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Evaluation of the Functional Performance for Carbonated Beverage Packaging: A Review for Future Trends

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Abstract
Carbonated beverage packaging are widely used all over the world and in Egypt.. Aluminum cans and PET bottles using increased day by day versus glass bottles. Although, the glass bottles means quality, Aluminum cans and PET bottles are still the first and second choices for most consumers. Carbonated soft drinks CSD packaging require ease openings, handling, and high gas barrier properties. Glass bottles in 1980s remained the dominate packaging in the Egyptian market before plastic bottles and aluminum cans invaded the markets..

Aluminum cans undergone many important developments throughout years to compete with glass and PET bottles. The research aimed to evaluate the current situation of carbonated beverage packaging for best performance according to consumer and product requirements. The study questioned if aluminum cans and PET bottle have good performance and respond to what are expected. Furthermore, if they will forefront the markets with its current state.

The study findings ascertained that there are some challenges for both PET bottles; concerning carbonation loss and aluminum cans that related to reclosing and proper sanitary problems.

In The following years, there may be active PET bottles and re-closable aluminum cans seen in the markets.

Key words: Carbonated beverage, Aluminum cans, carbonation loss, closing system, PET, Glass bottle, REOE, CSD

1. Introduction

Soft drinks are sweet beverages that do not contain alcohol. Typically, it contains carbonated water, a sweetener and a natural or artificial flavoring. The sweetener may be sugar, high-fructose corn syrup, fruit juice, sugar substitutes. They are carbonated by dissolving carbon dioxide in the beverage at high pressure during packaging. co_2 gas from pure source is dissolved in water.), Soft drinks can be consumed at room temperature or more often chilled. (Pietka 2015; NPCS board 2012)

Carbon dioxide gas gives the beverage its sparkle and tangy taste and prevents spoilage. Soft drinks are packaged in glass or plastic bottles and aluminum cans. (Pietka 2015)

Two major deteriorative changes that might occur in carbonated drinks are; the loss of carbonation and rancidification of essential flavoring oils. The first is largely a function of the effectiveness of the package in providing a barrier to gas permeation. Oxidative rancidity is reduced by the effectiveness of the package in providing a barrier to gas permeation. (Yam 2010; NPCS board 2012)

Most carbonated beverages are negatively affected by oxygen. If there is oxygen present in these beverages it will, in a very short time, at the very least, change the flavor profile of that beverage and at most cause the beverage to go bad.(ed. Robertson 2009; The little book 2015)

The packaging of carbonated products is limited to glass, metal cans, and PET.

Unlike many other packaging materials, glass bottles do not interact with the packaged product but they are heavy and tend to break easily. PET bottles are more flexible and lighter but they have a shorter shelf life because of the gradual loss of carbonation.

Aluminum cans are lightweight and better at holding carbonation but they have a shorter shelf life than glass bottles.(ed. Robertson 2009) The visual aspect of the closing is very important for the quality and it may conduct to serious defect that can affect the innocuity of the filled beverage. (Boda 2014)

2. Packaging Convenience

Consumers are clear about the qualities they look for in packaging and what they find acceptable and unacceptable

• Easy to use and functional; how it feels is important.

• Easy to open and pour; Screw tops are preferable.

• Stable and strong; Packaging that is seen as fragile is a weakness.

• Easy to reseal and reclose; Airtight conditions are seen as being vital to protect the contents.

• Durable; Shelf-life durability is essential to ensure the contents retain their quality and taste.

• A convenient shape for easy storage; Consumers dislike inconvenient shaped containers that take up too much space in fridges or cupboards.

• Lightweight and portable; the total weight of shopping often impacts on consumers' purchasing decisions and the amount they spend.

• Easy for consumers to access the contents; Consumers dislike packaging where 'the last bit' does not come out easily, if at all.

• Unbreakable; Packaging that is seen as safe to carry and use is a vital consideration for many consumers.

• Distinctive with shelf 'standout' appeal.

• Easy to recycle; this is an important factor in Scandinavian countries where consumers are keen on packaging that is easy to flatten before disposal.

• Small and compact whenever possible; Packaging that is significantly greater in size than the contents is not appreciated. (Coles 2011; Smye Holland 2013)

The main requirements of carbonated soft drink containers are:

• Preserve co_2 levels inside the packaging. This is important especially for small size containers.
• Reduced bottle expansion due to internal pressure (Shape keeping)
• Burst and drop resistance
• Shape and bottom designed to resist high internal pressure (creep and burst resistance)
• Reduce bottle weight while assuring bottle stability.(Zoppas n.d.)

3. Research Aim and Methods

The research discusses aluminum cans among other carbonated beverage packaging especially that cans tend to be the most dominant one. The paper focused on two important factors; carbonation loss and closing system.

Looking at what are expected from carbonated beverage packaging, how aluminum cans and PET stacks up against competition, is the aim to provide an overview of the challenges of carbonated beverage packaging.

The second aim is to further explore the future of carbonated beverage packaging.

The study is conducted by several steps as follow:

First, assessment by comparing the gathered information to give an overview of the three packaging used for carbonated beverage. This step is important in determining the challenges concerning CSD packaging

Second, analysis of the closing - opening system for aluminum cans and carbonation loss of PET bottles then the innovation and developments concerning these areas were discussed.

4. Carbonated Beverage Packaging Assessment

Carbonated beverages packaging are very popular throughout the world. The performance of the package is measured by its ability to keep the contents in a condition that is as close to the taste, appearance, and nutritional or other standards required**.** (ed. Robertson 2009).

Packaging convenience that determined by; how package respond to product and consumer requirements and each packaging characteristics; advantages and challenges are the key factors.

4.1 An Overview of Carbonated Beverage Packaging

Carbonated beverage packaging material have different characteristics. The beverage can is enjoying growing popularity; Consumers appreciate the beverage can as modern, practical and recyclable packaging. Young consumers especially find cans cool and trendy. (Draskovic 2009)

In some areas the aluminum can is by far the most favorably viewed of the three beverage packages, significantly outdistancing either glass or plastic bottles.(Can manufacturing institute 2015)

Plastics are the fastest-growing materials for packaging and PET is cost-efficient material which meets the demanding supply-chain requirements.(Smye Holland 2013)

What consumers find most appealing about PET are the energy and cost savings from its low weight and the fact that it is almost unbreakable. Consumers choose PET over glass to consume drinks outdoors and at events such as festivals, concerts and social gatherings where convenience and easy portability are important considerations.(Smye Holland 2013)

An overview of carbonated beverage packaging is summarized in Table (1)

Table (1) An Overview of Perceived Advantages and Disadvantages by Packaging Type for Carbonated Beverage

Packaging Type	Advantages	Disadvantages
Glass bottles	• Can be either single trip or returnable • Considering the cost factor, returnable bottles are preferred more than the single-trip bottles.(Ghose 2013) • Excellent barrier properties; Supporters claim the "feel" of the product creates a favorable impression in terms of quality; glass is synonymous with "class". (Smye Holland 2013)	• Glass containers have the disadvantage of being breakable and sometimes heavy**.** (Ghose 2013)
Aluminum cans	• Beverage cans are convenient, unbreakable and above all, light weight. • They are easy to open. • Because of metal good thermal conductivity, can cools beverages faster than other packaging. • Good printability. (Draskovic 2009; Liew 2005)	• Cans cannot be resealed, cans have only a one-time purpose, as is demonstrated with carbonated drinks and tinned food products. Products in cans is often said to leave an 'aftertaste of metal'.(Smye Holland 2013)
PET bottles	• PET is transparent, unbreakable, and lightweight. • Low-cost production capability. (Smye Holland 2013) • The lightness of PET enables easier and more cost-efficient transport – especially when delivered to brand owners as preforms, which are then blown into full-size containers on their own premises. (Smye Holland 2013, Steen 2008)	• Lower gas barrier characteristics compared to glass and aluminum. • Shorter shelf life. (Draskovic 2009)

4.2 *Challenges of Aluminum Cans and PET Bottles*

According to Carbonated soft drinks CSD requirements and packaging convenience, this part of study focus on two factors, which are considered critical areas, that might affect the future of carbonated beverage packaging.

- Closing and opening system of aluminum cans
- Carbonation loss of PET bottles.

4.2.1 Closing and Opening System of Aluminum Cans

Aluminum cans history and Development

Aluminum beverage cans have undergone many changes throughout the years, but cannot stay stagnant if they want to be ahead of the competition, (Liew 2005)

Aluminum cans have been used since 1960s first for frozen juice concentrate then; it was produced for larger quantities, after that its usage increased considerably when Coca Cola and Pepsi converted to aluminum cans.

In the 1990s, the growth of demand for aluminum cans began to slow with the market maturing with PET plastics applying pressure on soft drinks. Can makers have improved technologies to "light weight" the can by using lighter gauge sheet stock in order to make it more competitive with other beverage containers. Thickness of the can wall has been reduced so considerably that its metal content over that time period has been cut in half, while end diameter has been reduced from 206 to 204 and more recently to 202 as a means of reducing the cost of the overall container. (Pinkham 2013)

Aluminum beverage cans embody several innovations that illustrate the importance of taking a comprehensive approach to product design. Through continuous improvements over the past 40 years, this widely used product has features that accommodate a range of design requirements from functionality to ease of use, sustainability, and brand identity. (Kuhn 2009)

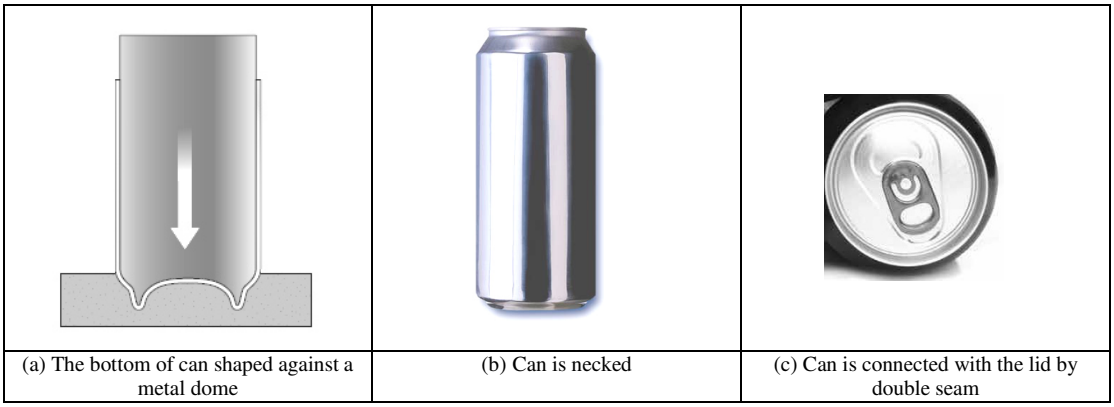
Figure (1) indicate the three important enhancements made for aluminum cans.

The most important development factors can be summarized in the following points:

- The body is made of the soft alloy 3004 (contains 1% Mn and 1% Mg), which makes it easy to form. Early attempts to make can bodies included traditional deep drawing and innovative methods of impact extrusion. However, drawing and ironing (D&I) proved most cost effective. D&I transforms a 5½-in.-diameter, 0.011-in.-thick blank into a cylindrical can using two drawing operations followed by three ironing passes through die rings. And all of this happens at the rate of five can bodies/second.(Kuhn 2009)
- Also highly polished surfaces had been created that can be decorated with colorful, eye-catching logos and designs.
- Geometrically, can bodies conform comfortably to the grip of a human hand and contain the standard 12 oz of liquid.
- The bottom-edge contours were developed to transfer the vertical load from can to can without highly localized stresses that would cause buckling. (Kuhn 2009) see figure (1)a
- Meanwhile, the can lid is made of the alloy 5182 (contains 4% Mg and 1% Mn) which is stronger and harder to form than the can-body alloy. This is needed to accommodate the easy-opening feature and contain the carbonation pressure. As you lift the tab, a crack opens at one end of a line scored in the lid. The crack quickly moves along the curved score line, letting the tab be bent down. (Kuhn 2009)
- The secret of the tab opener's ease of use is the score line. The score line is actually an indentation created by a punch forced into the lid. (Kuhn 2009) figure (1) c.
- Cans makers decrease the diameter of the lid so that it is smaller than the diameter of the cylinder. Then they neck down the top part of the cylindrical wall, from 2.6 to 2.1 inches, to accommodate the lid see figure (1) b. The lid is scored so that the can opens easily. (Americas 2010; Yam 2010)

Despite the success of current can design and manufacture, can makers are still searching for refinements.

Much of the investigation focuses on ways to use aluminum more efficiently, also closing and opening system of carbonated beverage cans have been developed successfully by achieving environmental and functional benefits. However, the question is if there still some problems by using this system and still need further improvement.



(a) The bottom of can shaped against a metal dome	(b) Can is necked	(c) Can is connected with the lid by double seam

Figure (1) The main Development Keys of Aluminum Cans

Can Opening and Closing System Analysis

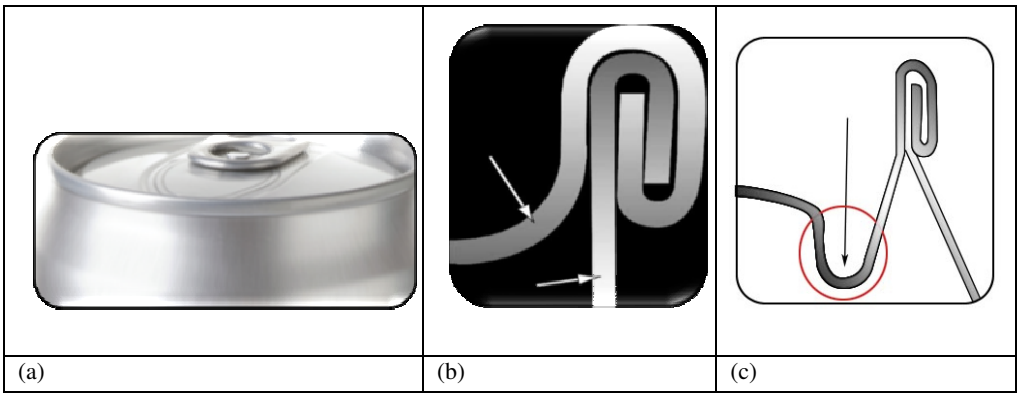
The original design of easy-open lid, introduced on drinks cans from about 1963, used a ring-pull design in which the tab detached from the lid completely. Environmental considerations in the US and Europe led to the development in 1975 of the stay-on tab which remains on the lid after opening. Almost all US and European drinks cans use stay-on tabs, and although it is being introduced elsewhere, there are many markets, which prefer ring-pulls (for example the Middle East and China) because of concerns that any contamination from the tab will find its way into the drink after opening,(Lingle 2014)

In Egypt, both tabs are used for carbonated beverage cans.

- Aluminum cans are closed by seaming the circular lid with the can body after necking (this is very important step that help to reduce can diameter) by double seam as it is illustrated in figure (2) a,b
- Manufacturers have modified cans by providing them with upper marginal lips to facilitate stacking large numbers of cans.
- One of the major problems of such a construction is that dirt and other contaminants are easily caught and contained by the can top wall which requires that the can be washed prior to use. Sanitation problems may also occur.(Tabeshnekoo 2005)
- The geometry of the shape give advantages for material reduction and cans stacking but as it is shown in figure (2), a groove contouring the can is formed. This could be a problem in a country like Egypt. In dusty and warm weather, there could be germs and bacteria in this area.
- The removable "pull tabs," could present a safety issue “in that the tabs could be swallowed by small children. (Lingle 2014)

  A study investigated the cleanliness of can top; Scientific AmeriKen provides evidence regarding the cleanliness of soda cans. From the study data, it appears as though cleanliness is an issue concerning soda cans. Although not ever soda can may contain bacteria on it, it seems that one was found when only two were tested. Even if bacteria is not in question, the dust found on the soda cans was also quite significant.(HeatGenie 2007)

  Although the study results were not confirmed but it is still an issue considering dusty warm environment like Egypt, the situation would be more harmful when drinking carbonated beverage without using of straw.



(a) (b) (c)

Figure (2) Can End Double Seam

Table (2) The Advantages and Limitations of Can Closing System

Advantages of current can closing system	Limitations of current can closing system
• Stackability of cans	• Cannot be re-closed
• Easy opening by pull-tab with the help of the internal pressure of liquid	• Sharp edges after opening
• Hermetic sealing	• Dust and bacteria existence probability
• Environmental and economic	• Accidental drop of tab into the can

4.2.2 Carbonation Loss of PET Bottles

Carbonation loss is a considerable factor when discussing carbonated beverage. Glass bottles give the highest level of quality test preserving carbonation from loss. PET bottles are the lowest barring due to the permeability of polymers.

The rate at which carbonation is lost is dependent on a number of factors but in the first instance most bottlers increase the level of carbonation in the package at the point of production when compared to a can or glass bottle of the same product.(Steen 2008)

While considering carbonation loss, PET is not a perfect gas barrier, though it is much better than polyethylene or polyvinyl chloride. Carbonation loss occurs as carbon dioxide permeates through the PET walls.(Steen 2008) Being impermeable to gases such as co_2 than other low-cost plastics, PET is a popular container for carbonated drinks – particularly as carbonation tends to 'attack' other plastics – as well as for acidic drinks including fruit and vegetable juices. (Smye Holland 2013)

When considering the use of PET bottles for soft drinks a critical aspect to be considered is the rate at which a bottle of a particular size will lose carbonation over time.

The smaller the bottle size the higher the rate of loss due to the relation between the surface areas of the bottle and the liquid volume it contains.

PET bottles up to 5 L in size are now available in some countries but not yet in Egypt; resulting in considerable savings in container cost per unit volume. In addition, the larger the bottle the more co_2 is retained per unit of time because of a smaller surface area volume ratio (i.e., a reduced area for permeation). (Robertson 2012)

The factors that influence the taste and odour of carbonated beverages packaged in plastic containers are depicted schematically in figure (3)

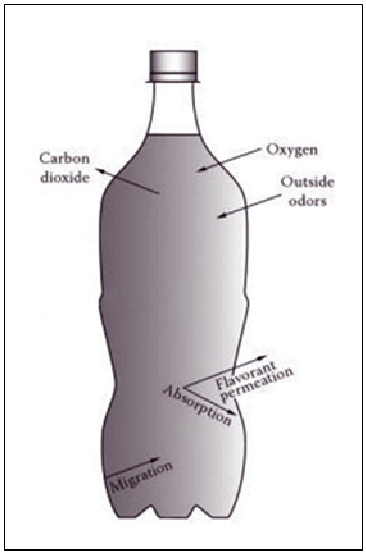


Figure (3)

Compared to glass, there is a loss of co_2 through the bottle walls which must be allowed for. While increasing the wall thickness will decrease the rate of co_2 transmission, this will also increase the cost of the bottle. (Robertson 2012)

5. Inventions and Future Trend

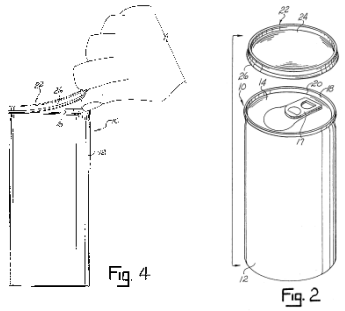
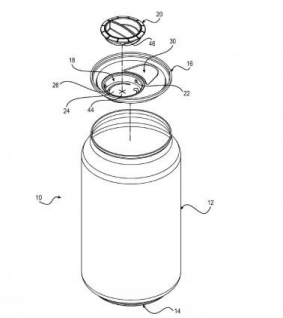
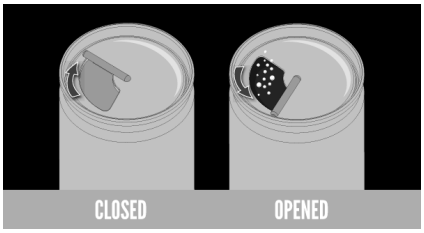
5.1 Carbonated Beverage Cans

Innovation and patent have been introduced since 1988 till 2015 for new innovative closing system for carbonated beverage cans some of these invention are described in table (3).

Innovations may enhance the functional performance of beverage can; screw top cans offer consumers convenience and on-shelf differentiation. In addition, reclosable closure provide more convenience and portability for consumers. (Can Manufacturers Institute 2015)

The can allows for many innovations "super end" beverage can end, which is said to be the first significant innovation in beverage can ends in decades, improving can quality and performance for both beverage fillers and consumers. (Pinkham 2013)

Table (3) An Overview of Cans Closing System Invention

The invention	Features and advantages	Representative figure
"super end" beverage can end	• A removable End; to provide for a beverage can lid which effectively seals the can top wall against entry of dirt and germs. • Another object of this invention is to provide for a disposable can lid which is economical.(Tabeshnekoo 2005)	 (Tabeshnekoo 2005)
Cam-operated reseal for beverage can "patent assigned to Powercan Holding LLC, Pompano Beach, FL"	• An aluminum beverage can provided with a cap that is twisted by the consumer to open. • offers a different take on beverage can resealability. • The twist or rotational movement of the cap is converted into linear motion by a cam mechanism to drive the cap open. Once the can is opened, the cap can be reverse-twisted to remove it from the opening, and then after drinking, the consumer can twist the cap back into a sealing position within the opening. Optionally, the cap can be discarded if the entire contents of the can are consumed.(Lingle 2014)	 (Lingle 2014)
Reclosable Easy Open End technology REOE	• Improved safety by eliminating sharp edges • Reclosable to reduce potential for spills or contamination • Customizable aperture configurations from partial to full • Compatible with conventional filling operations • All metal construction (no mixed materials for recycling) • Cost comparable to existing closure systems. (HeatGenie 2015)	 (HeatGenie 2015)

5-2 PET Carbonated Beverage Bottles

The most direct ways to increase the gas barrier characteristics of a PET container are:

(a) To increase the wall thickness of the container so that gas transmission through the wall is slowed (the so-called “tortuous path” solution)

(b) To put a barrier coating on the container.(Bockner 2015)

A barrier coating can be applied in one of three ways:

1. To the inside—if approved for food-contact;

2. To the outside of the finished bottle;

3. Or in a process, which remains pre-commercial, to the preform itself before it is stretch-blown based on an assurance that the coating material will neither fracture nor delaminate during the stretch-blowing process.

A barrier coating can also provide two additional benefits:

(1) It may help to resist creep in a container for carbonated products.

(2) With certain sensitive products, an internal (SiOx) coating would assure a totally inert (glass) contact surface for the product with no risk of either scalping or leaching.

Both of these solutions, however, are relatively costly.

A potentially more cost-effective (and flexible) solution currently being proposed is to increase the gas barrier properties of the PET resin itself by taking advantage of the chemically active nature of the oxygen molecule, and using a "scavenger" molecule pre-blended into the PET.

In conclusion, it appears that coating of finished bottles can be the superior approach to extending the shelf-life for oxygen sensitive product in PET unless and until the preform coating system now under development by Pepsi-Cola can be implemented commercially (Bockner 2015; Robertson 2012)

However, development are going towards active PET packaging to increase gas barrier properties within a considerable cost.

6. Results and conclusion

Evaluation of carbonated beverage packaging can be summarized in the table (3)

Describing by symbols: √ highest, $_{x}$ lowest.

If we give '√ ' symbol, five points, which is the highest and '■' symbol three points, and '$_{x}$' one point which is the lowest to select the perfect package for carbonated beverage; glass will be the first choice for CSD, and PET will be the third.

However, it cannot be judged this way because of many other factors and the consumers themselves but it could be guidelines for the performance of carbonated beverage packaging.

Table (4) The Evaluation of CSD Packaging

Comparative elements	**Aluminum cans**	**Glass bottles**	**PET bottles**
Available size	250, 330,350 ml	200, 300 ml,1 liter	500ml,1 L, 2liter
Carbonation loss barring	■	√	$_{x}$
Thermal conductivity(Chilling)	√	■	$_{x}$
Closing feature	$_{x}$	■	■

- To conclude, the aluminum cans is the fastest chilling beverage container and is very effective at maintaining the fizz of the beverage until it is opened.
- When taste is the most important factor then glass package is the choice.
- Other advantages of aluminum cans include stackability, cost, filling speed, the ability to advertise right on the can and more efficient use of shelf space. (Pinkham 2013)
- Plastic bottle is the lowest package in giving the desirable taste but still has it's advantages especially for larger size bottles.
- Research showed that aluminum cans still have further development it is not yet the perfect closing system, some inventions and patent suggested solution for the can lid and closing features but there are still more to investigate for applicable ones.
- Carbonation loss is an area for more invention for PET bottles by coating but cost will be a limitation.
- PET active bottles might be a reasonable future trend for carbonated beverage.

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