Towards a bottle weight reduction - Evaluation in a selected milk plant in the United Kingdom

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Abstract

The United Kingdom is one of the biggest milk producers in the world. The dairy market is a competitive industry where cost is a driving force. Milk is considered a day-to-day product in this country, packaged primarily in HPDE bottles. The need for a cost effective product is driving companies to seek for alternative packaging solutions.

The thesis is focused on the weight reduction of a HDPE bottle in a selected production milk plant. The achievement of this reduction has a direct implication on material cost and environmental impact. A study of the different milk bottles on the market is included, evaluating designs and materials.

Five different tests are used for studying the standard and light weight bottle. In addition, the performance of the standard bottle in the milk production plant was assessed, identifying the critical points in the line.

An initial trial was carried out on the blow molding equipment that allowed the evaluation the bottles properties. The data obtained in this thesis allows proceeding with a weight reduction trial and provides the necessary information for comparing with the standard bottle.

Different materials and technologies were investigated as possible alternatives for cost reduction. Results from these investigations provide a frame for further study, where it is necessary to further assess the cost implications and its feasibility.

Keywords: light weight, HDPE bottles, milk packaging, pasteurised milk, PET bottles.

Executive Summary

Introduction

The dairy industry represents a significant role in most of the economies worldwide, due to the high consumption of dairy products and its relatively low prices. Goods for private consumption are being packaged increasingly in plastic. Pasteurized milk in the United Kingdom is mainly packed in HDPE, the most popular packaging material, accounting for a 71% volume share in 2016 (Euromonitor International, 2016). Over the years, the industry has developed ever lighter and thinner plastic packaging, while at the same time providing identical or improved functionality – a benefit for the environment, the industry and the consumer (Hanser Velarg, 2004).

Objectives

The primary purpose was to study the possibility of light weighting HPDE bottles used for pasteurised milk in a selected milk production plant.

The second purpose is to study alternative materials and technologies for a future implementation that can potentially reduce costs and supply the high production demand, evaluating the designs used by competitors and researching other possibilities.

Methodology

A combination of different methods was used in order to gather all the information needed:

i. Semi-structured interviews
   a. understanding the major problems encountered in the line production
   b. comprehending the effects of light weighting
   c. collecting information about alternative materials and technologies
   d. understanding the design used in the industry
ii. Observations - evaluation of the current packaging in the processing line.
iii. Literature review of the different topics.

iv. Weight measurement.
v. Thickness measurement - identification of the design's critical points.
vi. Drop test - evaluation of the ability to withstand free-fall impact forces.
vii. Vacuum chamber - evaluation of any leakage or closure problem.
viii. Compression test – measurement of the rigidity.

Results and discussion

The main findings were:

Designs available in the market

i. Milk packaging in the UK suffers a lack of innovation. Most companies use HPDE bottles with ECO or Infini designs for pasteurized milk.
ii. Other designs found in the market are mainly for Extended Shelf Life products or enriched milk, in either HDPE or PET. Different agents of decontamination are used for a more thorough cleaning (hydrogen peroxide or peracetic acid). In this case, an appropriate design is necessary for allowing an easy-flow of the solution in the packaging.
iii. Titanium dioxide a photo-responsive white compound that protects the milk from oxidation is included in the packaging, due to its ability to scatter light and absorb UV light energy (Johnson, et al., 2015).
iv. Clear PET is also used for enhancing the visibility of the product. A clean presentation gives an impression of transparency between brand and consumer, as well as a feeling of authenticity of the product itself (Bordbia, 2016).

Light weight HDPE pasteurized milk bottles

In the line study, only 0.08% of the bottles were damaged in the filling and cap station, due to a side-to-side deformation at the entrance of the equipment.

The results from the 10% weight reduction showed a diminution in the top load strength and positive results for drop and vacuum tests. Thickness values presented an even reduction. However, the top part sections had a lower value than the established in the specifications.

Alternative technologies and materials

PET prices are around 22% inferior to HPDE. Injection blow molding is the technology that produces PET bottles that unlike extrusion blow molding cannot produce a handle.

However, different packaging suppliers have developed technologies that can include an external or internal handle (Sidel, B&R Industries, Plastipak, etc.) in an injection blow molding system. Other similar resins such as PETG or EPET are compatible with extrusion blow molding.

Besides, there are alternative technologies to extrusion blow molding that can produce HDPE bottles and potentially reduce the cost.

i. Compression blow forming and compression stretch blow forming are recent processes developed by Sacmi.
ii. The use of foam blow molding HDPE (or PET) allows a reduction of material used due to its structure.
iii. LiquiForm™ a recent technology for HDPE and PET can reduce the production time.

Conclusions and further work

The market analysis of the milk products pointed out the lack of innovation in the sector. All the different packaging found were Extended shelf life products or with additional ingredients that need extra packaging protection due to its composition. Other products look for brand differentiation among competitors.

A suggestion is to continue exploring the products available in the market that can be used as a source of inspiration for future innovations in milk packaging.

The light weight trial presented controlled results for the weight values and successful results in the drop, compression and vacuum tests. Only thickness values in the top part section were below specification that can cause problems mainly in the packing and transport.

Further research is needed in the production line for ensuring the feasibility of the bottle. Moreover, the study of the bottle storage and transportation would be necessary for the complete assessment of the line. Environmental implications of the material reduction could be evaluated.

In regards to alternatives technologies and materials, there are possible solutions that can supply the high demand and can potentially reduce the costs. An extensive analysis is necessary for comprehending the total impact of substituting the line production and its economic and environmental repercussion.

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1 Introduction

This project is dedicated to testing the use of a lightweight bottle in a milk production plant, led by the current situation of the dairy market in the United Kingdom and the need for cost reduction.

1.1 Project Background

The dairy industry represents a significant role in most of the economies worldwide, due to the high consumption of dairy products and its relatively low prices. Food packaging directly affects food processing and shelf life, being a critical parameter to consider during the development of new products and their distribution through the supply chain.

Milk, due to its composition, is a highly perishable product of significant spoilage potential resulting in rapid deterioration of quality and safety. Quality deterioration may be associated to (1) the effect of oxygen and light, causing auto oxidation and light-induced oxidation, respectively, and (2) psychotropic bacterial activity resulting in undesirable flavour changes in the milk, due to insufficient heating. Product safety may be affected either by the incomplete destruction of pathogens transferred to milk through the animal or by cross-contamination at any stage after heat treatment (Kontominas, 2010).

The United Kingdom is the third-largest milk producer in the European Union after Germany and France, and the tenth-largest producer in the world. Only 3% of all UK produced milk was exported in 2014, with the rest for national use (Bate, 2016).The trend in the milk category has been towards falling prices. This caused the price reduction of other dairy categories. Nevertheless, the vote to leave the European Union led to a dramatic decrease in the value of the pound, leading the production cost – and overall prices – to increase (Euromonitor International, 2016). Dairy manufacturers continue making profit with small margins, with many farmers being paid less for milk than the production cost. Industry members are not stimulated to invest in innovation, which result in a more standard product offer and slowed the pace of product innovation within dairy packaging (Euromonitor International, 2016).

Within dairy industry, different packaging formats are used for milk all over the world. In the United Kingdom fresh/pasteurised milk are the most consumed milk options, with an increase of non-dairy alternatives like soya and almond milk and the apparition of other options like coconut milk. Fresh/pasteurised milk is packaged in a range of packaging formats, although HDPE bottles are the most popular, accounting for a 72% share of all fresh/pasteurised milk packaging (Euromonitor International, 2016).

1.2 Purpose

The purpose of this thesis is to study the possibility of light weight of the HPDE bottles used for pasteurised milk in a selected milk production plant. The primary motivation is to reduce the bottle cost. This includes a detailed study of the performance of standard bottle used from the bottle supply to the processing line, identifying design and critical production points. The achievement of this reduction has a direct repercussion on material cost and environmental implications.

The second purpose is to study alternative materials and technologies for a future implementation that can potentially reduce costs and supply the high production demand, evaluating the designs used by competitors and researching other possibilities.

1.3 Research questions

The research questions are:

Q1. Which are the designs and materials being used within the industry?

Q2. How can the weight reduction affect the milk bottle in an established production line?

Q3. Are there alternative materials or technologies that can reduce bottle cost?

1.4 Delimitations

The results of this master thesis cover the UK dairy market for plastic bottles for pasteurised milk, excluding glass and carton. Extended shelf life and UHT milk have not been considered due to the small share they hold in the market. The results obtained for the trial are only applicable to a particular supplier and processing line. Variations of the initial conditions would affect the outcome of the study. Although bottle light weight can affect several factors, only the manufacturing, filling and packing steps have been studied.

The research of alternative technologies and materials was based on the study of available literature and suppliers information.

Due to time limitation and internal discussions, a trial in the processing line was not possible to carry out, therefore, the feasibility of the light weight bottle in the actual line could not be evaluated.

2 Methodology

This section presents the used methodology for solving the research questions. It stresses the central role in the research questions and in the use of empirical data for answering them.

The followed research model is presented in Figure 1. For obtaining the required information, the data collection phase is divided into qualitative and quantitative data. The integration of qualitative and quantitative data is made by a continuous collection of both kinds of data (Huberman & Miles, 1994).

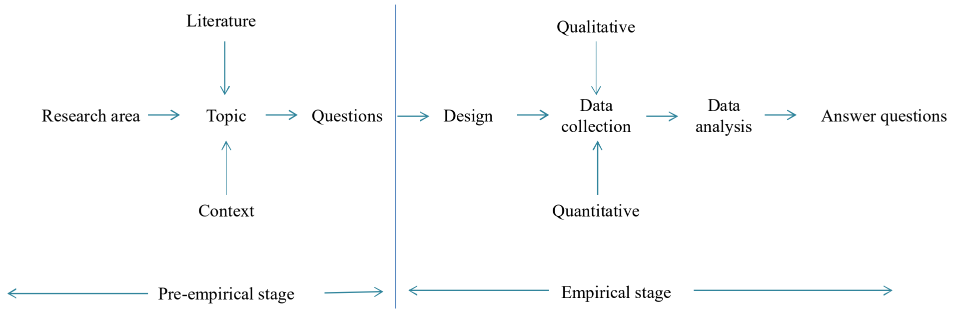


Figure 1. Research model with modifications (Punch, 2013).

2.1 Qualitative Data

Qualitative data help to provide rich descriptions of phenomena.Thus it helps move inquiry toward more meaningful explanations (Soafer, 1999).

Figure 2 represents the followed approach, a cyclical method that allows making decisions based on the research design.

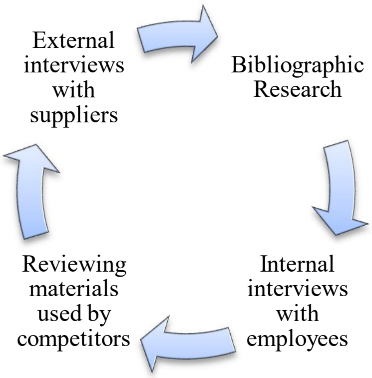


Figure 2. Cyclical research approach.

2.1.1 **Interviews**

Semi-structured interviews are used in this study (see questionnaires in Appendix). They combine predefined questions, like those used in structured interviews with the open-ended exploration of an unstructured interview. The general goal of the semi-structured interview is to gather systematic information about a set of central topics, while also allowing some exploration when new issues or questions emerge. Interviews allow rich engagement and follow-up questions (Wilson, 2014). It is possible to collect historical data that is not recorded anywhere, as well as elicit opinions and impressions in richer detail than people would provide through written communication (Bird, 2016).

The description of the groups that were interviewed is presented in Table 1.

Table 1. Description of the interviewed group.

Group	*In order to understand*	*Formed by*
Group 1	Light-weighing bottles effect	Packaging Technologists
Group 2	Main problems with the current bottle weight	Process Engineers, Operators, Management Team
Group 3	Alternatives technologies for milk bottles	Packaging Suppliers
Group 4	Competitors packaging	Packaging Technologists, Packaging Suppliers

2.1.2 **Observations**

Participant observation is an exploratory research strategy useful for documenting setting and identifying contextual clues for future inquiry (Dent Goodman, 2011). The researcher aims to become part of the social contexts in which the phenomena she or he studies are embedded (Moen & Middelthon, 2015). This method was used during the entire study, mainly during the evaluation of the current packaging in the processing line.

Although, this method is included as part of the qualitative research it was also used in the quantitative research (explanation section 2.2).

2.1.3 **Literature Reviews**

Literature analysis set the basis for designing the used methodology. The main topics of research are:

- Understand the bottle-making process and its implications for the design.
- Study of alternative materials and technologies that can potentially reduce cost.
- Determining current options used in the market.

Information was obtained from databases, scientific articles and documents provided by the suppliers in combination with interviews.

2.2 Quantitative Data

Quantitative data was represented by five different tests (Table 2), for standard and lighter bottle (more information in 2.2.1. to 2.2.5.), carried out in the company laboratory and in the bottle manufacturing site. Due to the number of bottles examined it was not possible to evaluate all at the same facility. Nevertheless, the equipment used in the company and manufacturer laboratory is the same. The temperature was constant during measurements.

Table 2. Tests carried out.

Test studied
Weight Measurement
Thickness Measurement
Drop Test
Compression Test
Vacuum Chamber

Initially, the different steps in the bottle supplier and milk processing line were studied, using a designed protocol. The evaluation of the current bottle was done through observations in combination with the analysis of the bottle mechanical properties and its characteristics.

2.2.1 **Weight Measurement**

A Kern precision balance model KB 10K-2N (Figure 3) with 1% accuracy was used in order to ensure the right bottle's weight during production.

Figure 3. Kern precision balance model KB 10K-2N.

2.2.2 **Thickness Measurement**

Wall thickness has a substantial effect on the performance and operational characteristics of materials; for instance occurrence and magnitude of internal stresses, the accuracy of machining and the period that the product has stayed under pressure during molding, etc. (Atanasova, 2007).

When the walls in a product vary in thickness, uneven shrinkage takes place, which causes bumps, deformations and cracks. The greater wall thickness leads to increased shrinkage, and hence to the occurrence of gas cavities and higher deformations (Atanasova, 2007). The bottle thickness is related to the mechanical properties of the material. Consequently assessing the adequate thickness of the product walls is essential. Besides its influence on bottle formation, wall thickness also affects certain parameters, such as line speed and therefore productivity.

The study of wall thickness for the standard and lightweight bottles allows for the identification of the design's critical points.

The equipment used was a Magna-Mike 8600 thickness gage (Figure 4), which makes measurements on nonferrous materials, based on the Hall Effect principle (Olympus, 2015). Wall thickness is measured by placing a small ball on one side of the test piece and the magnetic probe on the opposite side. Daily multipoint calibration (6 points) was carried out for ensuring the accuracy of thickness readings (2% accuracy). The selected steel ball diameter was 3.18 mm and the probe used was 86PR-1, due to the minimum curvature of the material, maximum thickness, accuracy needed, compressibility and surface hardness (Olympus, 2015).

Figure 4. Magna-Mike 8600 by Olympus.

2.2.3 **Drop test**

Drop test evaluates the ability of the bottles to withstand free-fall impact forces from a determined height. The sample is placed in the device, and it is released and dropped onto a plate, where it can be inspected. The samples are previously filled with water. Different heights are used depending on the bottle's size. The selected height was the same as the one used at the bottle supplier in their quality checks.

2.2.4 **Compression test**

A compression test determines the stacking characteristics and the rigidity of the materials studied (Zwick Roell, 2016). The bottle has a determined load applied when it is closed (when the cap is put on) and during filling, and it must withstand these processes without problems. The equipment used for testing the critical top load was Zwick Roell Z2.5 TS (2.5 kN cell) with 0.01% accuracy, and the data was recorded through testXpert® software. Periodical calibrations were carried out for ensuring the precision of the equipment. The speed selected for the test was 70mm/min. Deformation force was applied in the direction bottle neck-bottom.

2.2.5 **Vacuum chamber**

Multivac vacuum chamber C300 is used for controlling off-line if there is any leakage or closure problem in the bottle. Samples are filled with water and closed. A vacuum pump sucks out the available air until the selected millibar value, which is defined in the machine control. This process removes the atmosphere present in the vacuum chamber.

3 Theoretical framework

This chapter provides an understanding of the current situation of the dairy industry and its packaging in the United Kingdom. The competitive landscape of the market and the packaging trends in Europe aim to structure the thesis and to communicate the need for a cost-effective solution for milk packaging. Information about blow molding process and the implications of light weighting illustrate the study and its expected outcomes.

3.1 The dairy industry in the UK

The dairy industry is an important sector in the UK due to the high production and consumption. Milk accounted for 17.8% of total agricultural output in 2014 and was worth £4.6bn in market prices (Bate, 2016). In 2015/16, 45% of raw milk produced in the UK went into the production of liquid milk. While, 27.6% went into cheese and 12.3% to condensed milk and powders (Agriculture and Horticulture Development Board, 2016).

Milk is primarily sold in retailers and discounters. Nevertheless, there is still doorstep market with a share of 3%. Discounters have increased their share of the milk market by both volume and value. Although the retail value sales increased by 1% in 2016 to reach £1.2 billion, the average price for private label milk decreased by 4.2% (Agriculture and Horticulture Development Board, 2016) (Euromonitor International, 2016).

3.1.1 **Milk plastic bottle packaging – United Kingdom**

In the United Kingdom, the prevalent packaging among milk products is HDPE bottles for pasteurised milk for private label and brands. Glass bottles continue to decline, while PET bottles grew by 3%, but held a category volume share of less than 1% (Euromonitor International, 2016).

Plastic screw closure is the most popular closure type for milk beverages. Additionally, for maintaining the integrity of the product, there is a peel-off plastic. The peel-off plastic is a multilayer material made of plastic and foil that facilitates the bottle opening. It is used in products packaged in rigid plastic, like HDPE or PET. As the population ages and with more people also living alone, consumers are seeking closures that are easy to use (Euromonitor International, 2016).

The 1136ml and 2272ml (2 and 4 pints, respectively) sizes are the most prolific. Nonetheless, there are other formats available such as 1-1.5-2-3 litres and 1-6 pints (Figure 5).

Figure 5. Different bottles sizes. From left to right 6 pints, 4 pints, 2 pints and 1 pint.

Transparency remains a selling point for brand owners, as consumers like to see the product they are buying. Consumers also seek convenience in the packaging of pasteurised milk, demanding packaging that is easy to pour and which keeps the product fresh as long as possible.

3.1.2 **Competitive landscape**

The UK's leading grocery retailers lead the drinking milk products category. The price of cow's milk is volatile, and many retailers reduced their prices or held radical promotions in 2016. Bigger retailers have most of the market share of dairy products, being milk a product sold primarily in convenience stores, hypermarkets and supermarkets. As in other food categories, discounters and internet retailing recorded strong growth in 2016 (Euromonitor International, 2016). Tesco, Sainsbury, Asda and WM Morrison account for 57% of overall value sales.

Due to the low prices for milk, many UK dairy farmers are likely to seek out niches with higher margins. This could lead to a growing range of alternative products focusing on fortified milk and milk from grass-fed cows, which could help boost the value of milk sales and thereby bring value back to the category (Euromonitor International, 2016).

3.1.3 **Prospects in the United Kingdom**

Dairy, the largest food category for packaging volume, will increase in volume of 1%, resulting in total sales of 12.3 billion units by 2020 (Euromonitor International, 2016). Despite steady consumer demand, dairy packaging suffers from a lack of innovation within dairy as the industry becomes increasingly mature. Nonetheless, the growing awareness of eating healthy should help dairy packaging to maintain consumer demand thanks to on-the-go consumption.

In the UK, drinking milk products will remain the largest category in dairy. Fresh/pasteurised milk will account for an 81% volume share, with this group shaping the performance of drinking milk products as a whole. A reduction of glass bottles is expected led by the growing environmental concerns, as brand owners will seek to decrease their environmental impact by using lighter weight bottles. In addition, the predicted volume increase of 1pint HDPE bottles should, therefore, contribute to the volume decline of 1 pint glass bottles within fresh/pasteurised milk (Euromonitor International, 2016).

Other dairy prices, linked to the milk price, will most likely be volatile and highly dependent on the trade negotiations to come (Euromonitor International, 2016).

The convenience trend continues to shape the dairy packaging market and influences new product developments. Moreover, with the growth of e-commerce; an assembled package solution designed to meet the challenging e-commerce supply chain is a crucial consideration (Euromonitor International, 2016).

Personalised packaging is one of the global trends for using packaging efficiently as a silent salesman (Bordbia, 2016). PET offers an alternative for dairy products for standing out among competitors, growth is expected in this category (Figure 6). Transparent packaging builds trust and PET bottles could make impressive progress in dairy. PET bottles will often better meet the demand for greater quality and product freshness when compared to HDPE and liquid cartons (Dussimon, 2016).

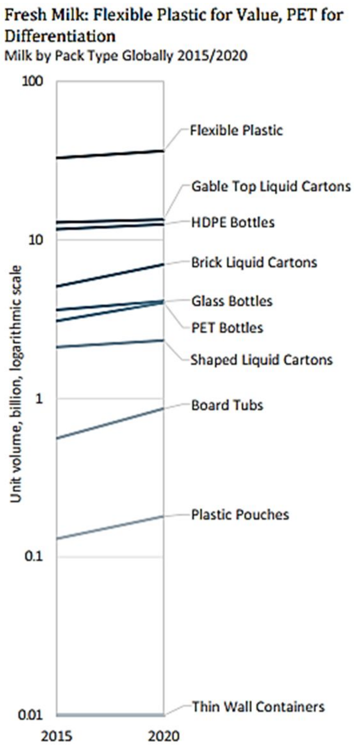


Figure 6. Packaging evolution for fresh milk – 2020 (Euromonitor International, 2016).

3.1.4 **Milk packaging in Europe**

The milk packaging in Europe varies significantly, depending on the country and the prevalent product consumed (pasteurised milk or UHT). Nonetheless, the predominant packaging among European countries is liquid cartons.

Liquid cartons are made from a combination of different materials: LDPE, paper, aluminium or PVdC. Depending on the product and its expected shelf life, the combination varies, making possible to have aseptic packaging (in the milk case, UHT products). Different suppliers provide technology that allows applying a heat treatment in the product followed by a filling station.

There are mainly two technologies. In the first system the material is supplied individually, the cartons are erected at the filling line, filled and sealed. In this technology, a headspace is created allowing mixing the product by shaking and reducing the risk of spillage on opening. Companies such as SIG Combibloc and

Elopak use this technology. The second technology creates a continuous tube with the multilayer material that is formed, sterilised and cut to the desired size and filled immediately after. Tetra Pak and IPI use this system.

In Sweden and The Netherlands, the primary format used for milk packaging is liquid cartons. Gable top liquid cartons are the prevalent packaging in pasteurised milk, and they increased significantly in 2015 in Sweden. 48% of gable top liquid cartons in pasteurised milk were fitted with a screw style liquid carton closure (often renewable) (Euromonitor International, 2016). In Nordic countries, sustainable packaging will be the key packaging trend in dairy, and the renewable version of Tetra Rex (gable top) is expected to be a success. In The Netherlands, growth in HDPE and PET is expected (Euromonitor International, 2016). In Switzerland, the milk consumption is slightly dropping in the last years. HDPE bottles are the dominant packaging used for pasteurised milk (Euromonitor International, 2016).

Although in France brick liquid cartons are set to remain a primary packaging type for all dairy products, new innovative carton formats are expected. These will ensure that milk products meet consumer's demands, as well as helping the products to stand out on retailers' shelves (Euromonitor International, 2016).

In other European countries as Germany and Italy, the trends predict growth in smaller packs led by environmental concerns related to food waste (Euromonitor International, 2016). A modest increase is expected for glass (relevant in premium products) and rigid plastics. A reduction of the liquid cartons is anticipated in Germany.

In Italy and Spain, growth in liquid cartons is predicted in this category, due to the high consumption of UHT milk. However, value-for-money aspect has to be considered in Spain. If a new form of packaging can offer a unique benefit, it will prevail only if this benefit is available at a reasonable cost to consumers (Euromonitor International, 2016).

3.2 High Density Polyethylene bottles

High Density Polyethylene is one of the largest volume plastic used in packaging because it is economical and can be formed in a wide range of forming processes. HPDE is stiff, has a good tensile strength and heat resistance. Its high density makes it a better water vapour barrier than LPDE, but it is still a poor oxygen barrier. To the touch it feels slightly waxy (Peacock, 2000). Clarity is poor, and the material can usually be recognised by its opaque appearance. Chemical resistance is good and can be improved by surface treatments. It has only moderate environment stress crack resistance (Twede, 1998). Aggressive manipulation can produce permanent deformation, with some whitening in the bend region (Peacock, 2000). In the study, a blow molded HDPE lightweight bottle is evaluated and compared to the standard bottle. Only the weight is modified, the shape and dimensions are maintained.

3.2.1 **Blow Molding Process of HDPE**

Blow molding includes three main thermoplastic processes: injection blow molding, stretch blow molding and extrusion blow molding. Extrusion blow molding is the most widely used, followed by stretch blow molding and injection blow molding. The entire blow molding industry is growing approximately 3–5% annually and will continue to rise at this rate (Belcher, 2017).

3.2.1.1 Extrusion blow molding system

The HDPE bottles are formed through an extrusion blow molding system. A typical blow molding system is represented in Figure 7. This continuous system can create irregular and complex shapes like milk containers.

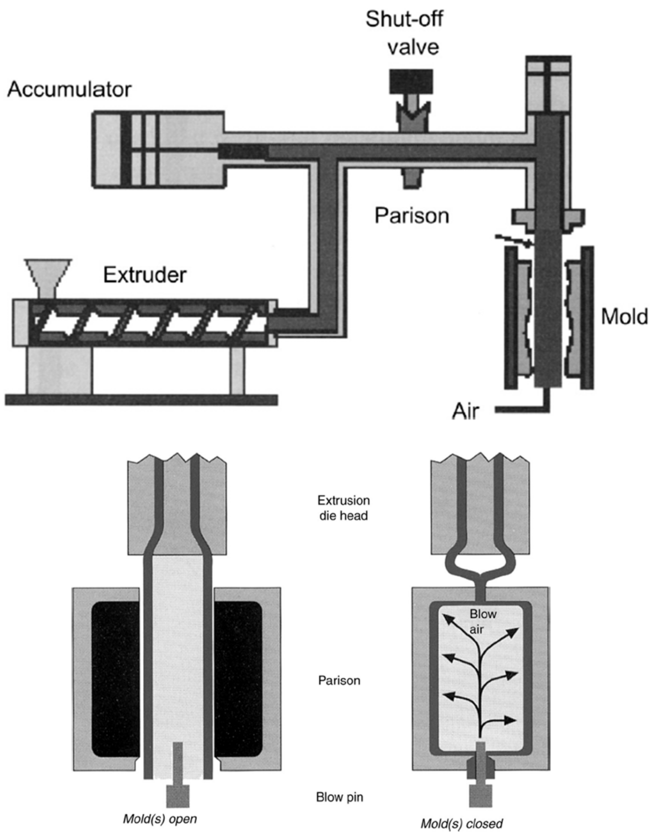


Figure 7. Blow Molding System (John, et al., 2014) and cycle (Belcher, 2017).

Initially, the system is fed with resin granulates and melted at the selected temperature. The plasticated formulation is regularly delivered to a mold in the shape of a long, hollow, molten tube called a parison. After the mold closes around the parison, pressurised air is injected for expanding the area (John, et al., 2014). When forcing a polymer through a die, the resin molecules will try to orient in the direction of flow. As the extrudate leaves the die area, parison's weight exerts a force on the parison. Before releasing the bottle, the temperature is decreased, solidifying the bottle. In the following step, the undesired parts such as tail, neck, and handle extra material are removed from the bottle (John, et al., 2014). The removed part is usually put back into the system as regrind. The deflashed HDPE containers are then frequently tested in line before being transported to the processing line.

In general, the continuous extrusion blow molding process provides a more uniform temperature parison. The accumulator machines allow dropping faster the parison (Belcher, 2017).

In the production of HDPE bottles, weight, wall thickness, handles, and neck dimensions must be considered. The type of resin, melt index, and hot melt strength, all have an effect on the pin and bushing design (Belcher, 2017). The die land length and the cross-sectional area must all be contemplated. Nonetheless, producing a quality parison with solid wall distribution is the most crucial part of the procedure. Programming, defined as controlling the wall thickness of the parison from the moment the parison is exiting the die head, is used for achieving the desired distribution of the plastic (Belcher, 2017).

3.2.2 **Bottle design**

During the development of a new bottle design, several requirements and recommendations must be followed to create a design fit for purpose. Basic steps for designing and developing a new plastic bottle were described by Mandel (2002).

They can be summarized as follows: (1) define bottle requirements: product to be contained, use, distribution, aesthetics and environmental issues; (2) define manufacturing and filling requirements: type of equipment available and filling and packaging systems; (3) materials selection; (4) rough drawings; (5) model and/or rapid prototyping; (6) mold drawing; (7) unit cavity; (8) unit cavity sampling and testing; (9) finalize drawings; (10) mold production; (11) testing; and (12) production startup (Mandel, 2002).

In this study, the bottle shape is not modified. Regardless of that, the light weight bottle could lead to an alteration of some of its features that could negatively affect the bottle purpose. The steps suggested by Mandel (2002) are useful as a benchmark for the evaluation of a lighter bottle, for determining if the new bottle fulfils all requirements needed for the current bottle.

3.2.2.1 Requirements for the lightweight bottle

The new bottle must maintain the milk quality and safety standards, avoiding any problem that can cause contamination of the product that it contains. The material must be approved by the European Commission according to Regulation (EC) No 1935/2004, which highlights the importance of the Declaration of compliance, a written declaration stating that the material complies with the rules applicable to it (The European Union, 2004). In the study, the same composition of HDPE is used.

Some specific regulations apply directly to plastic as Regulation No 10/2011, where information regarding substances migration can be found (The European Union, 2011) or Regulation No 282/2008 where information of recycled plastics is included (The European Union, 2008). The end-user is not targeted to change, the shape and dimensions are maintained, considering that the consumer will use the bottle in the same way.

3.2.2.2 Manufacturing, filling and packaging requirements

In the study, only the bottle weight is modified. The cap, foil and label attached do not suffer any modification, neither the tertiary packaging. In the extrusion blow molding system, the parison was adjusted in order to obtain a different weight. Nonetheless, the quality checks online and offline were taking place with the same specifications.

In the filling and packaging steps the yield, conveyors speed, machinery will not be altered, maintaining the same overall speed. The new bottle should withstand the parameters selected for the previous bottle. The efficiency should not be modified.

3.2.3 **Light weighting**

Light weighting plastic bottles is a common activity in the food industry. Light weighting implies the reduction of the packaging weight by decreasing the amount used or by using alternative materials. Light weighting has been described as one of the main criteria when designing sustainable packaging since it produces benefits throughout the life cycle due to avoided material production, waste and reduction of transport costs (Kang, et al., 2013). The finished light weight container is expected to have the same technical performance characteristics and functionality as the existing packaging formats, which makes the production of lightweight packaging materials ever more technically demanding (Ramos, et al., 2016).

Weight reduction of bottles affects the mechanical performance of the bottle modifying the top load, vacuum and impact resistance. Moreover, due to a thinner wall thickness permeation values can be affected such as higher oxygen permeation rates, hereby affecting the overall quality characteristics and shelf-life of the packed product (de Oliveira, et al., 2000).

A severe restriction is that sufficient under pressure in the plastic bottle could finally cause substantial deformation. This phenomenon is known as panelling and results in an unaesthetic pack that gives the consumer the impression that something happened to the content (van Dijk, et al., 1998). Due to the relatively low bending stiffness of the bottle wall, plastic containers are sensitive to this type of deformation. Panelling is currently a major factor that complicates further weight reduction in plastic bottles.

Panelling of a bottle is caused by an under pressure that can occur due to one or more of the following factors (van Dijk, et al., 1998) (1) height variation; (2) temperature fluctuations; (3) chemical or physical reactions between the product and the air in the headspace of the bottle.

For avoiding panelling, there are three choices (van Dijk, et al., 1998):

i. Rigid container procedure, i.e. trying to make the bottle as stiff as possible by either increasing the wall thickness or modifying the design with the addition of ribs.
ii. Flexible bottle procedure, i.e. to allow general deformation of the bottle and to 'regulate' this deformation.
iii. Mixed procedure, where the bottle is stiff, but locally it is able to deform. Several solutions have been developed and are available such as adding liquid N_2 to the content to reduce impact on internal bottle pressure.

Apart from these options, there are more expensive alternatives for solving the panelling phenomenon.

3.3 Waste management and producer responsibility in the United Kingdom

3.3.1 **Waste management**

Food retailers are concerned about environmental issues, demanding more requirements to their suppliers to reduce the environmental impact. They are looking for packaging that uses minimal materials and energy to maximise food protection. Not only for reducing their environmental impact, but also for addressing those customers interested in environmental issues (Marks & Spencer, 2016). Requirements set by the retailers, force the suppliers to look for alternative solutions. Among these solutions, it is usual to find weight reduction.

The British government is responsible for the management of the waste produced in the industry and the household waste.

The UK household sector accounts for over 88% of the UK's municipal waste. The Department for Environment, Food and Rural Affairs (DEFRA) is responsible for meeting the UK's waste management obligations, set down by the EU's Landfill and Waste Framework Directives (Abbott, et al., 2011). Waste management differs in each region (England, North Ireland, Scotland and Wales); there is not a unique process.

Once, targets are stipulated by DEFRA, English regions delegate individual goals for each local authority. DEFRA specifies goals for the English regions, which are then devolved into individual targets for local authorities in England. In Northern Ireland and Wales, national objectives are applied at local authority level, whereas Scotland has national dry recycling goals and composting (Abbott, et al., 2011).England has 354 local authorities, which are classified as either Waste Collection Authorities, Waste Disposal Authorities or Unitary Authorities, the last mentioned undertaking both disposal and collection activities. Scotland and Wales have 32 and 22 authorities respectively, while Northern Ireland is divided into 26 districts of local government (Abbott, et al., 2011).

In each region, the waste composition and treatment vary. England (an area with 83% of the total population) produced 5.7 million tonnes of dry recycling in 2015. The composition of the household waste in England and the final treatment method for the waste in the UK are presented in Figure 8.

The composition has remained similar compared to previous years. Plastic represents 8% of the dry waste (HDPE milk bottles belongs to this category). In 2014 the total packaging waste for plastic was 2,220 million tonnes, and 38% of this was recycled.

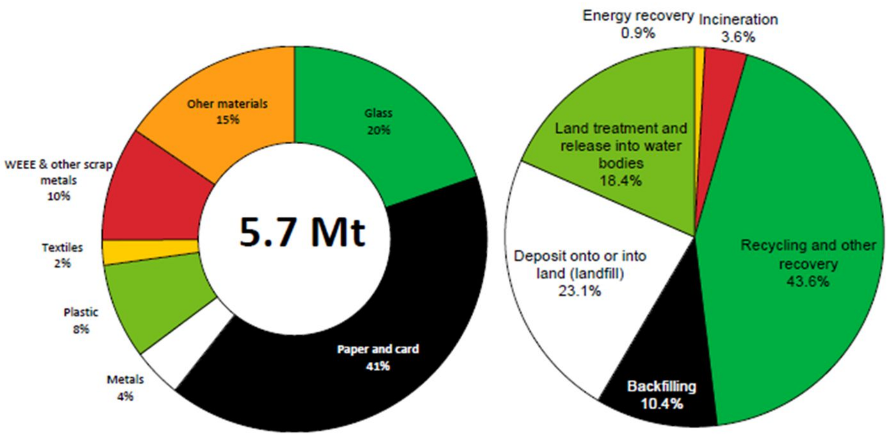


Figure 8. The composition of "Waste from households" dry recycling in England, 2015 and waste split by final treatment method in the UK (Department for Environmental Food & Rural Affairs, 2017).

The European Union in Directive 94/62/EC on packaging and packaging waste set the recycling targets for 2008. In a proposed Directive that amends Directive 94/62/EC on packaging and packaging waste new targets were suggested for no later than 31 December 2025. These objectives are:

- Minimum of 65% by weight of all packaging waste will be prepared for reuse and recycled.
- Specific materials contained in packaging waste in Table 3.

Table 3. Targets set by the European Union for different materials.

Materials	*Minimum*
Plastic	55%
Wood	60%
Ferrous metal	75%
Aluminum	75%
Glass	75%
Paper cardboard	75%

To calculate the adjusted rate of recycling and preparation for re-use by the proposed Directive, Member States shall use the following formula:

$$E = \frac{(A + R) * 100}{(P + R)}$$

E: adjusted recycling and re-use rate in a given year.
A: weight of packaging waste recycled or prepared for re-use in a given year.
R: weight of products and components prepared for re-use in a given year.
P: weight of packaging waste generated in a given year.

3.3.2 **Producer Responsibility**

In order to ensure that the Packaging and packaging waste Directive is executed by British companies, the government transposed into the UK regulation through the Producer Responsibility Obligation Packaging. These regulations introduced the concept of shared responsibility by all economic operators involved in the life cycle of packaging. It includes importers of packaging, manufacturers of packaging and packaging materials, packers, fillers and retailers (Ferreira da Cruz, et al., 2014).

Although there is not any recycling objective for 2017, the UK set targets for ensuring the compliance suggested for 2025 (Table 4). These goals apply to businesses under the Producer Responsibility Regulations, and they will ensure that the UK continues to meet EU Directive targets.

Table 4. Targets for 2017 set by the British government (Department for Environment Food & Rural Affairs, 2015).

Materials	*Minimum*
Plastic	51%
Wood	22%
Steel	76%
Aluminium	55%
Glass	77%
Glass by remelt	67%
Paper cardboard	69.5%

The producers of packaging and/or packaging materials can transfer their responsibilities to an accredited company (compliance scheme). There are 22 compliance schemes in the UK. The economic operators (or the compliance schemes) have to prove that they respect the recovery and recycling obligations by submitting yearly certificates/statements of compliance that are obtained through the Packaging Recovery Note (PRN) system (Ferreira da Cruz, et al., 2014). PRNs are the evidence required by producers of packaging waste to comply with the Producer Responsibility (Packaging Waste) Regulations 2005 in the UK. PRNs are issued by authorised reprocessors and act as an incentive to recycle and as a means for businesses to balance the amount of packaging that they place into the UK market (The Environmental Exchange, 2015). Companies are obligated to buy PNR when they handled over 50 tonnes of packaging and had a turnover of £2 million in their last audited accounts. Each business must calculate their PRN obligation in each particular material (plastic, paper, aluminium, glass, steel and wood) used for their industrial activities.

The PRN market is an open market allowing PRNs to be traded between obligated companies that have a packaging obligation and accredited reprocessors. The cost of the PRN will vary throughout the year (see Figure 9) (The Environmental Exchange, 2015).

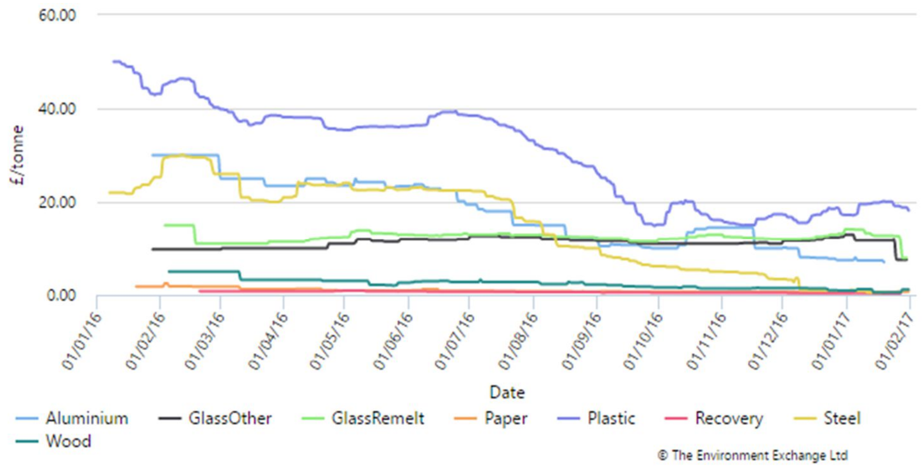


Figure 9. PRN materials price for 2016/2017 (The Environmental Exchange, 2017).

The proportion of the recycling cost to which an obligated company is responsible is calculated based on the activity they have carried out on that material (see Table 5). There are four main activities in the packaging chain, each of which takes responsibility for a percentage of the packaging (The Environmental Exchange, 2015).

Table 5. The responsibility of placing packaging material in the market.

	Activities packaging chain	
Raw Material	Manufacturer of the raw material	6%
Converter	Turns the raw material into packaging	9%
Packer / Filler	Places goods into or fills packaging	37%
Seller	Supplies packing on to the end user	48%

In the case of HDPE milk bottles, the recycling process differs in the production plant. If the bottle does not comply with the quality standards and hence it can not be used in the plant, it is reground for its later utilisation in the production of new bottles. In the case that the quality problem has been identified after the milk filling station, the bottles are emptied and recycled in the standard plastic stream. Its use as a regrind is not possible due to the organic contaminates in the bottle.

4 Results and discussion

In this chapter, the outcomes of the investigation are presented in order to solve the research questions. The research questions are (1) the designs and materials used within the industry, (2) how can the weight reduction affect the milk bottle and (3) alternative materials or technologies that can reduce the bottle cost.

Different milk bottle designs used in the United Kingdom are studied. Emphasis is placed on the study of a light weight bottle in a milk production plant, evaluating alternative materials and designs for reducing cost.

4.1 Different milk bottles in the United Kingdom

HDPE bottles appeared in the 1990s, and since then, it is the predominant material used for pasteurised and Extended Shelf Life (ESL) milk in the UK, unlike other European markets. The packaging variation among milk producers is scarce, observing more differences in ESL products. Day-to-day milk packaging is dominated by two designs; ECO and Infini that are used among dairy manufacturers and retailers with their private labels.

A recompilation of competitors, their bottles, product description and sizes are included in Table 6. Figure 10 and 11 shows the two main designs used in the UK for 1 pint (they can also be found in different sizes) and some of the alternative models available in the market. These two models are recent, and they have substitute an old design that some companies are still using. Commonly, each range of products has whole, semi-skimmed and skimmed milk, but regarding packaging, only the cap colour and the label design is modified.

The vast majority of caps are generic, following the D2911-94 (2005) Standard Specification for Dimensions and Tolerances for Plastic Bottles published by ASTM. This specification covers standard screw closure, neck finish dimensions, threads, and tolerances for various ranges of bottle capacities and body dimensions (ASTM INTERNATIONAL, 2005). The existence of standard finishes greatly facilitates the interchangeability of various stock and custom closures that might be available.

Glass packaging has not been considered, due to the reduced market share (3%) (Euromonitor International, 2016) and its characteristics. It is accepted that plastic packs have some advantages over glass packaging, for instance, they are lighter, unbreakable and cheaper. Nonetheless, some properties as top load strength, vacuum resistance and permeability, are superior for the glass bottle (van Dijk, et al., 1998).

Figure 10. 1pint Eco and Infini design.

Figure 11. Different milk bottles designs.

Table 6. Different milk bottles designs.

Brand	*Range*	*Product Description*	*Packaging Description*	*Available Sizes*
Arla	Cravendale	Filtered milk	PET white bottle without handle	0.5 litre
	Cravendale	Filtered milk	HDPE white bottle with handle	3 litres
	Cravendale and B.O.B. Milk	Filtered milk and improved tasted milk	PET white bottle without handle	1 litre
	Cravendale and B.O.B. Milk	Filtered milk and improved tasted milk	HDPE white bottle with handle	2 litres
	Big Milk	Enriched milk	HDPE white bottle with handle	2 litres
Flora	Pro-Activ	Enriched milk	Multilayer carton non-aseptic	1 litre
Graham's	Light and Low	Buttermilk added	HDPE white bottle with handle	1 litre
	Gold smooth, Gold top and Organic	Cream added and organic	PET without handle	1 litre
	Jersey Gold Smooth	Cream Added	HDPE white bottle with handle	1 litre
Tesco	Finnest Channel Island	Unhomogenised	PET without handle	1 litre
McCallums	Scottish Milk	Scottish Milk	HDPE bottle without handle	1 pint

All these products are kept refrigerated, due to their limited shelf life. Among the competitor's products, the ESL category is predominant.

ESL milk can be either produced by direct or indirect heat treatment or through a combined gentle heat treatment (pasteurisation) with a mechanical filtration step (microfiltration/ deep-bed filtration). During microfiltration, skimmed milk is filtered through a 0.8-1.4 mm ceramic membrane coupled with a subsequent pasteurisation (Boitz & Mayer, 2017). The microbial load is reduced; therefore the product shelf life is prolonged (generally around 21 days in the microfiltration case). Nonetheless, ESL-packaged products are not completely sterile. Products will spoil if they are not adequately refrigerated during storage and distribution.

For achieving an ESL product, a combination of processing and packaging conditions is necessary for ensuring a longer shelf life. Although an aseptic filling system may be used to fill a non-sterile ESL product, the cost benefit of an ESL or Ultra Clean filling machine makes this a more logical choice (ESL products do not need aseptic filling or packaging). The packaging material for ESL products may also have lower price compared to aseptic products, as a high barrier is not required. Packaging systems for ESL applications are available in a range of formats and capacities. Most systems have clean air in the filling zone, as either a laminar flow of HEPA air, or an overpressure of sterile filtered air, and a decontamination of the packaging material (Rysstad & Johnstone, 2009).

Hydrogen peroxide is the predominant agent for decontamination of packaging material in filling machines for ESL products in the food industry, usually at 35% concentration in combination with heat (Rysstad & Kolstad, 2006). Another system used by some suppliers in ultraclean applications (equipment used for sensitively processed products that need high hygienic levels) is the combination of low concentration peroxide and UV-C light (it could also be used for aseptic filling). Another commercial method used mainly for PET (ESL products) is the use of peracetic acid in combination with hydrogen peroxide followed by rinsing with sterile water, which cannot use the combination of hydrogen peroxide and heat due to its heat sensitivity (Rysstad & Kolstad, 2006).

There are more alternatives methods for the decontamination of packaging; however, these have not been proved suitable for milk filling machines (Rysstad & Kolstad, 2006). To apply any of these methods, it is necessary to have an appropriate design that allows an easy-flow of the solution in the packaging. The alternative designs present a wider handle (compared to ECO and Infini designs) or a format without a handle.

For short-term refrigerated distribution for pasteurised products, HDPE suppliers claim that it is inert to flavour changes, and since little oxygen barrier is required for the short delivery time involved, the plastic's deficiency in this regard is of little consequence (Brody, 2009). Nevertheless, PET has better barrier properties (not for light), and its use is growing in ESL lines, usually in smaller sizes.

Furthermore, due to ESL products longer shelf life, added protection is needed for avoiding off-flavours in the milk. Milk is susceptible to light induced oxidation reactions, which can negatively affect odour and flavour attributed to increased oxidation derived volatile compound production and leading to reduced shelf life. Photooxidation of milk occurs under the presence of light (artificial, sunlight) and in both UV and visible light wavelength regions (Johnson, et al., 2015). Longer storage periods increase the risk of alterations due to light. It can be observed that all the ESL products packed in either HDPE or PET have a white colour in order to avoid the light transmission. Packaging for enriched milk is also coloured for protecting the additional ingredients.

For avoiding this deterioration, Titanium dioxide is included in the packaging (either PET or HDPE). Titanium dioxide is a photo-responsive white compound that protects the milk from oxidation, due to its ability to scatter light and absorb UV light energy (Johnson, et al., 2015). The amount used in each packaging depends on the protection desired.

This addition implies an increased price. However, microfiltered milk is marketed in several countries as more ‘pure’ and ‘natural’ than regular heat-treated milk, and it has achieved a higher price as a branded product.

Without exception, these brands have their packaging design, to differentiate their premium products from similar products. Besides, clear PET is also used for enhancing the visibility of the product. Their clean presentation gives an impression of transparency between brand and consumer, as well as a feeling of authenticity of the product itself (Bordbia, 2016).

4.2 Weight reduction of HDPE bottles

The possibility of using a light weighted HDPE bottle for pasteurised milk in a milk production plant is evaluated, taking into consideration the standard bottle performance.

4.2.1 **Bottle description**

The design selected for the study is made of HDPE with different resins blend that provides the needed properties. It is considered a day-to-day packaging/product, produced massively and sold across the country. It presents a handle that facilitates its use, and it fits perfectly in the fridge door.

Extrusion blow molding is the technology used for its production. The bottle has label and cap. For ensuring the complete closure of the bottle a multilayer material of foil and plastic is adhered to the top of the neck, also facilitating the opening. The preciseness of the neck screw thread ensures the cap adherence.

The bottle does not have secondary packaging. It is directly distributed by trolleys to the retailers (no stretch wrap used).

4.2.2 **Bottle-making line and processing line**

A production line is a common type of production system. It is also known as transfer line or flow line and can be represented as a tandem queuing system. A production line consists of workstations or machines in series with intermediate buffers between successive workstations or devices (Soufiyan, et al., 2017). The bottle making process is formed by blow-molding station and bagging and debagging station (optional).

After the bottle is formed, it is subjected to quality controls in-line and off-line. Quality controls off-line are visual checks, designs checks, thickness measurements, weight check, drop test, compression test and leakers test. Pinholes are tested in-line in the bottle supplier with an air injection system.

Usually, bottles are directly transferred to the milk processing line (entire process showed in Figure 12). However, if the bottles are not used, they are stored until they are needed. If their use is required, they are incorporated into the line. The bottle's transportation to the manufacturing plant is made by conveyors. Hygienic conditions are maintained through the entire process to ensure the quality and safety of the bottles. The milk manufacturing process is composed by filling station, cap application station, label application station and packing station.

Once the bottles arrive at the manufacturing plant, they are filled and transferred to the cap station (cap and foil are added). The method used for applying the label is in-line labelling, where labels (plain paper and glue) are applied on the filling line. After, they are moved to trolleys for distribution.

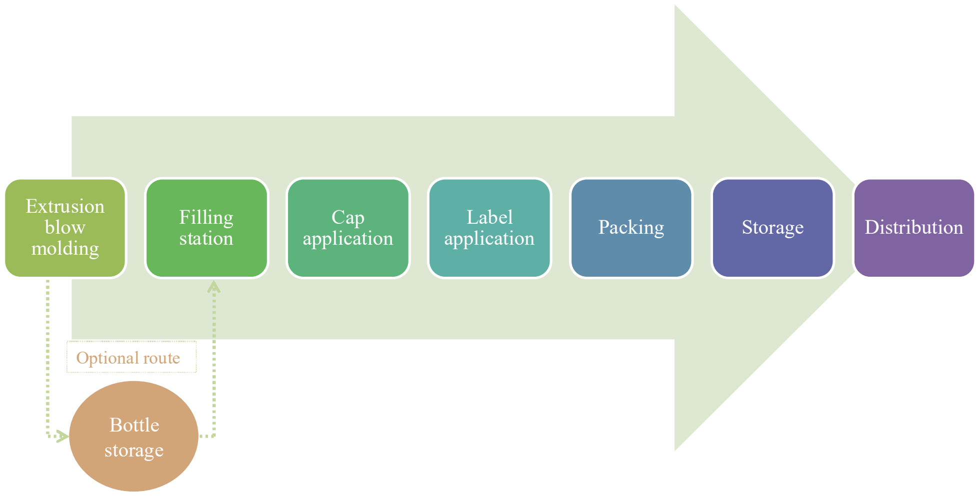


Figure 12. Milk process.

4.2.3 Evaluation of the reference bottle and the production line

For evaluating the standard bottle performance, quality data was reviewed (see example in Appendix). The manufacturer provided the data for the last two months where the results of the different tests were presented and compared with the actual specification.

The quality data provided by the supplier is formed by the test's set that they performed during the bottle production. Mainly the results are from the first production after a stop or from regular quality checks that are done on every shift. This sample population gives an adequate representation of the reality due to its size and time distribution. Table 7 presents the sample's percentage that were "in specification" for each test. These percentages show the viability of the bottle election for reducing the current weight, considering this failure percentage as frequent failures during production.

Table 7. Quality results from previous months.

Tests	*% in Specification*
Weight	99.98%
Thickness values	100%
Drop test	100%
Compression test	100%
Vacuum chamber	100%

Apart from the quality data reviewed, bottle's wall thickness and compression test were evaluated more in depth in order to determine the weakest points. The bottle was divided into different sections - A to F- each height was formed by various points (e.g. A_1, A_2, A_3, A_4, A_5, etc.). The minimum thickness value was recorded in a small area around each selected point (See Figure 13 as an example). For ensuring a representative sample's group for conducting the test, bottles from all the mold cavities were selected and measured. All cavities must be identical; however, small differences due to a non-adequate cleaning or deterioration of the cavities could affect the process (John, et al., 2014).

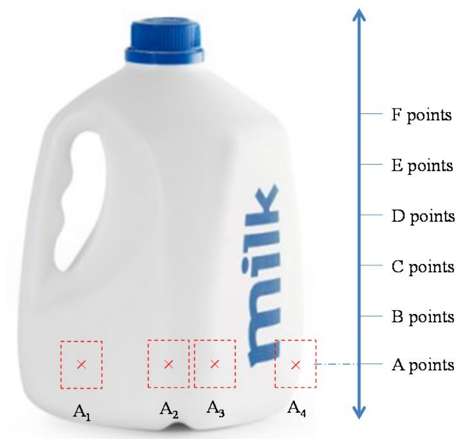


Figure 13. An example of the point's distribution (not real design).

The thickness study showed an uneven material distribution in the bottle, typical of the blow molding process (Mandel, 2002). Mainly, top part has higher values compared to the bottom. This distribution provides more stiffness in determined points that provide integrity during the bottle transportation, general requirement that a bottle must have (Mandel, 2002). Nevertheless, 100% of the samples were within the specification (different limits are depending on the section). These results confirmed the viability of reducing the bottle weight with a positive result.

A protocol was created for ensuring that the current specification meets the line demands and for identifying the critical steps in the processing line. Moreover, it would enable the comparison between standard and lightweight bottle. Initially, the length of the study and the line speed were selected. The study was done from the bottle making to the packing area; distribution and bottle storage were not considered. This observation was done in a steady-state condition of the system's parts. At every step of the process, the damaged bottles were counted and later the cause of the damage was assessed. The initial hypothesis is that the lightweight bottle, will present bottle's damages at the same stations and probably in others.

The system was evaluated using the designed protocol. The number of damaged bottles (bottles that cannot be used) was counted in each station, except for filling and cap application that were counted together.

Different forces are applied to the bottles during the processing that can cause deformations. Typical stresses on a bottle during filling and packing are presented in Figure 14. The bottle design should withstand these forces. In each stage of the process, different forces were identified (1) bottle side-to-side compression in some steps of transportation (bottom and top part) and packing station (middle and bottom part) and (2) bottle body torsion and neck distortion due to cap application. Due to the trolley design depending on the layer where the bottles were placed the side-to-side deformation is at different heights (top, middle and bottom).

The results showed that 0.08% of the bottles produced were damaged in the filling and cap station. This is due to a side-to-side deformation at the entrance of the equipment. Thickness and weight of these bottles were measured, values were in the limits agreed. Also, it has to be considered that is the first step in the filling production. After this step, the number of damaged bottles is reduced dramatically. In the label station, the number of damaged bottles encountered was negligible.

It is important to mention that at the packing station, no damaged bottles were found but, due to line speed, it was not possible to check all bottles. Only the bottles placed on the trolley's sides were checked. Several bottles in the trolley were deformed (not completely damaged), that could potentially cause leakages during distribution due to the application of forces for a long-term period.

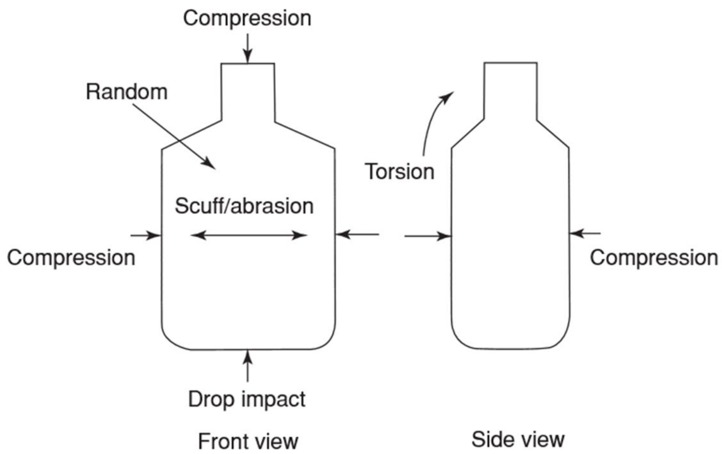


Figure 14. Common stresses on a bottle on a filling and packing line (Mandel, 2002).

4.2.4 **Initial evaluation of light weight bottle – Blow molding process**

Supplier quality data was the reference for selecting the feasibility of the weight reduction. The sampling for standard and light weight bottles was done at the same time, for avoiding time variability.

The selected reduction was 10% of the total bottle weight. For ensuring the bottle feasibility, an initial trial was executed. This limited test allowed studying the bottle's characteristics and based on the results its possible use in the milk production plant. To compare the results with the standard bottles, the same analyses were done. A representative sample was selected; bottles from all cavities were analysed. Initial bottles were discarded to avoid possible variations due to adjustment in the machinery.

All the measured weights are presented in a histogram (see Figure 15). The normal distribution is plotted based on the mean and standard deviation (SD). Comparing both sets of data, it can be assumed that the weight distribution corresponds to a normal distribution. If a process presents a normal distribution 68% of the values are within ± 1 SD of the mean; 95% of the values are within ± 1.96 SD of the mean, and 99% of the values are within ± 2.58 SD of the mean (Rutledge, 2015). Taking into consideration the weight variation agreed with the supplier, 99% of the data would comply with the specification. This result shows the accuracy of the process for producing a precise weight, according to the company standards.

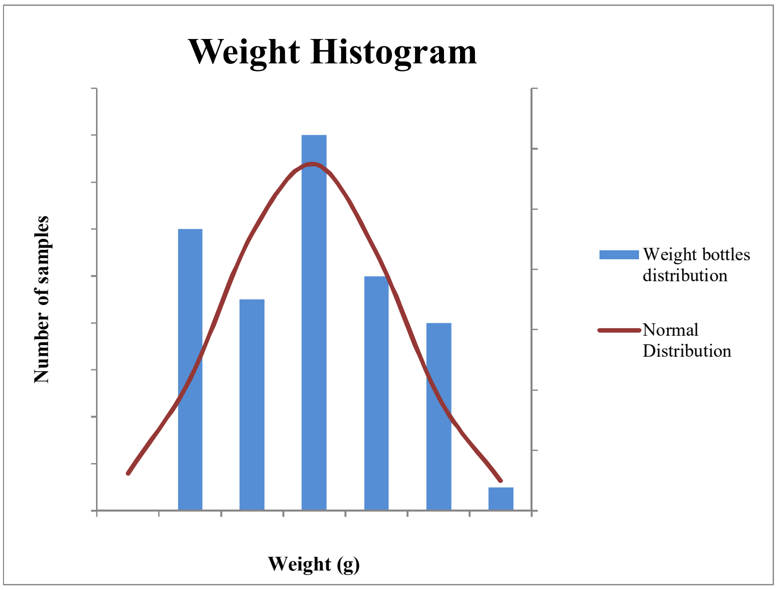


Figure 15. Histogram of light weight bottles.

Minimum thickness values were studied and compared with the standard bottle. Figure 16 presents the results of this comparison. Results show a homogenous reduction in wall thickness. Due to weight reduction B points are out of specification that could potentially cause problems on the filling line. These points are located at the top part of the bottle and could affect the force resistance during transportation. However, a further study is necessary for evaluating its feasibility.

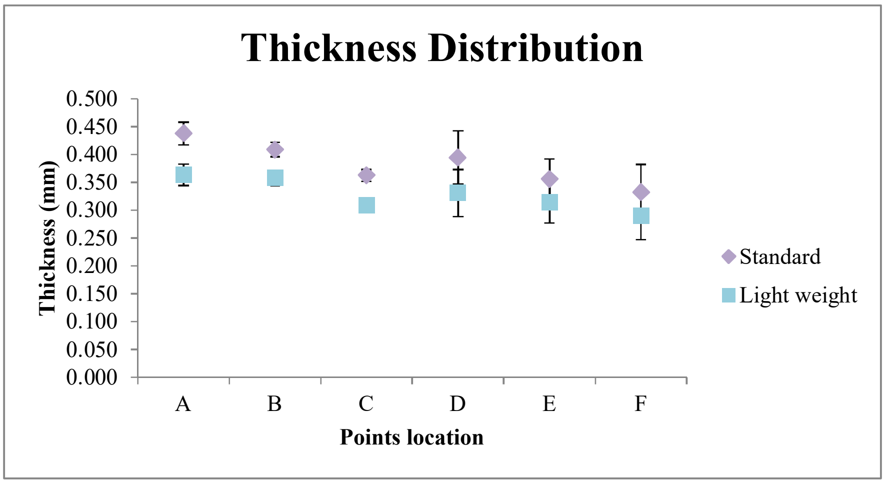


Figure 16. Standard and light weight bottle minimum thickness values comparison.

Compression force was also evaluated in the bottle in the moment of the production and after 24 hours. Shrinkage is known to happen with most materials (higher crystallinity polymers have higher shrinkage values). For HDPE shrinkage values around 1.5-3% have been observed (Belcher, 2017). After 24 hours no more shrinkage occurs. Results show an increase in the standard and light weight bottle after 24 hours (Figure 17). In many semi-crystalline polymers, the tensile modulus (directly related to the stiffness of material) increases with the degree of crystallinity (Luckey Jr., et al., 2001). Lower values are obtained for the light weight bottle. This outcome was expected, less material in the structure, less resistance to a compression force. Nevertheless, for both cases, the obtained compression force was above the specifications.

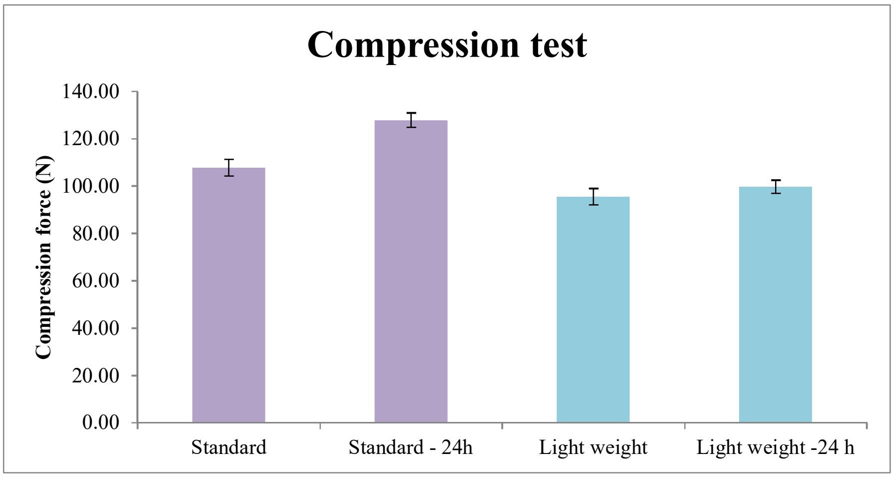


Figure 17. Standard and light weight bottle compression force values (N) comparison.

Inversely, the impact resistance can decrease with increasing degree of crystallinity. With an increase in stiffness, it is reasonable to expect a higher degree of crystallinity and, therefore, possibly a more brittle container (Luckey Jr., et al., 2001). However, results from drop test and leakers test were all successful (for in-situ test and after 24h), none of the samples failed.

4.3 Alternative materials and technologies

Currently, there are alternative materials to HDPE that are being used for pasteurised milk. The objective is to look for different polymers that can reduce the cost, maintaining the same bottle's characteristics (handle and size) and that consider environmental aspects that will facilitate the recycling in the national system. Not only must the design be considered, but also the production rate that can ensure the high output and its barrier properties.

The price of different polymers is presented in Table 8. A general trend can be observed; prices are increasing in all plastics. Due to polymer's characteristics and cost implications, PET is the only polymer that could be a feasible alternative for producing milk bottles. PET prices are around 22% inferior to HPDE. Due to its characteristics it presents severe limitations for producing a handle, that should be considered.

Table 8. Plastic price report September 2016-February 2017 (Platt, 2017).

Plastics price report September 2016–February 2017 (€/tonne)

PRODUCT	SEP '16	OCT '16	NOV '16	DEC '16	JAN '17	Market Price FEB '17	
HIGH DENSITY POLYETHYLENE (HDPE)							
Injection moulding	1420-1470	1420-1470	1400-1470	1400-1440	*1430-1460	1485-1515	▲
Film (extrusion) grade	1365-1395	1360-1400	1350-1390	1320-1360	*1360-1400	1415-1455	▲
Blow moulding	1410-1450	1415-1485	1425-1465	1400-1440	*1435-1475	1490-1530	▲
LINEAR LOW DENSITY POLYETHYLENE (LLDPE)							
Film grade (butene-based)	1340-1370	1350-1380	1355-1385	1325-1355	*1360-1390	1420-1450	▲
LOW DENSITY POLYETHYLENE (LDPE)							
Film grade	1440-1480	1440-1480	1440-1480	1410-1450	*1455-1485	1505-1535	▲
POLYPROPYLENE (PP)							
Raffia film	1280-1320	1295-1335	1305-1345	1280-1320	*1310-1350	1360-1410	▲
Homo injection	1205-1245	1240-1280	1245-1285	1215-1255	*1245-1285	1295-1335	▲
Copolymer injection	1310-1350	1325-1365	1325-1365	1290-1230	*1335-1375	1390-1430	▲
POLYSTYRENE (PS)							
General purpose	1640-1680	1600-1640	1610-1650	1750-1790	1850-1890	2110-2150	▲
High impact injection	1725-1765	1685-1725	1700-1740	1840-1880	1940-1980	2200-2240	▲
POLYVINYL CHLORIDE (PVC)							
Pipe grade	1240-1280	1245-1285	1260-1300	1250-1290	1275-1315	1300-1340	▲
High quality grade	1290-1330	1295-1335	1310-1350	1320-1360	1345-1385	1370-1410	▲
POLYETHYLENE TEREPHTHALATE (PET)							
Bottle grade	970-1010	980-1020	990-1030	1020-1060	*1080-1120	1150-1190	▲

Commodity resin pricing data based on average net prices for standard grades delivered in western Europe to large consumers in 20-25 tonne lots. *revised since last edition

Source: Plastics News Europe

4.3.1 **PET and its technologies**

PET is semi-crystalline thermoplastic polyester derived from polyethylene terephthalate that has high clarity and is inert. There is no restriction on its use for food contact, and most of the applications are for food. It is strong, robust and, in the molded form, stiff (Twede, 1998).

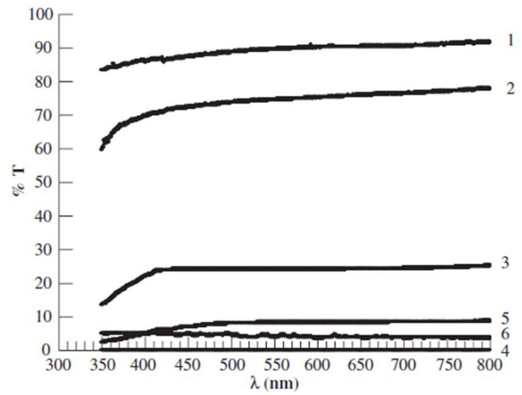
It is a relatively good gas barrier for CO_2 and O_2 (Table 9 different permeation values for polymers), being very effective for nearly every kind of product (mainly used for carbonated drinks) (Marco & Chevalier, 2009). PET density is superior to HDPE (Azapagic, et al., 2007) (see table in Appendix).

Table 9. Permeation factors for different polymers (Weissmann, 2011).

Polymers	*Oxygen*	*Carbon Dioxide*	*Water Vapour*
PET amorphous	10.4	-	-
PET heat set bottle	5.5	20	2.5
PET double blow bottles	4.3	9	1.2
PVC	8-15	20-40	2-3
LDPE	480	1500	1.5
HDPE	95	580	0.3
PP	150	450	0.5
PS	416	1250	13
PC	225	550	14
ANS (Barex)	1.1	3	6.1

Note: Permeability rates at 25 ºC (cm^3)(mil)(24 hour)(100in.^{2})(bar) ASTM D1434
Water vapour transmission at 38 ºC 50-100%RH (g)(mil)(24 hour)(100in.^{2}) ASTME-96
The data in the table is based on Barrier Polymers (Nemphos, et al., 1976) and other information provided by Morris Salame.

It tolerates relatively high temperatures, allowing its use for hot and aseptic filling. These properties can be improved by orientating, coating or copolymerizing (Twede, 1998). It is easily recyclable. Due to its characteristics and its recyclability, growth is expected for milk beverages (Euromonitor International, 2017). Its transparent feature allows more light transmittance than HDPE in the range of visible light (see Figure 18), making necessary to evaluate the light effect in milk through the supply chain.



Spectral transmission curves of the milk packaging materials. (1) Clear glass, (2) clear polyethylene terephthalate (PET), (3) pigmented PET, (4) 3-layer pigmented high-density polyethylene (HDPE), (5) monolayer pigmented HDPE and (6) coated paperboard carton (T=transmittance, λ=wavelength).

Figure 18. Spectral transmission curves of the milk packaging materials (Karatapanis, et al., 2016).

The leading technology utilised for PET is injection (stretch) blow molding (Demirel & Daver, 2012). PET does not have controllable melt strength, making its use difficult its use in extrusion blow molding (technology used mainly for HDPE). Nevertheless, different modified resins are suitable for extrusion blow molding. These technologies and resins are explained in the following sections.

4.3.1.1 Injection blow molding and injection stretch blow molding

Injection blow molding and injection stretch blow molding are often confused (see differences in Figure 19).

Injection blow molding is the process where the plastic preform is injection molded and the preform travels on the core rod to the blow mold station, where blow air enters through the core rod and lifts the hot preform material off the core rod and forms it by air pressure to the design blow mold.

Injection stretch blow molding is the most common technology for manufacturing PET bottles.

Within this technology, there are two different ways of processing: single-stage and two-stage process. In the single-stage process, the preform is shaped and blow molded in the same equipment. Preforms are not cooled down completely after injection; instead, the residual heat inside the preform allows blowing without reheating. Evidently, this makes it inherently more complicated than the two-stage process. Processors must know both parts of the process. There is also some interaction present between injection and blow, adding to the overall complexity (Brandau, 2012).

In the two-stage process, the preforms are created in different equipment and transported to the reheat stretch-blow machines, where the preforms are heated up, stretched and blew in a blow mold.

Advantages and disadvantages of both methods are presented in Table 10.

There are also machines called integrated two-stage machines that fall into the two categories (Brandau, 2017).

Table 10. One stage and two-stages injection stretch blow molding: pros and cons (Belcher, 2017).

ONE STAGE	
Advantages	*Disadvantages*
Production more cost effective	Relatively slow machine's output
Lower investment costs	Worst barrier properties compared with two-stages
Produce a more optically clean container	Need of bigger infrastructure
	Necessary more prepared personnel
	Slow adaptation to changes

TWO-STAGES	
Advantages	*Disadvantages*
Possibility of producing the preforms in one location and to blowing in other	Usually dependence of preform supplier
More adaptability in the planning production	Higher investment costs
Higher volume production	
Better wall distribution	
Better barrier properties	

The difference between injection blow molding and injection stretch blow molding primarily is that in injection blow molding the preform is transferred to the core rod (Figure 17). In the second process, the preform travels from the inject station to the conditioning station, to the blow molding station to the eject station using neck rings. The core rods are removed from the preform at the injection station after the injection-molded preform has exited the injection mold cavity (Belcher, 2017).

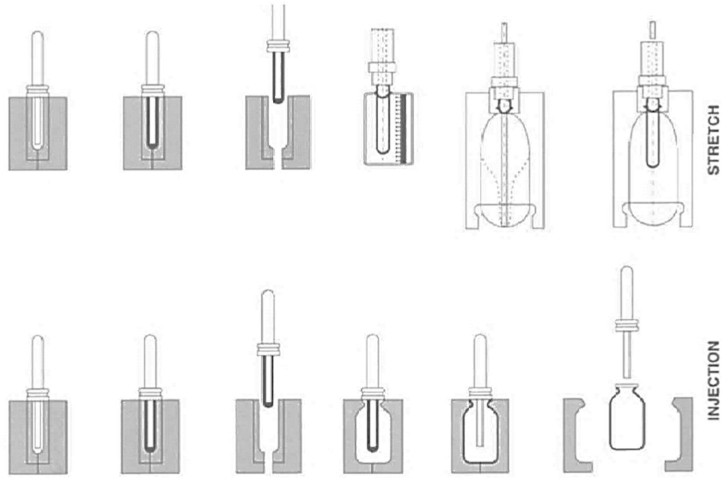


Figure 19. Stretch Injection Blow Molding and Injection Blow Molding process.

However, considering the characteristics of the standard bottle, a handle is needed. Although these technologies are widely used for bottle production, they do not allow creating a handle in the design. Alternative technologies have been developed for overcoming this problem, adding in one way or other a handle.

4.3.1.2 Handle addition

To maintain the current bottle requirements, a handle is needed in the design. Due to PET properties, a handle cannot be produced. In this section, several technologies that allow including a handle in a PET bottle are explained. Various solutions are available in the market.

<u>External handle</u>

- *Plastipak*

Plastipak offers an alternative solution for adding a handle in the PET design (see Figure 20.A).This technology allows incorporating a handle after the injection stretch blow molding process, filling and capping. The handle can be from different materials such as HDPE or PP. With this technology, product quality is not affected.

The main disadvantage of this technology is the use of an additional station on the line, increasing the total time production.

- *SIPA, SMF Germany and Amcor*

SIPA is an Italian company, specialised in PET containers from the preform creation to finished products. They have developed the SFL linear blow molding machines that claim to provide great flexibility in the production of a vast range of different types of containers (see Figure 20.B). Nonetheless, the production of these containers is for medium-small scale production, due to the low line speed. Unlike other companies due to the use of the same material, the recycling method is optimised because here is no need to separate both parts. SMF Germany has also developed a technology that adds a handle in the design (SMF Germany, 2016).

Amcor developed a similar concept for liquor in collaboration with McCormick. However, as the previous case, this technology does not allow to have a high production rate.

<u>Integral handle</u>

- *B&R Industries*

B&R Industries has patented the technology to manufacture a stretch blow molded PET bottle with an integral handle (see Figure 20.C). This technology is commercialised and ensures a high volume production in two stages.

The first stage produces a 'preform' by injection molding PET resin with a handle made of PVC (polyvinyl chloride) integrally attached. The second stage of the process comprises taking the preform after it has been left for a suitable curing time, reheating it to a blow temperature and then passing it through a specially enhanced stretch blow molding machine which gives to the preform the desired shape of the bottle (B&R Industries PTY LTD., 2017). Different sizes are available. The recycling process is complicated due to the use of PVC in the handle.

- *Sidel-Plastic Technology and Urola*

Other companies have developed what is called Deep Grip. Deep Grip technology enables significant grip depth, with an extremely thin grip “web” thickness (the grip web is where the hole would be in traditionally handled bottles, see Figure 20.D). This was the result of collaboration between Sidel and Plastic Technologies INC. It is designed for big containers for allowing an ergonomic experience. The grip is enough to facilitate the handling of the bottles, and the comfort is similar to the one experienced with a bottle with handle (average size hand results) (PTI Plastic Technology INC., 2017).

The first step is conventional stretch blow molding of preforms, followed by a subsequent operation within the same machine to form the handle. Both the container and the handle are made from the same material. The productivity of the machine developed by PTI is up to 1200 bottles per hour per cavity (low productivity). Urola has the same technology available (Urola, 2015).

Figure 20. PET bottles with handle. *A.* External handle developed by Plastipak. *B.* External handle developed by SIPA. *C.* Bottles with a handle designed by B&R Industries PTY LTD. *D.* Deep Grip developed by Plastic Technologies INC.

4.3.1.3 Extrusion blow molding

Although PET is not suitable for extrusion blow molding, chemical alterations of its structure have been studied, that allow adaptation of the polymer to this technology. Two new polymers appeared because of this development: PETG and EPET.

The amorphous copolymer of PET, called PETG presents an additional glycol group along the polymer structure of the copolymerizing agent poly(1,4-cyclohexylenedimethylene terephthalate). Specifically, PETG consists of 31 mol% PCT and 69 mol% PET. PET and PETG exhibit quite similar deformation behaviour, have a similar glass transition temperature and are visually nearly indistinguishable. There is a substantial difference: PET readily undergoes strain induced crystallisation, whereas crystallisation is virtually impossible to achieve in PETG at processing temperatures, that it makes it suitable for extrusion blow molding (Dupaixa & Boyceb, 2015).

However, glycol-modified grades tend to soften at 160ºC and can gum up the recycle stream. For this reason, they are identified on the packaging as “Other 7” (see Figure 21.A) according to the ASTM International Resin Identification Coding System.

Although these resins are used in the industry, new resins have been developed ensuring a compatibility with the current recycling systems.

Extrusion blow molding for PET or also known by EPET are the more recent resins suitable for the recycle streams, being identified by ASTM International Resin Identification Coding System as a PET (see Figure 21.B). They present the same clarity as the regular PET, but due to its modifications, they can be used for extrusion blow molding. They have been designed to have the melt strength and slow crystallisation rate required to produce containers with handle by extrusion blow molding. In Table 11 are presented companies that sell distinct modified resins classified as EPET.

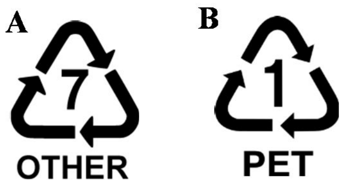


Figure 21. ***A.*** **Identification of PETG in the packaging.** ***B.*** **Identification of EPET in the packaging.**

Table 11. Companies that produce PET suitable for EBM.

Company	***Resins***
Indorama Ventures PLC.	Polyclear® EBM PET 5505
Eastman	Aspira™ Copolyester EB062
DAK Americas	Array® EBM

4.3.2 **Alternative technologies for HDPE - Compression blow forming and compression stretch blow forming**

A new technique developed by SACMI that allows creating a bottle from the resins in one single station (see Figure 22). The material used in this technology is HDPE.

The extruder is fed with resin that creates a continuous supply. After the resin supply is separated in pellets of the same weight which are then inserted into a compression mold, where the preform is formed. These pellets have the exact weight of the final bottle. Then the preform is blown into the final desired shape without wasting any material (SACMI, n.d.).

Although this technology is available on the market and it is suitable for different industries, it has only been used in the pharmacy sector. The maximum volume obtained is 350ml; however, they continue developing the technology. Furthermore, it is not compatible with a handle production.

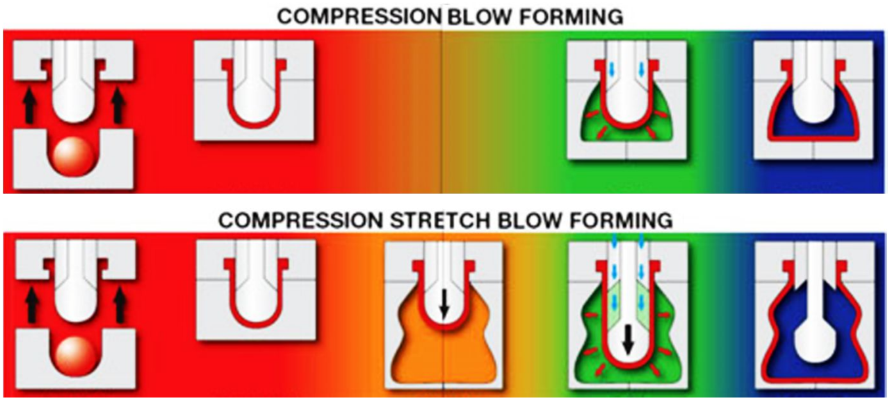


Figure 22.Technology developed by SACMI.

4.3.3 **Foam blow molding for PET and HDPE**

Foamed structures are produced by incorporating a gas into the polymer melt under pressure in the extruder. As the molten polymer exits the die, the pressure is removed, and the gas bubbles expand, creating a polymer structure with many small controlled voids (Giles Jr, et al., 2005). The main advantage is the weight reduction, due to a lower density. Two general foam structures are currently produced with extrusion equipment; however, the microcellular foam is the only used for packaging. Cell size is approximately 10µm and a cell population density around 109cells/cm^3 (Giles Jr, et al., 2005). Different polymers can be used.

In the case of HDPE wall stiffness and strength of the bottles is reported to be equivalent to solid HDPE bottles (with a density 0.68 g/cm^3). Foam blow molding is still in early stages of development, but it is an interesting technology for food packaging (Selke & Culter, 2016).

4.3.4 **LiquiForm™ for PET and HDPE**

LiquiForm™ is a new technology developed by Amcor, Sidel, Yoshino Kogyosho Co and Nestlé Waters (Figure 23). It can be used for hot and cold drinks in bottles (LiquiForm, 2017). Several materials can be used such as PET, HDPE, combination HDPE-LDPE, etc.) (Saxena, 2017). Unique preforms are designed for the process. The main advantage of this technology is that allows blowing the bottle with the liquid that aims to contain, avoiding one step in the production, which could potentially reduce the time and the resources needed. The technology is in the early stages of development, and it will be available in the market in the following 24-36 months.

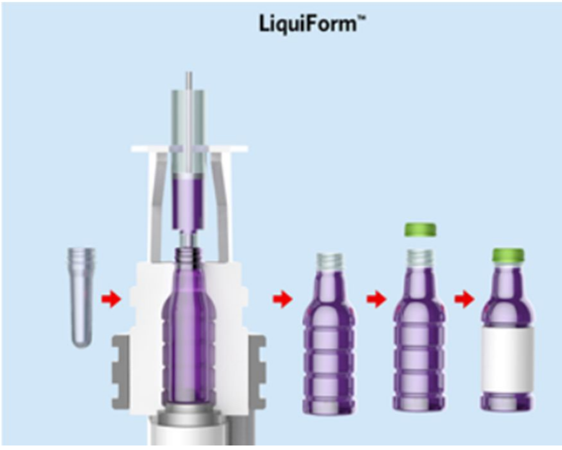


Figure 23. LiquiForm™ process.

5 Conclusions and Further Work

5.1 Conclusions

This thesis work served as an initial evaluation of a light weight HDPE milk bottle in a selected manufacturing plant. The weight reduction of the HDPE bottle could be a feasible option for decreasing the cost and environmental impact of the pasteurised milk packaging. However, other designs, materials and technologies were considered in the research as alternative solutions for cost reduction. The answers to these questions are summarized below.

Q1. Which are the designs and materials being used within the industry?

The analysis of the milk products in the UK market provided an understanding of the different packaging options for milk. This study showed that most of the products use ECO and Infini design. Other packaging options were presented. Nevertheless, due to the characteristics of these products (mainly ESL milk), their packaging has different properties not needed for the preservation of pasteurised milk, which increase the material cost.

Q2. How can the weight reduction affect the milk bottle in an established production line?

The light weight trial carried out in the supplier facility showed positive results for drop test, compression test and vacuum test that complied with the specification for the selected production line. Nonetheless, thickness measurements revealed that in the top part of the bottle results are not in the specifications. Due to the position of these points, this could cause problems during transportation and packing.

Q3. Are there alternative materials or technologies that can reduce bottle cost?

Alternative technologies open a broad range of opportunities for substituting the HDPE bottles. Although, PET is a promising polymer other considerations need to be addressed such as the weak light barrier compared to HDPE or its higher density that could lead to a heavier bottle. Having in mind that the same design want to be maintained a handle would be necessary, being required in this case the use of EPET and PETG. Alternatives technologies of HDPE and foamed materials are also interesting. However, they are in early stages of development, so cannot be implemented in a short-term period. Performance and a cost comparison must be verified.

5.2 Further Work

The observation of the different designs and materials used in the market is necessary for understanding how the market is evolving. This can be used as a source of inspiration for future innovations in milk packaging.

For further work, the study of the light weight bottle in the milk plant production is recommended for ensuring the bottle feasibility. In addition, the performance of the bottle during distribution and storage would be necessary, for understanding the entire manufacturing process. As a first approach and taking into consideration the supplier's recommendation, programming distribution has been discarded. It could potentially lead to failures in other parts of the bottle.

In regards to alternative materials and technologies, further research is needed for comprehending the total impact of substituting the line production and its economic repercussion.

Although PET has poor light barrier properties, there are additives in the market that can block the light enabling the use of this material for milk. Some of the technologies presented are in the early stages of development. Following-up the progress of these technologies would be interesting for evaluating its suitability.

Sustainability has become in the last years a concern for retailers and consumers, and it will have a bigger repercussion in the upcoming years. Packaging affects the environmental impact of the product, making it necessary to consider this factor before choosing an alternative material or technology.

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Appendix

Appendix A

Group 1

Interviewees - Senior Packaging Technologist, Principal Packaging Technologist and Packaging Technologist.

- Have you ever work with bottles before? Which material?
- Have you reduced the weight on these?
- Which effects did you realize?
- Which effects would you expect?
- Which tests do you recommend for evaluating the light weight effect?
- Are there any critical values that can compromise the bottle performance in the processing line?

Group 2

Interviewees - Operations Manager, Manufacturing Manager, Site Operation Manager, Sleever Team Leader and two Operators.

- From your point of view is it viable to reduce the bottle weight?
- In which station does the bottle cause problems? What does it happen? Do you know the reason?
- Where does the bottle present problems? Do you know the reason?
- How do you reduce the number of damaged bottles?

Group 3

Initially, a group of companies was selected based on an internet search, packaging fairs and different company contacts that develop alternative technologies to EBM for HDPE and can incorporate a handle in the design. Interviewees - Sales Manager and Technology Specialist for various Packaging Suppliers.

- How does the technology work?

- Can it be used with dairy liquid products?
- What are the strengths and weakness of the technology?
- How many bottles can be produced per hour?
- Is it already used in the market?
- Do you thinks is possible to produce a similar bottle?
- When will it be completely developed?*

*only in case is not available on the market.

Group 4

In this case, the images and information of the different packaging formats found in the market were presented. Interviewees - Packaging Supplier position Packaging Manager and Principal Packaging Technologist.

- Is there any reason behind the packaging design?
- Which material are they using?
- Why do they use this material?
- Could this potentially reduce the material/production cost?

Appendix B

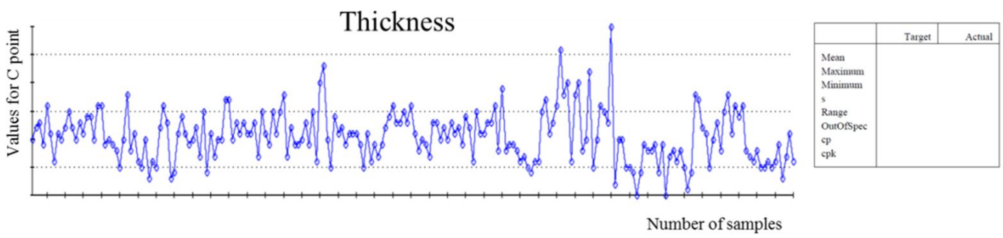

Figure 24. Example of the quality data review with the supplier.

Appendix C

Table 12. Density values for different polymers (Azapagic, et al., 2007).

Material	*Density (g/cm^3)*
HDPE	0.96
LDPE	0.92
LLDPE	0.94
PET Amorphous moulding	1.30-1.34
PET Crystalline moulding	1.32-1.38
PP	0.9
PS	1.04