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Effect of PET Bottle Compaction on the Saturation of the Waste Container

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Abstract

Engineers and users are being pushed by environmental concerns to maximize efficiency while minimizing ecological damage. Waste collection vehicles require fossil fuels during their collection route, as well as when lifting and emptying the containers, even if the design of separate waste collection islands has focused on the idea of recycling. Even in a computer plan–assisted collection, saturated containers may have low waste density, meaning that a sizable portion of the container becomes unusable due to the shape of the waste. To maximize container utilization, this study will investigate the type and compaction potential of each container. The simulation study will provide an answer to the question of how the density of waste placed in the various containers changes as a result of compressing each bottle.

The research and development will optimize not only the saturation of the container but also the number of collection routes; in addition to the economic benefits, the environmental load will be reduced. The frequency of lifting and emptying the container will decrease, resulting in reduced maintenance and repair costs for the vehicle's lifting system and container.

It is a misconception that compaction by hand in one place, throughout the diameter of the PET bottle, is the optimum way to increase the efficiency of waste collection. Based on the tests carried out in this paper, foot diameter compaction at full height is considered to be the most appropriate method after the use of a costly compactor.

Keywords

selective waste, PET waste, capacity utilization, container filling, optimizing

1 Introduction

Studies on solid waste in cities have indicated that the economy and urban development play significant roles in determining the amount of waste produced (Oribe-Garcia et al., 2015; Saukenova et al., 2022; Phiri et al., 2023). In developing countries, inadequate waste management facilities and a lack of sanitation services have led to significant environmental pollution, landscape degradation, and adverse health impacts on local residents (Apostol et al., 2012).

Separate waste collection islands have been established in a few of the municipalities' catchment areas to reduce the environmental impact. To better integrate into the cityscape, the article by Komar and Kucharczyk-Brus (2020) presents various concepts for the new containers. Based on several articles, selective waste collection is essential (Benavides et al., 2018; Foolmaun and Ramjeeawon, 2012). To maximize collection efficiency, we utilize route optimization (Gilardino et al., 2017; Nguyen-Trong et al., 2017; Paul et al., 2016; O'Connor, 2013), adjusting collection intervals, and implementing telephone saturation notifications in Hungary. These actions contribute to environmental protection (Stefan and Paul, 2008;), but efficiency can be further improved by identifying and recognizing additional options. Although a high level of container collection has been achieved, further work is needed to increase the density of container waste.

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This article examines the potential for each bottle to be compacted and provides information on the container waste density values achieved through compaction.

2 Examining the compaction potential of PET bottles

For the best solution, the compaction process should be carried out before the waste is placed in the container. There are different solutions for compaction, but the simplest ones will be examined.

The most common ways to reduce the volume of a PET bottle are:

- Hand compression unit: PET bottles are compressed by hand using a height-based device instead of a thickness-based one (Fig. 1). During compression, only a decrease in height is achieved; their cylindricality and diameter are "unchanged." It is uncommon to use the compacting roll due to hygienic concerns because it is manually operated.
- Compression with hand (Fig. 2): The user has the option to choose the degree and location of compression; typically, compression is performed at a smaller diameter in a comfortable area for the hand. The bottle is flattened where the compression occurs, but the rest of it retains its original shape. The user can have "peace of mind" knowing that they have contributed to environmental protection thanks to this type of compaction.
- Foot compaction (Fig. 3): When properly stepped on, the PET bottle is compressed over its entire height (diameter). The shape of the bottle changes during compression to a flat one. Because it requires bending over, this compression method is not frequently used for hygienic reasons.

The following tables present examples of the PET bottles evaluated in the computer simulation (see Tables 1–7).

Tests were performed on commercially available mineral water bottles.

Fig. 1 Hand PET bottle compression unit

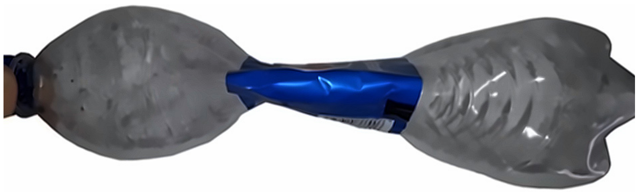


Fig. 2 1.75 ℓ PET bottle compressed with hand

Fig. 3 1.75 ℓ PET bottle compressed with foot

Table 1 Measuring a 0.50 ℓ PET bottle

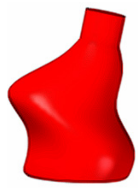
	0.50 ℓ PET bottle			
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	18 g			
Volume	520 cm^3	470 cm^3	390 cm^3	440 cm^3
Volume reduction	-	–10%	–25%	–16%
Average density	0.0346 g/cm^3	0.03829 g/cm^3	0.04615 g/cm^3	0.40909 g/cm^3

Table 2 Measuring a 1.00 ℓ PET bottle

1.00 ℓ PET bottle				
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	28 g			
Volume	1030 cm³	540 cm³	276 cm³	595 cm³
Volume reduction	-	–48%	–73%	–42%
Average density	0.02718 g/cm³	0.05185 g/cm³	0.10144 g/cm³	0.04705 g/cm³

Table 3 Measuring a 1.25 ℓ PET bottle

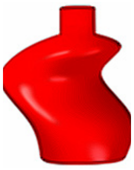
1.25 ℓ PET bottle				
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	33 g			
Volume	1295 cm³	730 cm³	390 cm³	650 cm³
Volume reduction	-	–45%	–70%	–50%
Average density	0.02548 g/cm³	0.04520 g/cm³	0.08461 g/cm³	0.05077 g/cm³

Table 4 Measuring a 1.5 ℓ PET bottle

1.5 ℓ PET bottle				
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	34 g			
Volume	1555 cm³	920 cm³	470 cm³	775 cm³
Volume reduction	-	–40%	–69%	–51%
Average density	0.02186 g/cm³	0.03695 g/cm³	0.07234 g/cm³	0.04387 g/cm³

Table 5 Measuring a 1.75 ℓ PET bottle

1.75 ℓ PET bottle				
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	36 g			
Volume	1790 cm³	880 cm³	420 cm³	820 cm³
Volume reduction	-	–50%	–76%	–54%
Average density	0.02011 g/cm³	0.04090 g/cm³	0.08571 g/cm³	0.04581 g/cm³

Table 6 Measuring a 2.00 ℓ PET bottle

2.00 ℓ PET bottle				
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	37 g			
Volume	2045 cm³	930 cm³	444 cm³	930 cm³
Volume reduction	-	–54%	–78%	–54%
Average density	0.01809 g/cm³	0.03978 g/cm³	0.08333 g/cm³	0.03978 g/cm³

Table 7 Measuring a 2.25 ℓ PET bottle

2.25 ℓ PET bottle				
Used compr.	-	With hand	With foot	Hand compr. unit
				
Weight	43 g			
Volume	2250 cm³	1020 cm³	470 cm³	950 cm³
Volume reduction	-	–55%	–79%	–58%
Average density	0.01911 g/cm³	0.04216 g/cm³	0.09149 g/cm³	0.04526 g/cm³

The PET bottles tested were the following:

- 0.50 ℓ,
- 1.00 ℓ,
- 1.25 ℓ,
- 1.50 ℓ,
- 1.75 ℓ,
- 2.00 ℓ,
- 2.25 ℓ.

The PET material density is 1350 kg/m³.
The tests carried out are:

- Original condition: the PET bottle was used in the simulation without deformation. In comparison to the initial state, no difference in shape or volume is visible (green-coloured bottle).
- Manually compressed: The diameter of the bottle is loaded. The bottle's "gripping" point is where the compression is applied. The bottle's cap and bottom do not even deform at all. Following compression, the PET bottle is released according to the material's characteristics (blue-coloured bottle).
- Foot-loaded PET bottle: The bottle's overall diameter decreased in proportion to its volume. In this case, the bottle was also dislodged when the load was taken out. The bottle flattened due to the load (as shown by the violet-coloured bottle).
- Use of a compression device: Reduced cylinder height resulted from the loading force being applied perpendicular to the longitudinal axis. The cylinder moved once the force was released. The diameter of the cylinder did not decrease noticeably (as indicated by the red-coloured bottle).

It is understood that the compression of PET bottles varies in each case, but there is little difference in volume or shape.

The mass data in the table were measured with a weighing accuracy of 1 g. The volumetric data were determined using the water displacement principle with a closed bottle to eliminate possible water pressure. The shape of the bottle was modelled using photographs (Fig. 4).

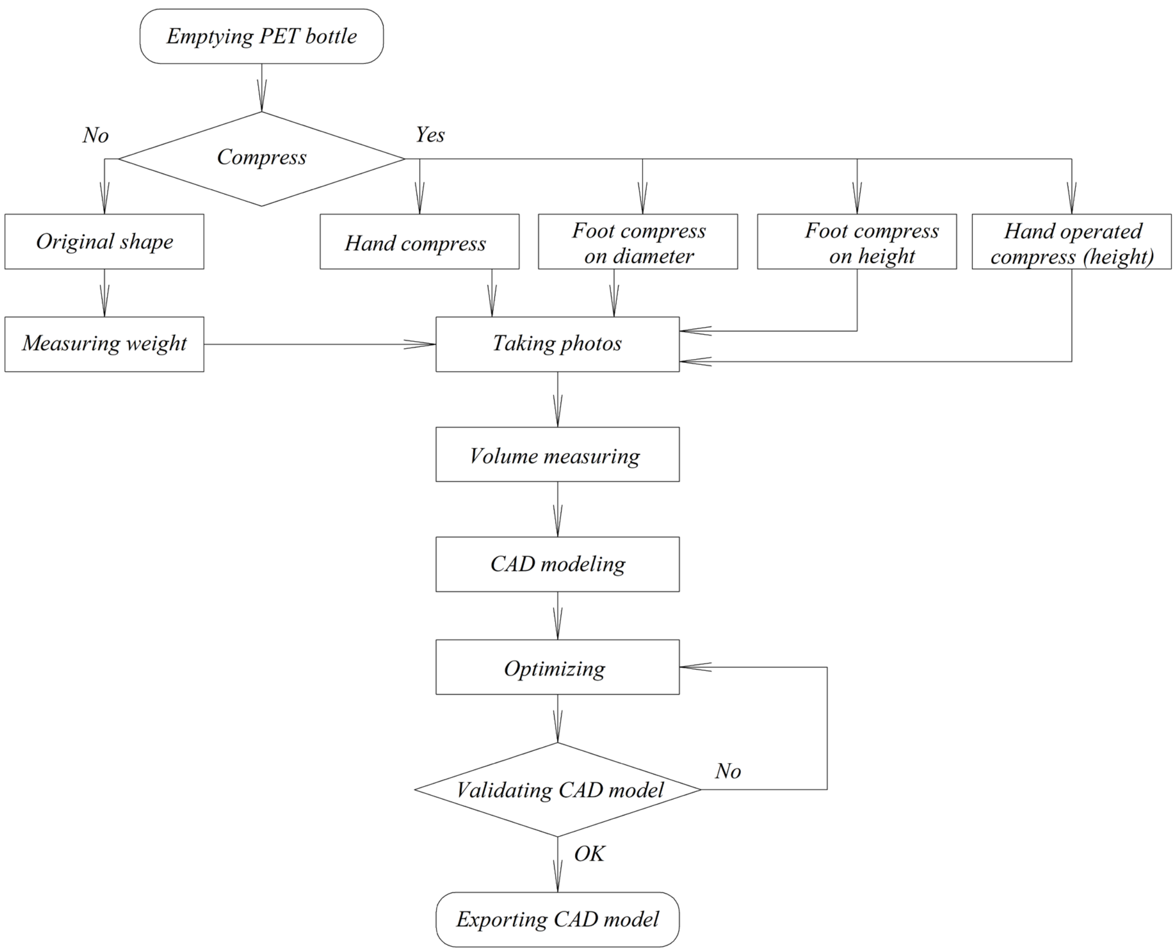


Fig. 4 Modelling steps

The photos (front, side, top) were inserted into CAD software (Autodesk, online) as a background image, which was used to model the PET bottle.

Tables 1–8 show the results for different compression methods. The first column shows the original (test-optimized) model. The second column illustrates the compaction with hands. The model is marked in blue. The third column illustrates the foot compaction, which is coloured violet. Column four illustrates the use of a hand compression unit. The model is marked in red.

Fig. 5 and Table 9 summarize the various conditions of PET bottles of different volumes for a better evaluation of the data.

3 Waste container saturation test

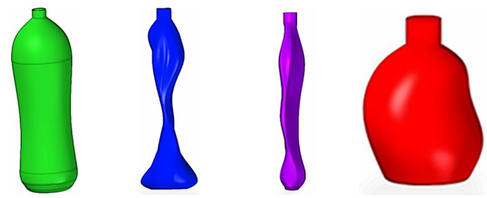
Different results were obtained for each compression mode in the measurements. In addition to loading, it also affects volume and shape. The issue of how compression modes impact the saturation of the container is addressed in the following simulations. Of course, the variety of the cylinders, the various compaction modes, and the various container saturation states will affect the maximum quantity of waste that can be contained. In addition to the 4-wheel top-opening container, dealers also provide a standing container with various capacities, so another factor must be considered (Fig. 6).

Autodesk 3DS Max software (Autodesk, online) was used to perform the tests.

Due to the shape of the container and the presence of both compressed and uncompressed PET bottles, there are significant air gaps resulting from the positioning of the individual bottles. As the bottles are not inserted by a machine, even chance plays a significant role in the utilization of saturation. Based on the measured data (Tables 1–9) and simulation data (Table 10), it can be concluded that bottle compression and shape have a significant impact on the waste container's saturation. Based on the results, the following can be concluded:

- The number of PET bottles thrown into the container increased by 10–20% due to the hand compression's 40–50% reduction in volume in the simulated study.
- A 70–80% volume reduction can be achieved when compacting with a foot, allowing 40–50% more waste to be placed in the container.
- Compacting PET bottles with a manual compactor can reduce volume by 50–60%. In this case, the collection container can handle 40–50% more waste.

Table 8 Measuring a 2.50 ℓ PET bottle

	2.50 ℓ PET bottle			
Used compr.	-	with hand	with foot	hand compr. unit
				
Weight	45 g			
Volume	2540 cm³	1230 cm³	590 cm³	960 cm³
Volume reduction	-	–52%	–77%	–62%
Average density	0.01771 g/cm³	0.03658 g/cm³	0.07627 g/cm³	0.0468 g/cm³

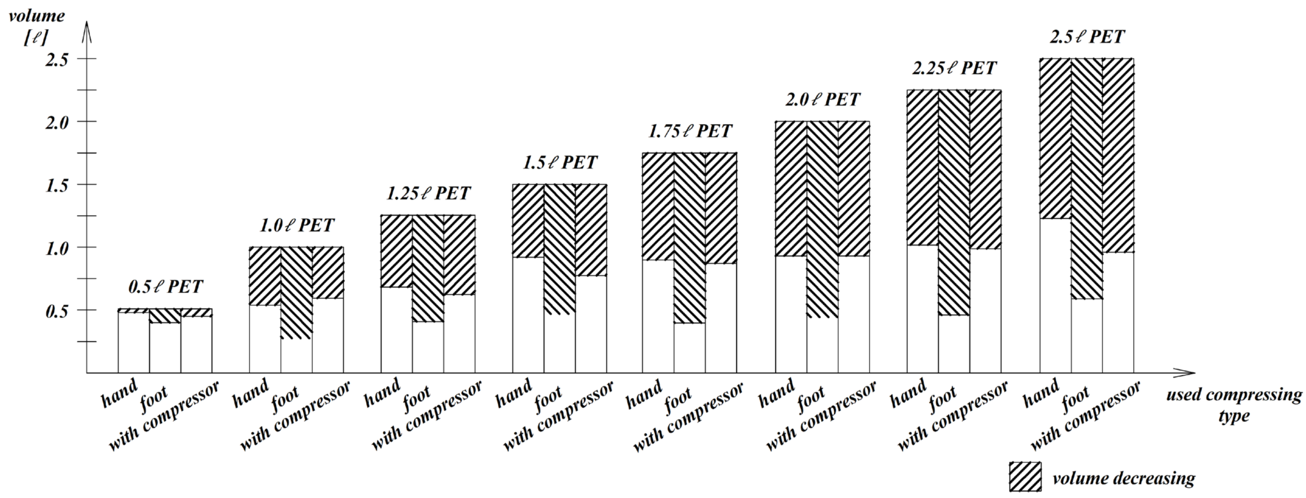


Fig. 5 Volume reduction on PET bottles using different compression types

Table 9 Tabular summary of PET bottle measurements

Bottle vol. (PET)	Bottle weight [g]	Original volume [cm³]	Compress type	Compr. volume [cm³]	Volume red. [%]
			Hand	470	10
0.50 ℓ	18	500	Foot	390	25
			Hand compr. unit	440	16
			Hand	540	48
1.00 ℓ	28	1000	Foot	276	73
			Hand compr. unit	595	42
			Hand	730	45
1.25 ℓ	33	1250	Foot	390	70
			Hand compr. unit	650	50
			Hand	920	40
1.50 ℓ	34	1500	Foot	470	69
			Hand compr. unit	775	51
			Hand	880	50
1.75 ℓ	36	1750	Foot	420	76
			Hand compr. unit	820	54
			Hand	930	54
2.00 ℓ	37	2000	Foot	444	78
			Hand compr. unit	930	54
			Hand	1300	55
2.25 ℓ	43	2250	Foot	470	79
			Hand compr. unit	820	58
			Hand	1230	52
2.50 ℓ	45	2540	Foot	590	77
			Hand compr. unit	960	62

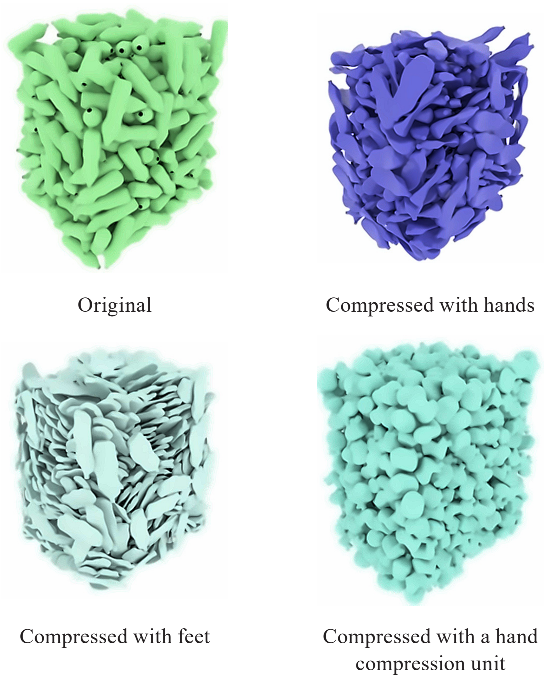


Fig. 6 1500 ℓ container filled with 1.50 ℓ PET bottle

Table 10 Waste container characteristics for PET bottles with different compaction

Cont. size	Waste (bottle) type	Comp. type	Bottle pieces	Trash weight [kg]	Trash density [kg/m³]	Utility rising [%]
1500 ℓ	0.50 ℓ PET	Original	~776	~13.97	9.31	-
		Foot	~1635	~29.43	19.62	+52.5
		Hand compr. unit	~1434	~25.81	17.20	+45.8
		Hand	~1243	~22.37	14.92	+37.6
1500 ℓ	1.00 ℓ PET	Original	~637	~17.84	11.89	-
		Foot	~1195	~33.46	22.31	+46.7
		Hand compr. unit	~1137	~40.60	27.07	+56.1
		Hand	~726	~20.32	13.55	+12.3
1500 ℓ	1.25 ℓ PET	Original	~518	~17.09	11.40	-
		Foot	~722	~23.83	15.88	+28.2
		Hand compr. unit	~784	~25.87	17.25	+33.9
		Hand	~612	~20.19	13.22	+13.8
1500 ℓ	1.50 ℓ PET	Original	~378	~12.85	8.57	-
		Foot	~706	~24.00	16.00	+46.4
		Hand compr. unit	~803	~27.30	18.20	+52.9
		Hand	~398	~13.53	9.02	+0.04
1500 ℓ	2.25 ℓ PET	Original	~364	~15.65	10.43	-
		Foot	~667	~28.68	19.12	+45.5
		Hand compr. unit	~889	~38.22	25.48	+59.1
		Hand	~598	~25.71	17.14	+39.1
1500 ℓ	2.50 ℓ PET	Original	~345	~15.52	10.35	-
		Foot	~658	~29.61	19.74	+47.6
		Hand compr. unit	~825	~37.12	24.75	+58.2
		Hand	~412	~18.54	12.36	+16.3

4 Conclusions

The most common PET bottles were tested in order to maximize the efficiency of further waste collection. The volume and shape changes of the PET bottle were examined using various compaction techniques, including hand compaction, foot compaction, and manual compaction. Based on the collected information, a saturation simulation was performed using the 1500 ℓ waste container. The simulation results demonstrate the importance of both volume and shape in determining the quantity of PET bottle waste that can be placed in the container.

It is understood that properly compacted waste can allow approximately twice as much waste to be disposed of, thus halving the collection frequency. In many cases, an effective solution illustrated by a simple picture can be said to be appropriately applied by the user.

Future research will aim to address the effect of PET bottle compaction on the saturation of the waste container by focusing, e.g., on AI-driven design and data analysis optimization (Ficzere, 2023; Zamfirache et al., 2023; Nosonovsky and Aglikov , 2024), fuzzy logic (Taran et al., 2023; Mishra et al., 2023; Radovanović et al., 2023), or traditional statistical analysis (Ézsiás et al., 2024; Fischer et al., 2024; Fischer, 2025). Sophisticated finite element simulation and modelling methodologies can be applied for supplementary investigations (Kuchak et al., 2020; Kuchak et al., 2021; Dižo et al., 2018; Melnik et al., 2024). The aspects and trends of cognitive mobility and sustainability must be examined in detail (Zöldy et al., 2023; Zöldy et al., 2024; Zöldy, 2024).

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