adhering between the discs and remaining inside the machine to be removed easily.

The successful construction of the equipment confirmed the feasibility of integrating process design, mechanical design, and in-house manufacturing in the development of small-scale experimental comminution devices.

3. Results and conclusion

One pilot study had been conducted to test the methodology developed for examining the contamination of food waste (Figure 1) and the new axial-gap rotary shear. Sampling took place on May 16th, 2025, at the premises of MiReHu Kft. in Miskolc, Hungary as part of the national level MSW sampling campaign of SPRING 2025.

The total mass of the >100 mm and the 20-100 mm size fractions of the sorted 1.1 food waste sub-category of the residual MSW average sample of M-XI (balance sheet number: W17079-02509766) were delivered to the lab. The analysis of the two food waste size fractions was carried out according to Figure 1. Figure 4 shows the skimmed materials which were floated on the surface of the suspension in the mixing tank.

Table 1. Material composition of the examined sorted food waste category.

	2D plastics	3D plastics	Paper	Others	Bio	Water	Total		Ratio	
>100 mm	6.11	2.42	2.42	0.65	29.29	59.11	100.0	%	0.618	-
20-100 mm	4.30	0.59	0.47	0.21	37.85	56.57	100.0	%	0.381	-
									1	
Total	**5.4**	**1.7**	**1.7**	**0.5**	**32.6**	**58.1**	100.0	%		

Without further describing the other done physical, chemical and biological examinations, Table 1 shows the measured final material composition of the food waste sub-category of the examined RMSW average sample.

Figure 4. The skimmed materials which were floated on the surface of the suspension in the mixing tank.

If water is considered to be food, then the total food content of the examined sorted food waste sub-category was 90.7 m/m%. And that means that the so called contaminants, namely materials - which should have been sorted into other waste categories - account for only 9.3 m/m% (Table 1). And this is the final conclusion that the key principle of the Hungarian MSW sampling methodology, - namely that each particle must be classified in its as-found state according to the material component representing the largest mass fraction – is correct. The mass balance of the waste materials can be correctly measured on the basis of this sampling principle, because the sorting errors of materials that do not belong to the actual category finally equalize. When the mass of the beverage in a PET bottle is greater, it should be classified as food waste, but PET bottles that only appear empty also contain beverage, so the resulting effect is balanced.

Another conclusion is that, the built axial-gap rotary shear has liberated the sorted food waste sub-category size fractions reliably.

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