Design of Machines and Structures, Vol. 15, No. 1 (2025), pp. 41–48.
https://doi.org/10.32972/dms.2025.004

ERGONOMICS OF PET BOTTLES

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Abstract: The article analyses the basic functions of standard-sized PET bottles from an ergonomic perspective. Accordingly, it analyses the storage, closing, opening, sealing, emptying, stability, gripping and information transfer functions from the user's perspective. It shows good and bad practices.

Keywords: *ergonomics, PET bottles, bottle size, bottle base, bottle cap*

1. PET AS A RAW MATERIAL

Polyethylene terephthalate (PET) is one of the most common polycondensation plastics, patented in 1941. The Dupont engineer Nathaniel Wyeth began to investigate the possibility of storing carbonated drinks in plastic bottles in 1967, and in 1973 he received a patent for bottles.
Due to its excellent chemical and mechanical properties, PET is still the most common raw material for drink bottles. From this point of view, its most important characteristics are outstanding thermoformability, high impact resistance, excellent transparency, good cold resistance, dimensional stability, excellent mechanical properties, chemical resistance. All these properties make it suitable for food packaging. This article specifically examines the ergonomics of normal-sized products with a maximum capacity of 2 litres from the customer's point of view (Figure 1), as containers with a capacity of 3-20 l affect a much narrower circle of users.

Figure 1. *Standard-sized PET bottles*
https://www.avu-online.de/en/polyethylene-terephthalate-pet/

2. BASIC FUNCTIONS

The most important task of a drink bottle is to store liquid food reliably, hygienically and without leaks for a long time.
Closely related to this are the closing and sealing as basic functions. The condition for easy access to the stored beverage is easy opening and emptying. Stability and a secure grip are also important aspects during use. A wide range of information transfer is essential for the sale, consumption and recycling of the product, which can take place on the wall of the PET bottle or on the labels attached to it.
The implementation of all these functions also has important, user-centred ergonomic aspects. Due to the latest European Union regulations, manufacturers have had to make several modifications to PET packaging recently, which primarily affected the design of the end cap and labels. The following chapters of the paper examine these interrelated functions of PET bottles from an ergonomic point of view.

3. STORAGE, STABILITY

The most important and unavoidable task of a bottle is storage. The first ergonomic aspect of this is the amount of liquid that can be stored, as most drinks lose their quality faster after opening, in contact with air, than unopened. From a consumer point of view –in the case of 1 person–, a differentiation must be made between single-drinking (2 dl-5 dl) and multiple-drinking (5 dl-2 l). Smaller bottles should also be more suitable for manual carrying, while larger ones should be more supportive of stable storage.

Ergonomic and aesthetic requirements must also be taken into account during the design process, so that the bottle provides practicality, usability and aesthetic appeal to the consumer. Rigidity is a primary consideration when storing (Ge-Zhang, Song, Huang, Li, & Mu, 2022), but from an ergonomic point of view, it is important that the bottle placed on its base stands stably on most nearly horizontal surfaces.

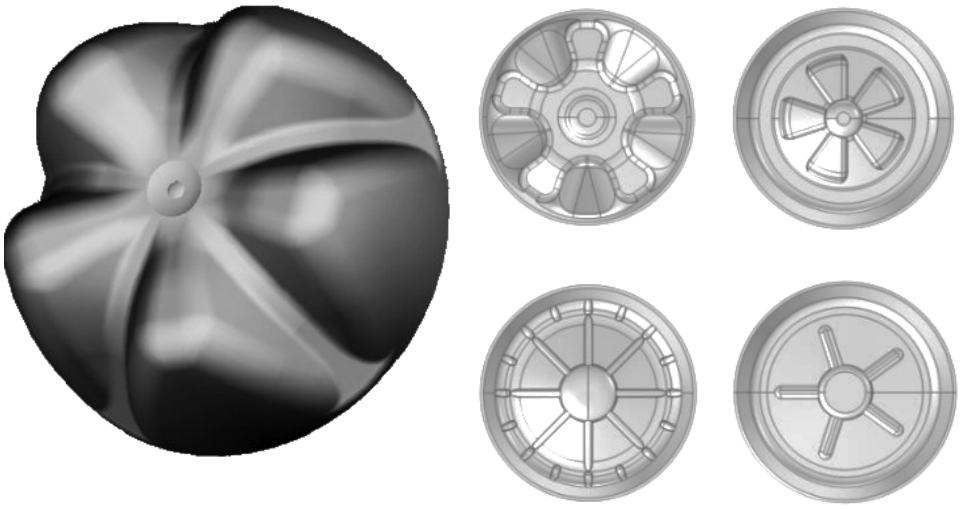


Figure 2. *Traditional bottle bases*
(Demirel & Daver, 2009), (Ge-Zhang, Song, Huang, Li, & Mu, 2022)

The most common solution for this is the 5...8-pointed star-shaped embossing at the bottom of the bottles (Figure 2). With this geometry that also serves as a bottom stiffening and provides multi-point support. The bottle can remain stable even on soft surfaces (e.g. grass, gravel, sand) and is even suitable for creating a tilt-free underlay surface for itself in the soil.
Another expectation related to storage is compliance with and controllability of food safety and hygiene requirements. The transparency of the polyethylene terephthalate raw material provides a good basis for this, as the cleanliness of the contents of the bottle can be easily visually inspected. The design of the cap also serves hygiene, which surrounds the mouth of the bottle and perfectly closes the spout from dirt. (Figure 3)

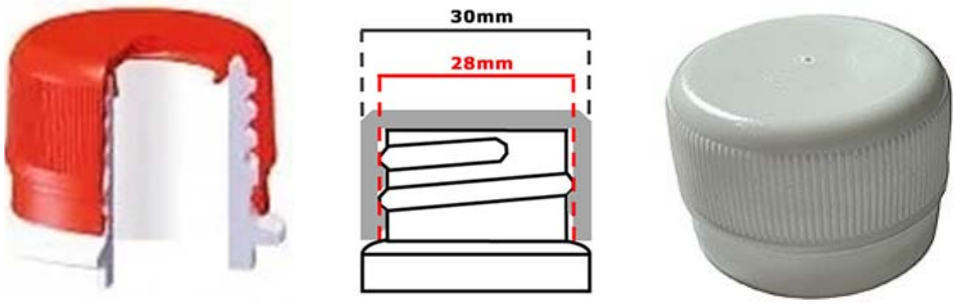


Figure 3. *Traditional bottle cap (Demirel & Daver, 2009)*

4. CLOSING, SEALING, OPENING

The design of the cap must also comply with a number of ergonomic principles and legal regulations. The warranty ring at the bottom of the cap, which detaches from the cap when first opened, is related to the already mentioned hygiene requirements. Separation of this part clearly indicates to the consumer that the product is no longer in the sterile condition guaranteed by the manufacturer.
However, according to the European Union's Directive 2019/904, from the summer of 2024, the warranty ring can no longer be completely detached from the cap. With this decision, the EU wanted to achieve more recycling and less plastic packaging waste emissions. If the cap is still attached to the neck of the bottle after opening, there is a good chance that they will be collected with bottles together for recycling, thus avoiding the environmental impact caused by carelessly discarded caps. The regulations set several conditions for new caps, so they must remain compatible with existing preform designs, mouth lips, thread types and filling systems.

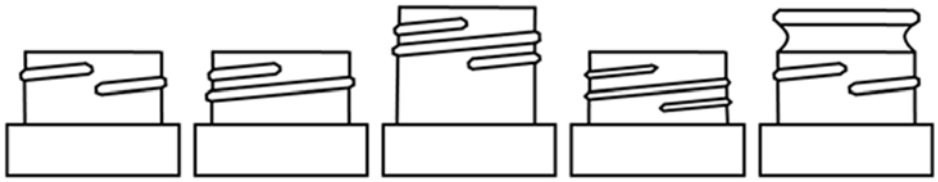
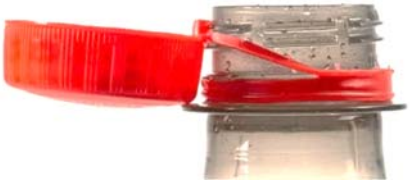


Figure 4. *Conventional PET thread types (Demirel & Daver, 2009)*
a) 1 thread turn; b) 1.5 thread turns;
c) 2 thread turns, tall neck finish
d) 2 thread turns, narrow threads; e) buttress finish

Nor should the convenience of the end user be reduced, i.e. the impact on the consumer should be kept to a minimum. The caps must be attached to the bottle throughout the product's life cycle until they are recycled.
The functionality of the caps cannot be changed even after opening and closing 15 times. The connection between the cap and the bottle must withstand a tensile force of at least 25 N. (https://transpack.hu/2024/10/23/csomagolas-rogzitett-kupak-mindennapjaink-resze/) There are several solutions for the inseparable cap, some of which are illustrated in Figure 5.



a)

b)

c)

d)

e)

Figure 5. *Inseparable cap solutions*
https://transpack.hu/2024/10/23/csomagolas-rogzitett-kupak-mindennapjaink-resze/

Another hygienic aspect is the seal, which must also perform its function in the case of high internal pressure during the shaking of drinks with a high carbon dioxide content, i.e. the contents of the bottle must not leak out. This sealing ability is created by tightening the threaded joint formed at the opening of the bottle between the upper edge of the opening and the inner surface of the cap. (Figure 3)

The cap is only considered to be properly sealed if the liquid in the container does not leak out and substances outside the container cannot enter. In addition, the end user must be able to open the bottle with reasonable effort. The average tightening torque of a PET soft drink bottle with a normal 28 mm cap is usually 2-3 Nm, depending on the manufacturer, while its opening torque is around 1-2 Nm.
According to the measurements, the opening torque requirement measured 24 hours after closure will be 40-60 % of the real tightening torque applied in the factory. However, these values are also affected by the time that has elapsed and the thermal effects that affect the bond. A 1999 study examined the effect of time on the cap removal torque and found that at any closing torque, the opening torque increased in the first 10 days and then slowly decreased. (Lai & Greenway, 1999)
Experience has shown that the 2-3 Nm closing torque, which is usually used for 28 mm caps, always ensures that the bottle remains properly closed, but at the same time it is also easy to open for consumers, regardless of the time that has elapsed.

Table 1
Average closing and opening torques of PET bottles
https://www.kinexcappers.com/faq/torque-guidelines.htm

Cap size [mm]	**Closing Torque [Nm]**		**Opening torque [Nm]**	
	min	**max**	**min**	**max**
10	0,45	0,90	0,23	0,45
13	0,56	1,02	0,28	0,51
15	0,56	1,02	0,28	0,51
18	0,79	1,13	0,40	0,56
20	0,90	1,36	0,45	0,68
22	1,02	1,58	0,51	0,79
24	1,13	2,03	0,56	1,02
28	1,36	2,37	0,68	1,19
33	1,69	2,82	0,85	1,41
38	1,92	2,94	0,96	1,47
43	1,92	3,05	0,96	1,53
48	2,15	3,39	1,07	1,69
53	2,37	4,07	1,19	2,03
58	2,60	4,52	1,30	2,26
63	2,71	4,86	1,36	2,43
70	3,16	5,65	1,58	2,82
83	3,62	6,78	1,81	3,39
89	4,52	7,91	2,26	3,95
110	5,08	7,91	2,54	3,95

Table 1 shows the closing and opening torques for different capping diameters published by Kinex Cappers, an American company that manufactures bottle capping, filling and testing machines.
From an ergonomic point of view, the first opening is the most important, the torque curve of which is derived from a specific measurement, but is also generally characteristic, is illustrated in Figure 6. When closing, consumers can apply the minimum closing torque required for efficient sealing, regardless of their strength.

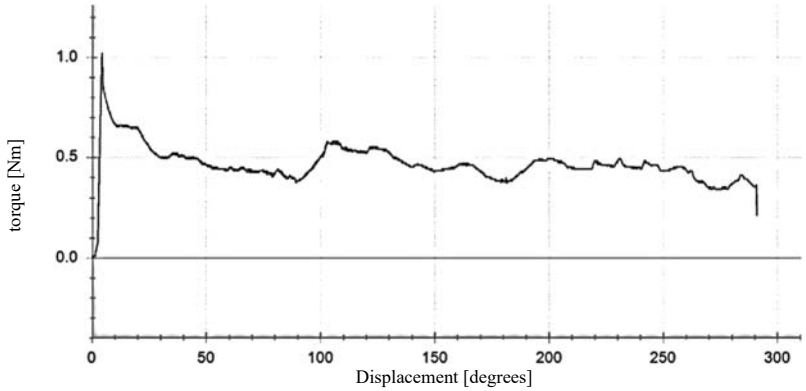


Figure 6. *Opening Torque Curve*
https://www.kinexcappers.com/faq/torque-guidelines.htm

Minimising the need for gripping clamping force to achieve opening and closing torque is also an ergonomic aspect. To this end, anti-slip grooves must be created on the outer side wall of the caps, which further improves the handling of the product. It is a basic expectation that caps rotated even with high clamping force should not cause injury to the user's fingers or palms.

5. GRABBING, EMPTYING

Smaller bottles are much more often used directly for drinking, while users prefer to pour the liquid into glasses from larger ones. This different usage practice must also be taken into account when designing the bottles.
Smaller bottles should be designed for one-handed use, as they should provide a stable grip even during sports. The waist of the bottle should be an ergonomically designed handle that even follows the fingers, so it fits perfectly in the hand. But the simplest solution is to narrow the bottle body and place anti-slip ribs perpendicular to the longitudinal axis on the outer surface, as can be seen on the products shown on the left side of Figure 1.

In the case of small bottles, the strengthening of the side wall is less significant, but as the bottle size increases, more and more emphasis must be placed on the bending forces resulting from the mass of the stored liquid during one-handed pouring. This is especially true for bottles that have been reduced while saving raw materials due to environmental or simply cost-efficiency considerations. The size of the 2-litre bottles is too large to be handled with one hand and the situation is getting worse due to the weak bottle walls. Because the consumer must squeeze the walls to hold the product firmly, he often accidentally squeezes out the liquid when he opens the bottle and tries to fill the drink. (https://bestinpackaging.wordpress.com/2013/07/21/ergonomics-in-bottle-design/)

For this reason, the handling of the opened bottle is part of the structural design. The thickness of the plastic wall of a 1.5...2 litre bottle should not be determined without engineering calculations. The rigidity of a bottle is determined not only by the thickness of the side wall resulting from the weight of the product thermoformed with air pressure during production. Significant material savings and increased sidewall rigidity can be achieved by designing the right bottle shape. The rigidity of the sidewall can also be increased most easily with ribbing, but many manufacturers choose a unique shape or pattern (e.g. crystal pattern, water drop shape, etc.), which also works well and provides a well-recognizable product appearance and an aesthetic experience.

The emptying function also includes the determination of the mouth size of the bottle. When drinking directly from the bottle, a narrower mouth size is preferable. When filling out, a wider opening makes it easier for the consumer, as it allows the bottle to "breathe" more easily, thus avoiding the inconvenience caused by flapping filling or denting the bottle.

6. INFORMATION TRANSFER

Beverage bottles, as food packaging, must meet several requirements in terms of information transfer. From an ergonomic point of view, the size classes and typography of the inscriptions and graphic signs play a key role here. The most important of these are the name (e.g. brand name) and classification (e.g. carbonated soft drink) and quantity of the product. In addition, a list of ingredients in order of quantity, allergen highlights, average nutritional table, best before date and storage information, name of manufacturer and/or distributor, barcode, return indication, recycling categories must be displayed other prescribed signals.

In this article, I will highlight the ergonomics of the return signal. In Hungary, Government decree 450/2023. (X. 4.) regulates the distribution of products subject to a redemption fee, on the marking system of which MOHU MOL Waste

Management Ltd. (https://repont.hu/hu/dokumentumtar) has also published detailed guidelines. For easy recognition, the position and size specifications are clearly fixed. From an ergonomic point of view, it is a particularly good choice that manufacturers have to place this new mark next to the barcode, as the barcode is needed when switching back anyway.

Figure 7. *Rollback sign next to barcode*

7. SUMMARY

The article examined the basic functions of traditional-sized PET bottles from an ergonomic point of view. Accordingly, it analysed the storage, closing, opening, sealing, emptying, stability, grasping and information transfer functions from a user perspective, highlighting good and bad practices.

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