Design of a sustainable closure for mayonnaise squeeze bottles

In collaboration with Unilever

Master Thesis

Integrated Product Design - TU Delft

Ing. M.M.A. Ballemans

TU Delft Unilever

I dedicate this thesis to my mother with great love.
Without her, I would have been unable to achieve this.
Thank you for all the hours you dedicated to reading to me and the patience for helping me grow.
Thanks to you, I'm where I am today.
♥

Ik draag deze scriptie met veel liefde aan mijn moeder op.
Zonder haar had ik dit nooit kunnen bereiken.
Bedankt voor alle uren die je hebt besteed om aan mij voor te lezen en het geduld zodat dat ik kon groeien.
Dankzij jou sta ik waar ik nu sta.
♥

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Master thesis

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Preface

Hi everyone!

As I am writing this, I am still a student at The Delft University of Technology. You are about to read my Integrated Product Design MSc graduation thesis, which I am very proud of and loved to write.

When I was still in high school, we went to Unilever for an in-house inspiration day. That day inspired me to be a designer, and if possible, a packaging designer. So, when choosing my Bachelor's degree, it was not a difficult choice. I became an Industrial Product Designer, which just became my hobby. So, when searching for an MSc graduation opportunity, I knew that Unilever would be the perfect fit.

This project suited me well, a technical problem with a small design area. A real challenge, supported by a sustainability argumentation. Of which I can proudly announce that I have designed a fitting solution for Unilever.

After 596 official squeeze tests, Figure 1, I can safely say that I became somewhat of a mayonnaise squeeze expert. A skill that I never expected to write down on my resume but may(o) come in handy in the future.

Enjoy reading my thesis and dive into the world of mayonnaise squeeze packaging.

Vlaardingen, September 25th 2023
Maartje Ballemans

Figure 1. Performing a squeeze test.

I feel that an apology is in order.

I am sorry for all who can never look the same way again at a mayonnaise squeeze packaging, or from what I have heard. Can never look the same way at any squeeze packaging, whether it is top-up, top-down, with or without a valve, mayonnaise, or non-mayonnaise packages.

Eating a "patatje met" will never be the same.

Acknowledgement

I am not the only one to take credit for the succeeding result of this project, it would have never been this great of a success without the people around me, that helped me, supported me, and guided me.

First, my mother, father, and sister. Who had to put up with my thesis writing stress and endless conversations about mayonnaise closures. They unconditionally supported me.

I want to thank my graduation committee, Sylvia and Stefan, for their coaching and time. It was always nice to have conversations about my project, receive new insights, and get confirmation that I was on the right track. I was truly supported and encouraged by you throughout my project.

To all the colleagues at Unilever, particularly Ruben, thank you for all the knowledge and guidance but mostly the confidence in me. It is thanks to you that this project has a real future.

My physics knowledge was not that up to date, I want to thank Dr. Boyle, J. for his support regarding the fluid dynamics of this project. I would not have been able to confirm the working principles if it wasn't for you.

To my friends, and especially Merel, Mirthe, Merlijn and Tom. I am grateful to have you, for not holding it against me if it took me days to respond to a singular text, for checking my "amazing" grammar, for planning fun things, but most importantly being there for me.

I appreciate you all helping me during this graduation journey, which I enjoyed and dare to say was a success.

Thank you all!

Executive summary

Dressings like mayonnaise can be stored in different ways. A popular way is in a rigid plastic bottle made from PET with a PP closure. This packaging can be designed top-up (the closure is on top of the bottle) or top-down (the bottle stands on the closure). The top-down rigid plastic packaging is the most used by Unilever for their dressings. This top-down configuration has an iconic closure, Figure 2.

Figure 2. The Original closure

The original closure has a unique aesthetic of a tapered design towards the nozzle. Besides helping the product move more easily towards the opening, this design also helps the user aim the mayonnaise onto the plate. The closure has a silicone valve to create controlled dosing and maintain cleanness inside the closure after dosing. Ensuring this dosing experience is vital to Unilever and Unilever brands. This silicone valve fits into a PP insert, which then is inserted into the closure, Figure 3.

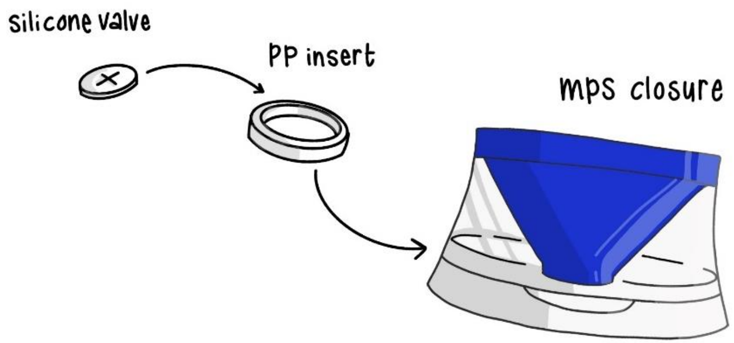

Figure 3. The silicone valve and PP insert that goes into the closure.

Despite the advantages described above, the downside of this closure is the silicone valve inside. With the upcoming Packaging and Packaging Waste Regulation (PPWR) changes in 2030 and the new legislation in France, the silicone material of the valve is no longer recognized as a recyclable material. The current closure is not recyclable according to the new PPWR legislation. A solution for the original closure is thus required.

This is why this new closure is developed, Figure 4. A valveless closure in line with the upcoming legislation and ensures the desired dosing experience.

Figure 4. The newly designed valveless closure

This newly developed closure consists of multiple features to create the so-called experience. The orifice of the closure is re-designed, to create ease of dosing, and the lid is designed to ensure a leakproof closure.

This newly designed closure as a replacer for the original closure is more sustainable since it is a mono-material closure, which enhances recyclability.

Contents

Glossary

Throughout this thesis, multiple definitions and abbreviations are used, below is a list of these with explanations.

Abbreviation	Definition	Explanation
Closure		Another word for cap
CTI	Consumer Technical Insights	The Unilever department handling consumer testing
DfR	Design for Recycling	Standards to analyse the recyclability of products
Dropper bottle		A bottle that drops one drop of liquid at a time
Flip-top cap		A cap with a hinge to open up the cap
KPI's	Key Performance Indicators	Unilever's way of identifying requirements and selling points
MPS	Marco Polo Squeeze	The unique squeeze bottle for dressings designed by Unilever
Orifice		The opening inside a closure where the product goes through
PET	Poly Ethyleen Tereftalaat	The material of the bottle
PP	Polypropylene	The material of the closure
PPWR	Packaging and Packaging Waste Regulation	Standards for Packaging and Packaging waste
Required dosing force		The force needed to dose a serving of 13 grams
R&D	Research and Development	The department in which this thesis and project were developed
STA	Structured Team Assessment	Testing principle of Unilever to test a new design or recipe
Top-down bottles		Bottles that stand on their cap
Top-up bottles		Bottles that have their closure on top
TPE	Thermoplastic elastomer	The more sustainable material for a valve
Variety sauces		Sauces other than mayonnaise, ketchup, and mustard

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Thesis introduction

The first chapter of this thesis explains the reasons for initiating the thesis project, the sustainable relevancy, and the design approach. This chapter explains the necessary background information needed to understand the project assignment as given by Unilever.

Introduction

Europe produces 58 million tonnes of plastic every year, of which 40% is used for packaging (Publications Office of the European Union, 2018). A large part of the produced plastic packaging is used to package food. Food packaging has a positive effect on quality, marketing, purchasing, food waste, preservation, and consumer experience (*Food Packaging Technology*, n.d.), but besides the advantages of plastic food packaging, there are also disadvantages. In 2014, only 30% of Europe's 25 million tonnes of plastic waste was recycled (Publications Office of the European Union, 2018). One-third of the waste ends up in landfills which influences the environment and contributes to climate change. Because of these negative developments, the European Commission decided to change the legislation to increase sustainability in food packaging (*Revision of the Packaging and Packaging Waste Directive | Think Tank | European Parliament*, 2023). This legislation also focuses on carbon emissions and microplastics, but this project does not tackle these.

1.1 Sustainable packaging legislation

The main goal of the European Commission regarding sustainability is to create a more climate-friendly Europe, with the key objective to create a circular economy for (food) packaging (Sam, n.d.-a). In November 2022, the European Commission published a review of the Packaging and Packaging Waste Regulation (PPWR) (Melissinou, 2023). This regulation defines the essential requirements for packaging design and composition and sets out packaging collection and recycling targets (*Proposal Packaging and Packaging Waste*, 2022). This review is aimed to ensure that all packaging in Europe is reusable or recyclable in an economically viable way by 2030. Which is in line with the EU Green Deal and the EU Circular Economy Action Plan (Sam, n.d.-b). The review of the PPWR introduces the Design for Recycling (DfR) guidelines from RecyClass (*Design for Recycling Guidelines - RecyClass*, 2023). These guidelines score products from A-E regarding sustainability based on a traffic-lights system (Figure 5). By 2030, products with an E-score will be banned. The A-E score is indirectly linked to the EPR (Extended Producer Responsibility) fee. Governments have their own score system regarding determining the EPR fee. However the European RecyClass system is often used to verify the sustainability. For producers, the aim is to score an A. This means that your product is sustainable, which is important for the company and the environment but also results in a lower EPR fee. Because of sustainability reasons and the revision of the PPWR, it is no surprise that increasing the sustainability of packaging is an important topic nowadays. A lot of companies are developing sustainable packaging innovations with short implementation time and future-oriented innovations, like paper bottles. For Unilever, this is no different.

Figure 5. RecyClass (DfR) guidelines overview. (*Design for Recycling Guidelines - RecyClass*, 2023)

1.2 Background Unilever

Unilever is a multinational consumer goods company, that produces products around the world (Plc, 2023b). All Unilever products are divided into 5 divisions: Beauty & well-being, Personal Care, Home Care, Nutrition, and Ice Cream. Across these five divisions of Unilever, a large part of their projects is focused on sustainability. For instance, focused on less packaging, more sustainable packaging materials, less food waste, more vegan products, etc. Since there is new legislation coming in 2030 regarding the sustainability of food packages. Unilever has also developed sustainability goals for 2025, to be in advance, prepared for the legislation changes of 2030.

Unilever produces multiple ton of plastics per year (Boshart & Unilever, n.d.). Because of the PPWR changes and Unilever's sustainability vision, Unilever developed sustainability goals for plastic specifically: **The Unilever Plastic Goals** (Plc, 2023c).

By 2025, Unilever will:

- Halve the amount of virgin plastic we use in our packaging and achieve an absolute reduction of more than 100,000 tonnes.
- Collect and process more plastic packaging than we sell.
- Ensure that 100% of our plastic packaging is designed to be fully reusable, recyclable, or compostable.
- Use 25% recycled plastic in our packaging.

(Plc, 2023c)

Unilever developed a framework to guide these ambitious plastic goals. Less plastic. Better plastic. No plastic (Plc, 2023e).

Less plastic: cut down the amount of plastic used by creating lighter designs, reuse and refill formats, and concentrated products which use less packaging.
Better plastic: using recycled plastic to design the products and making sure that the used plastics are designed to be recycled.
No plastic: using refill stations to decrease the amount of packaging and switching to alternative materials such as paper, glass, or aluminum.

These sustainability-driven plastic goals relate to the 12th Sustainable Development Goal: Responsible Consumption and Production, drafted by the United Nations in 2015 (*Goal 12 | Department of Ec onomic and Social Affairs*, n.d.).

Figure 6. Unilever logo (Plc, 2023d)

Figure 8. The Marco Polo Squeeze

1.3 Marco Polo Squeeze (MPS)

The division Nutrition of Unilever contains the sub-section Dressings. Unilever has a variety of dressings in its portfolio, these are packaged in three main plastic containers: Rigids, Flexibles, or Tubes, Figure 7. The Marco Polo Squeeze (MPS), Figure 8, is Unilever's most used rigid container for dressings.

Figure 7. Example of Rigid, Flexible, and Tube Packaging (left to right) (Plc, 2023a).

The MPS bottle is made from (100% recycled) PET, the cap is made from PP, and inside is a silicone valve, Figure 9. The Marco Polo Squeeze bottles are top-down bottles, which have an iconic aesthetic and are unique because of the created dosing experience. Top-down bottles are designed to stand on their cap in the fridge. The advantage of top-down bottles is the consumer experience, it is user-friendly because the product inside is easier to squeeze out of the packaging. Top-down bottles can also be more sustainable since food waste is less likely. This is because more of the product can be used. Due to gravity, it will move towards the cap, resulting in less residue product inside the container. The designed cap results in clean dosing and ease of dosing the right amount of product. To create this dosing experience, and to

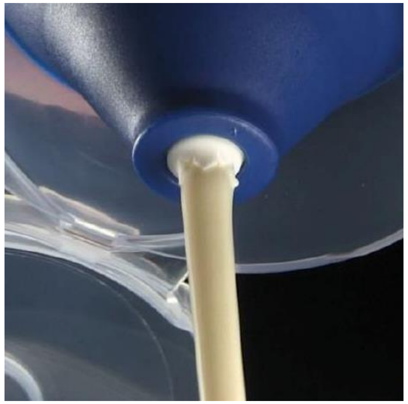


Figure 9. The silicone valve inside the MPS in use

make sure that the product does not leak through the cap, a silicone valve is placed inside, which makes the cap “non-recyclable”.

Originally, the recycled silicone valve would end up with the PET stream (which was polluting the PET). As counter measure, bubbles were added to the valve to create a valve with a different density than PET, but now the valve ends up with the PP stream. The PP cap is still recyclable but the silicon valve with bubbles causes pollution in the PP recycling steam. The silicone is recyclable if you would separate the valve from the cap, but that is a very costly procedure since it is only 0,7% of the weight of the cap, and silicone recycling facilities are not common. Unilever has developed a valve from TPE, which enhances the recyclability of the closure (in most European countries) but is more costly because the material is more expensive, and still requires an extra assembly step. The developed TPE valve is classified as recyclable in the PP stream (tested against RecyClass), and therefore, does not count as pollution in the PP stream. The only exception is France, where it has been classified as a non-recyclable material (Paragraph 2.4). As mentioned before, the TPE valve is more costly and would thus be an on-cost for Unilever. Implementing the developed TPE valve is postponed by Unilever’s marketing since this valve is more costly. To make sure that sustainability goals are met and not to increase prices, a more sustainable and cost-effective design is needed.

1.4 The assignment as given

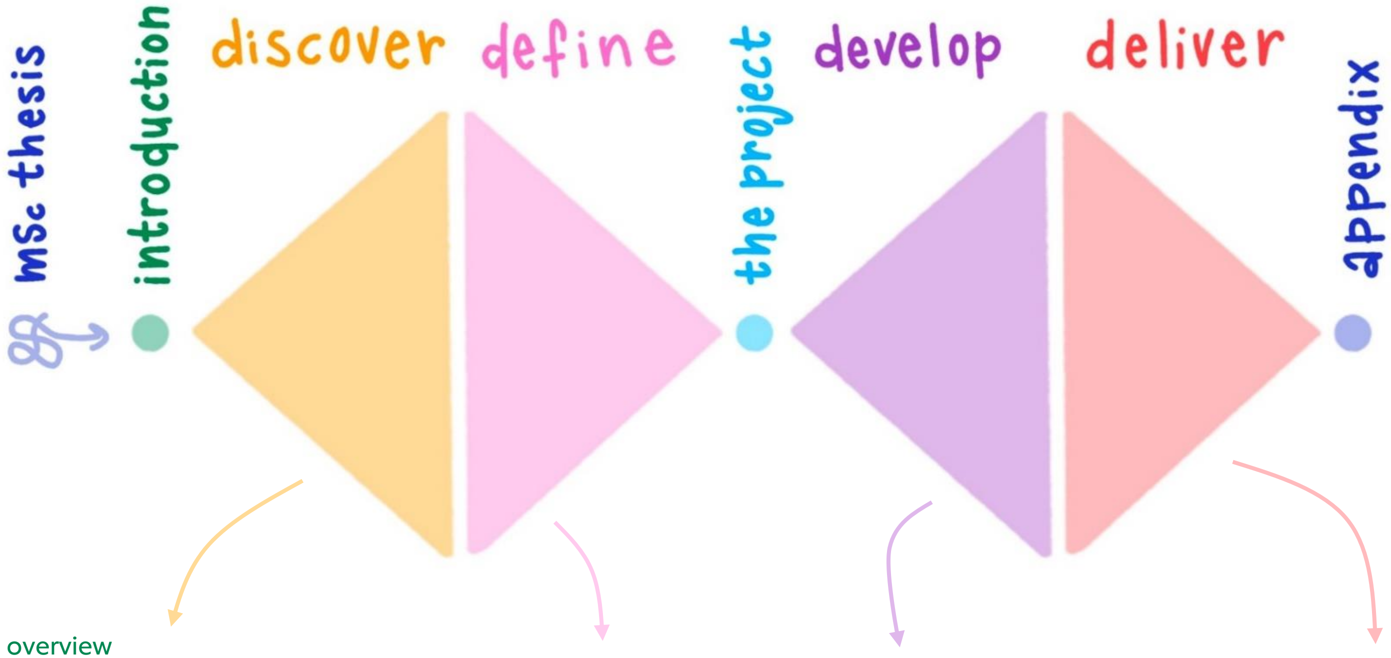
In line with Unilever’s sustainability goals of 2025, a fully recyclable closure for the squeeze bottles is desired, and by 2030 even mandatory due to legislation changes. A new design should be fully recyclable, but this should not change the current user experience of the Marco Polo Squeeze bottle. Unilever, the client, has proposed that the more sustainable design is a valveless design, to reduce an assembly step. Ideally, this new closure is more cost-effective, let users experience the same dosing, and can be used with the current production, assembly, and logistics of Unilever.

1.5 Project approach

The design process during this project follows the principle of the Double Diamond by the British Design Council in 2005 (*Double Diamond, Design Process Model Developed by the British*. . ., n.d.) (Figure 10). This method is chosen because it fits the design process of this project, first gathering all the needed information with testing and analyzing and then starting the design phase with all the acquired knowledge and variables. It is first important to fully understand the current design and working principle to start the concept, design, and iterating phase. This Double Diamond method is the perfect way to approach this. The Double Diamond (*The Double Diamond - Design Council*, n.d.) is built up into four different phases that diverge and converge to go from research in the Discover phase, to define the challenges and design scope in the Define phase. After which in the Develop phase, multiple designs are created, tested, analysed, and optimized, to conclude with a final design in the Deliver phase.

Each phase has a different focus and delivers different outputs. The steps from one phase to another phase are the most important ones, these will ensure that the right steps are taken to solve the problem definition.

Project overview



Research questions overview

Discover

What is the current closure situation of the MPS?

What is the context of the closure?

What other designs are on the market?

How do current closures perform?

Define

What variables determine the dosing experience and/or the cleanness after dosing?

What is the design space?

Which requirements and wishes are there?

Develop

What is the ideal design/solution for the mentioned problem?

What is the ideal ratio for the to-be-designed closure?

How can the cleanness inside be improved?

Deliver

What is the difference between the new closure and the original MPS closure?

What patents are related to the new closure?

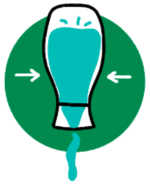
Does the new closure comply with the set requirements?

What are the future steps?

Figure 10. Overview of project

1.6 The activities

Below in Table 1, the different research activities of this project are explained.

Research design activities		Page	Appendix
	**Market research** – Researching solutions that are already on the market. • The dressings closures at the Albert Heijn • Existing closures	23 26	I
	**Interviews and conversations** – Gathering information and requirements from the stakeholders. • R. Boshart & R. Reinderman – Unilever • Dr. Boyle, J. – Fluid dynamics • Mike Ross – Injection moulding	53 81	XIV
	**Squeeze testing** – Testing the required dosing force to dose 13 grams of product with a Zwick machine. • The four existing closures • New orifices • 3D printed closures • The new designed closure	29 47 58 63	III VII VIII
	**Observing** – Noting down important remarks during tests and research activities. • Throughout the project		

	**Squeezing** – Squeezing bottles with new designs and experiencing the dosing experience and cleanness • The four existing closures • New orifices • 3D printed closures • The new designed closure	 29 47 58 63	
	**Physics and calculations** - Using fluid dynamics and physics to validate conclusions; and predict how designs will work	37 53	
	**Solidworks flow simulations** – Predicting the flow of mayonnaise inside a closure	60	
	**Stakeholder tests** – testing the new closure with stakeholders. • Investor board meeting • Structured Team Assessment	 65 73	XII

Table 1. Overview of activities

02

Discover

Creating a better understanding of the problem as given.
The second chapter, Discover, contains the analysis of the problem as given. During this phase the stakeholders are analyzed and mapped, existing closures are analyzed and tested, and the variables of the closure that influence the dosing experience are determined.

2.1 The context

As described in the previous chapter, there is a sustainability reason and motivation behind the given assignment. This influences the production and discarding requirements. This is only part of the context of the assignment and it is of utmost importance to understand the context of the to-be-designed closure. Understanding and taking this context into account during the design process will help with creating a viable solution for this assignment.

Besides the sustainability conditions, the stakeholders play an important role in this context. The two most important stakeholders of this project are the stakeholders from Unilever and the consumers who will use the packaging. These are further explained in the next two paragraphs. The context of using this to-be-designed closure is thus the surrounding temperature, the dosing force, way of doing and shaking the bottle. This context is translated into a list of requirements and wishes to include during the design process.

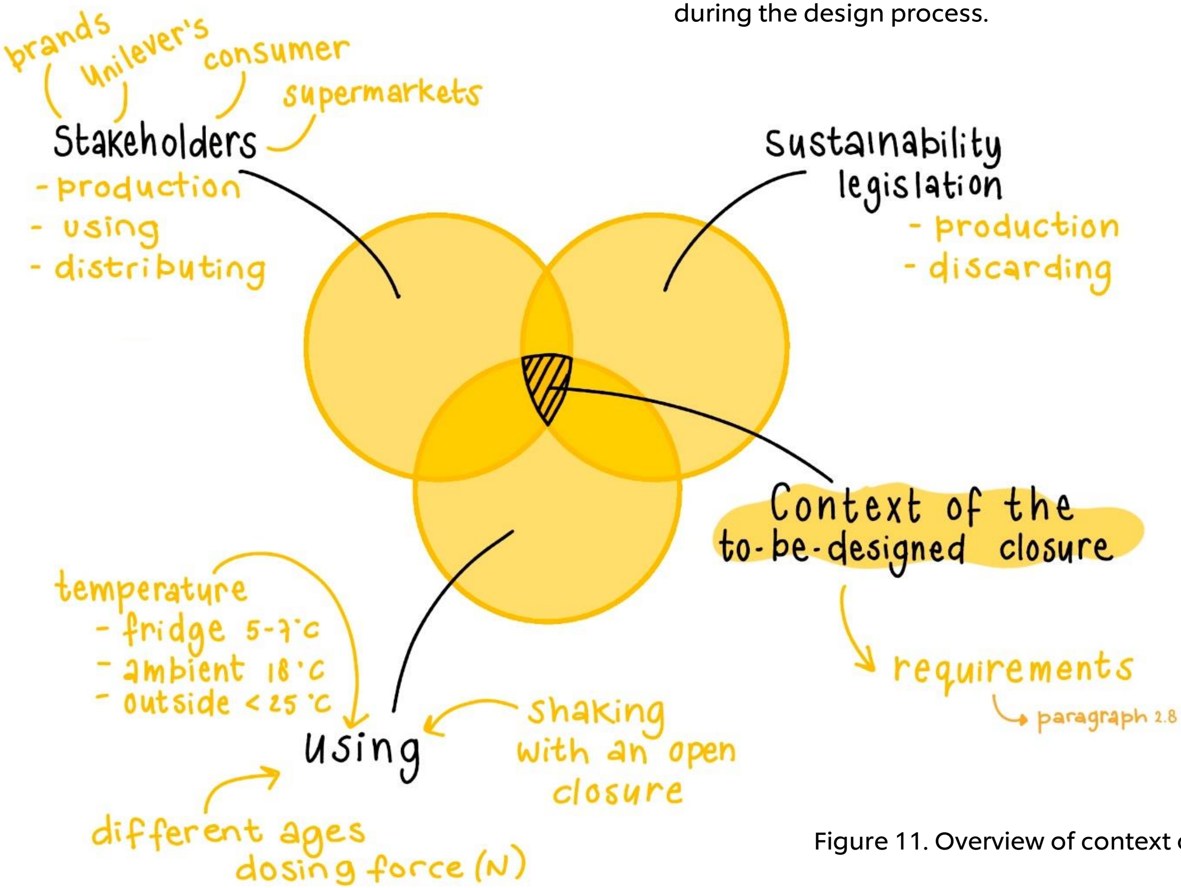


Figure 11. Overview of context of the to-be-designed closure.

2.2 The consumer

Besides the wishes and requirements of the Unilever stakeholders and sustainability conditions, the consumer is also an important stakeholder. The consumer of the packaging will buy the mayonnaise bottle in a supermarket, transport it home and use it when needed. At home, the bottle can be stored ambient (18 °C) when still unopened but should be stored in the fridge (5-7 °C) when opened. The difference between storing the product ambient or in the fridge is the temperature. The recipe will have a higher viscosity when stored in the fridge since the viscosity increases when the temperature decreases (Zhu et al., 2021). The ambient stored products are thus more likely to have some challenges regarding the cleanness since the product will be tinner. As previously mentioned, the MPS bottle is a top-down bottle, which means it is designed to stand on its cap. There is a probability that some consumers will also store the bottle top-up, since this is less risky (less chance of leakage inside the closure). The closure will be designed and tested with ambient stored products and stored top-down. This way the riskiest combination is tackled, storing the product could only improve the experience and not decrease it.

Testing and verifying the to-be-designed product with stakeholders and especially with consumers is always important. However, this to-be-designed closure will be (during the development phase) confidential and can thus not easily be tested with consumers. Due to these confidentiality conditions set by Unilever, the to-be-designed closure and iteration phase are not validated with consumers, but the usage of the packaging by consumers is taken into account in the requirements list. A final validation is done with Unilever employees (outside of the project team), who are also consumers. This is done by Unilever standards, which is called a Structured Team Assessment and can be found in Paragraph 6.3.

2.3 The Unilever stakeholders

This thesis project has the project name Monopoly within Unilever. Monopoly is a priority project with its own stakeholder team, the Unilever Investor Board. The Unilever Investor board will eventually give the official go of the project and consists of multiple departments; Marketing, Procurement, R&D, Quality, and Supply Chain, all with their own requirements and wishes. Understanding and mapping these are important to narrow down the scope of the design assignment. These requirements and wishes are included in the list of requirements, Paragraph 2.8 and Appendix IV.

Marketing

The Marketing department of Unilever is mostly focused on the consumer experience of the MPS. This contains the maximum dosing force, the cleanness of the orifice and cap after dosing, and the looks of the dosed product. The maximum dosing force is 60 N (R. Reinderman, March 2023). This originated because of gotten complaints about certain recipes, like Hellmann's light, lighter than light or garlic sauces. Those recipes are difficult to squeeze. Earlier tests of Unilever concluded that these require a dosing force of more than 60 N. An opportunity to improve with the new to-be-designed closure. The cleanness of the inside of the closure after dosing is important, this should be comparable to the current MPS closure (maximum of cleanness 3, Paragraph 2.7, Requirement C.021). The dosed product should also be comparable to the dosed product with the MPS closure. Marketing of Unilever desires a closure that will ensure the same squeeze experience as the current MPS but should comply with the sustainability legislations. Regarding the French legislation changes, as described in Paragraph 2.4, the new product should be compatible with the first-wave recipes.

Quality

The Quality department of Unilever is in line with the needs set by marketing. However, it is important that the closure performs constantly.

The dosing experience is more or less the same during the first squeeze of the packaging until the last squeeze.

Procurement

The procurement department of Unilever would prefer a valveless design for the MPS caps. This is to save costs, not only in comparison to the TPE valve but also the silicone valve. It is preferred that this valveless design is integrated into the cap and not via an insert. The project has a high priority in case of costs, since some moulds need replacement. Integrating this with a new design would save extra costs in the future.

Supply Chain

In line with procurement to reduce costs, the Supply Chain department of Unilever aims that the new design will need as limited as possible changes to current logistics. Preferably the new caps have the same outer dimensions because an adaptation to the outer dimensions will influence the production line which means in increase in costs.

Research & Development

The R&D department of Unilever is responsible for delivering the new design of the MPS cap. This thesis project takes place at the R&D team. This new design is in line with the set requirements of the Monopoly project set by the Investor Board.

2.4 Country-specific legislation

The new PPWR legislation that will go into effect in 2030 Europe-wide, as previously mentioned, is aimed at improving the sustainability of food packaging. The PPWR is binding for all EU countries and sets goals for countries to achieve within a certain time. The PPWD, Packaging and Packaging Waste Directive, is written by the country itself and describes how the country will achieve the goals set by the PPWR (*Types of EU Law*, n.d.).

Besides this European legislation, there are also country-specific regulations. These regulations are for instance incorporating more than the PPWR, are more progressive or are targeted earlier. This is the case for France. The government of France has announced a revision of its own legislation, the French Environmental Code (FEC) (Circpack [by Veolia], 2023). This legislation is targeted at 2025, 5 years earlier than the European legislation, pushing their own country towards sustainability. The French target is to recycle 100% of all plastic packages (*Plastics and Packaging Laws in France| CMS Expert Guide*, n.d.). France introduced in this new legislation the 3R strategy; reduction, reuse, and recycling (*The Government of France 2021 Global Commitment Report on Plastic Packaging*, n.d.). In the case of the recycling legislation, an important factor differs from the European one, using a TPE valve does not make the packaging 100% recyclable. Meaning that Unilever can no longer make that claim on French packaging. A similar legislation change occurred during this project in England.

When Unilever was considering what recipes would be part of the first base, generic project-wise and for this project thesis, the French legislation was decisive. The French recipes contain multiple variants of dressings, making them suitable to test and get useful results. These recipes are explained in the next Paragraph 2.5.

2.5 The recipes

Unilever has decided what recipes will be the first-wave recipes. This means that these recipes will be the first to be tested. The reason behind these chosen recipes is partly the French legislation, but also choosing multiple recipes of Hellmann's since this is one of Unilever's largest dressings brands. The first-wave consists of 14 recipes, and have all a different composition, resulting in different viscosities, experiencing syneresis or having chunks inside. Having this many recipes is challenging, the to-be-designed closure should be compatible with all these recipes.

Viscosity

Viscosity is the quantity that describes a fluid's resistance to flow (Elert, 2023). The higher the viscosity the more viscous the product is, for instance, honey has a high viscosity. The lower the viscosity the more liquid the product is, water has a low viscosity. It is likely that recipes with a higher viscosity require more dosing force and recipes with a lower viscosity are more likely to leak. Both extremes will result in challenges, but it is plausible that the lower-viscosity products will result in a greater challenge than the higher-viscosity products. The lower viscosity recipes will leak more with shaking the bottle and will decrease the cleanness of the orifice. This hypothesis is tested, by mapping the squeezed recipes and determining the cleanness of the orifices after dosing 10 times in Paragraph 2.11.

Syneresis

Syneresis is a phenomenon, that occurs in some products, this means that the particles will separate from the water. Ketchup, mustard, and fatty mayonnaise have a higher chance of this. The water that will be separated is going to be a challenge while designing the new closure. Water has a higher chance of leaking because of its low viscosity and high density. Syneresis can occur in two places, on the bottom or on the top of the recipe. Ketchup is more likely to have syneresis on the bottom, whereas mustard is more likely to have syneresis on top.

Chunks

Recipes like garlic sauce or burger sauce have small particles in them, these are often pieces of herbs, garlic or gherkin. Having these chunks inside the recipe increases the challenge of this assignment since smaller parts or holes will not be suitable for these types of sauce. The particles will be unable to fit through too small a gap.

Table 2 shows an overview of the different recipes, what the composition is and the reason for being in the first-wave recipes. The combination of these recipes should give a good view of a closure performance with the Unilever wide spectrum of dressings.

The average mayonnaise for testing

Testing each closure with 14 recipes before drawing a conclusion will take a lot of time. The first-wave recipes can be split into three types, low-viscosity recipes, normal-viscosity recipes and high-viscosity recipes. Low-viscosity recipes will be challenging regarding the cleanness, while high-viscosity recipes will be more challenging in lowering the dosing force. In consultation, Amora Mayonnaise de Dijon and Ligeresa Original were chosen as average mayonnaises to test with during the development phase, to get a good first average impression of the performance of the closure.

Recipe	Viscosity	Syneresis	Chunks	Reason
Amora Mayonaisse de Dijon	Normal			French recipe
Amora Mourtarde fine & forte	Low	X		French recipe
Amora Mourtade mi-forte	Low	X		French recipe
Ligeresa Original	Normal			French recipe
Globus Majonez Real	Normal			French recipe
Calvé Belgische mayonaise	Normal			French recipe
Calvé Sabor Casero	Normal			French recipe
Calvé Mayonaise	Normal			French recipe
Calvé Yofresh	High			French recipe
Hellmann's Garlic & Herb	High		X	Chunks
Hellmann's Vegan Mayo	High			Top seller
Hellmann's Light Mayo	High			Top seller
Hellmann's Lighter Mayo	High			Top seller
Hellmann's Real	Normal			Top seller

Table 2. The first-wave recipes

2.6 The Marco Polo Squeeze closure

The current design of the Marco Polo Squeeze cap is a screwable flip-top cap. Flip-top caps have their own terminology, see Figure 12. The orifice is the part where currently the insert with the valve is placed, this part is the focus area of this design project. The design of the orifice (and pin) determines the cleanness after dosing and the dosing force.

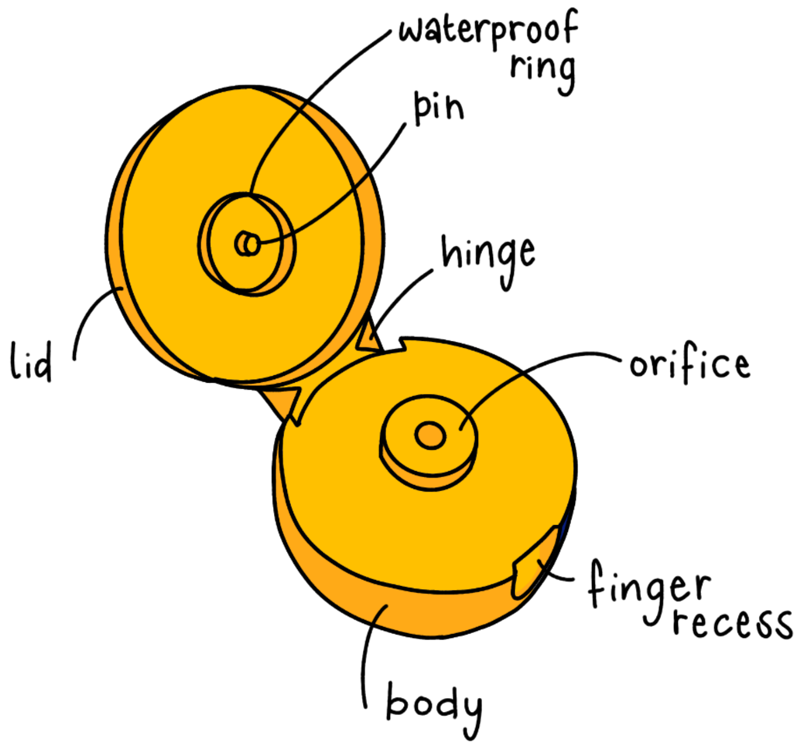


Figure 12. Flip-top cap terminology.

The pin is the part that fits on the inside of the orifice and the waterproof ring fits on the outside of the orifice, these two parts influence the leaking and the cleanness.

Part	Purpose	Current design	Is allowed to change in the redesign
Body	Is screwed onto the bottle, main part of the closure		No, outside dimensions are fixed.
Finger recess	Recess in the body, used to open the lid		No, should be unchanged.
Orifice	The opening where the recipe leaves the closure	Valve and PP insert in a orifice hole of 8mm	Yes, no restrictions
Hinge	Connects the lid to the body and allows the lid to open and close		No, should be unchanged.
Lid	The top and movable part of the closure		No, outside dimensions are fixed.
Pin	The part that goes into the orifice to cover the opening	Round 5mm with three chambers	Yes, no restrictions
Waterproof ring	The ring around the pin that restrains the residue from going into the lid	15 mm, fits around the outside of the orifice	Yes, no restrictions

Table 3. Overview of the parts of the flip-top MPS closure.

As mentioned earlier, the MPS closure, has a silicone valve as an orifice. This silicone valve creates the current dosing experience. The dosing experience contains the amount of force needed to dose, the leakage prevention when placed inside the fridge, and the cleanness of dosing.

The silicone valve is placed in a PP insert, which then gets placed inside the MPS cap, Figure 13.

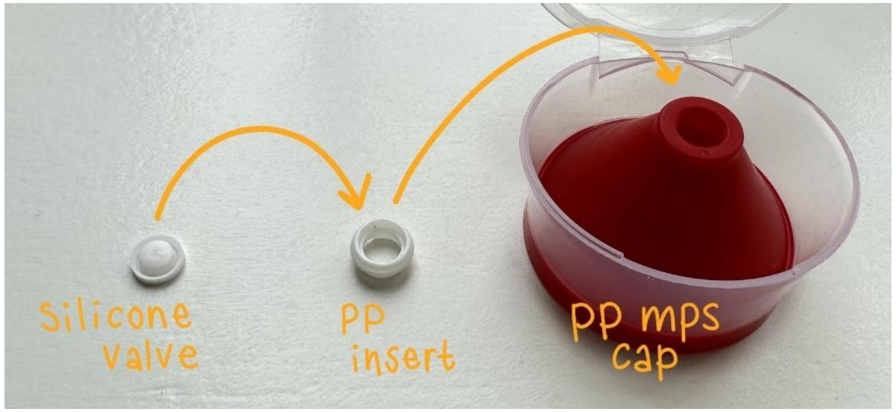


Figure 13. The silicone valve, the PP insert, and the MPS closure.

The impact of the silicone valve

Although the valve is only made from 0,07 grams of silicone, there are yearly many Marco Polo Squeezes sold, which results in a little more than 16.000 kg of silicone waste per year (Boshart & Unilever, n.d.). And even worse, this waste is polluting the PP recycling stream. To use the valve inside the MPS cap, the PP insert is needed. This PP insert is recycled along with the MPS cap but uses more material than a "normal" orifice. Yearly this results in almost 35.000 kg of PP material that is used to place the valve inside the MPS caps.

The sustainable impact can be decreased by designing an MPS closure that uses less material than the current MPS closure and creating a mono-material product that will not pollute the PP recycling stream.

2.7 Cleanness scale

To measure the cleanness of the closures after squeezing equally, a cleanness scale was drafted since there was not yet one developed by Unilever. This cleanness scale can be seen in Table 4.

In this cleanness scale, scale 1 is the cleanest and scale 5 the messiest. Scales 1, 2 and 3 are acceptable clean, whereas scales 4 and 5 are unacceptable. Scale 1 or 2 is desired. All closures during this project are scored on cleanness inside the closure with the use of this cleanness scale. But it is important to take into account that it is still slightly an opinion. If needed, for instance for further research, all pictures of the inside of the lid and outside of the body of the tested closures after squeezing can be found in Appendix X.

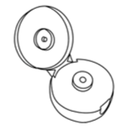
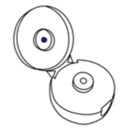
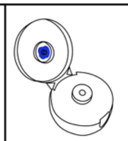
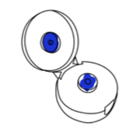
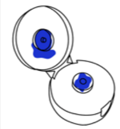
Overview					
Scale	1	2	3	4	5
Acceptabele	Yes	Yes	Yes		
Pin		x	x	x	X
Inside waterproof ring			x	x	X
Orifice				X	X
Outside waterproof ring				A little	A lot

Table 4. The cleanness scale (x means that there is residue on that part)

As mentioned above, this cleanness scale is still slightly an opinion but was drafted in collaboration with the project lead of R&D R. Reinderman. It was determined (with his knowledge of previous projects), that scales 1 and 2 is desired and scale 3 is also acceptable. To be sure of this estimation, the cleanness scale is validated with the stakeholders of Unilever.

Validating the cleanness scale

Goal: Validating the cleanness scale of Table 4 with the different stakeholders.

Method: Asking the stakeholders to note down of 11 pictures of closures after testing if the inside cleanness is acceptable, in between or not acceptable, and asking which part of Figure 12 is allowed to have residue on after dosing.

Results: The initially set cleanness scale is the right scale, it is slightly more strict than the results of the stakeholders. These results can be found in Appendix X.

Conclusion: The cleanness scale of Table 4 is validated, that it is slightly more strict than this scale is wanted. Then there is still a safety factor build into the cleanness scale. Something that was already mentioned, is that this scale is still based on an opinion. This was also validated with these results of the stakeholders, some features are allowed to get dirty but depending on the amount of residue is acceptable or not acceptable.

2.8 Requirements and whishes

As explained in Chapter 2, this project has several stakeholders, each with their own wishes and requirements.

Some requirements are more challenging than others because they are very strict or a challenge to achieve within the scope of the project.

The most important requirements are about, Figure 14:

- The cleanness inside the closure after dosing
- A dosing force lower than 60N
- Outside dimensions stay unchanged
- Aesthetics of the closure stay unchanged
- Mono material design
- Optimized for injection moulding
- In line with upcoming legislation changes

The full list of requirements and wishes can be found in Appendix IV. Below is a summary overview of the requirements that will play an important role in iterating a viable solution.

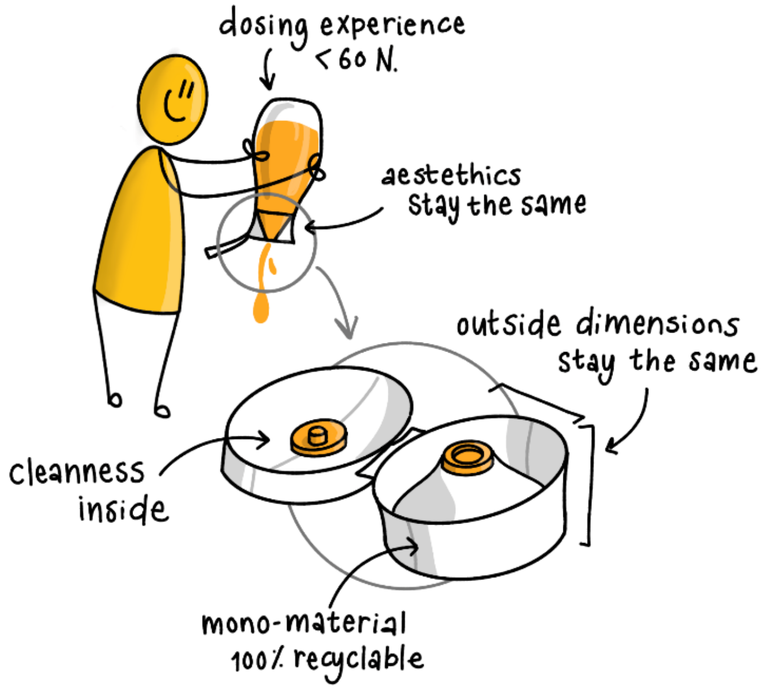


Figure 14. Requirements visualized

2.9 Existing closures

A lot of products are packaged in plastic squeeze bottles, they are commonly used for condiments and in the beauty industry. So, when you walk into the supermarket in search of your favourite mayonnaise or in the drugstore to buy your favourite shampoo, there is a high chance that you buy a squeeze bottle.

These squeeze bottles may look the same, but between almost every bottle there is a slight difference. For instance, the material of the package is different, or the orifice has a different design. These differences often have a reason. To understand these variables and to map them, most squeeze bottles are analysed in the Albert Heijn supermarket and the Etos drugstore, Figure 16. Information about the analysed closures can be found in Appendix I.

Conclusion existing closures

After analysing the different closures in the condiment aisle in the Albert Heijn supermarket, it can be concluded that there are slightly more top-up squeeze bottles (60,9%) than top-down bottles (39,1%) in this particular supermarket. It is likely that this is has a financial reason because most top-up bottles do not have a valve and most top-down bottles do have a valve, Figure 15. Most premium brands have a top-down with valve option, to offer a better dosing experience.

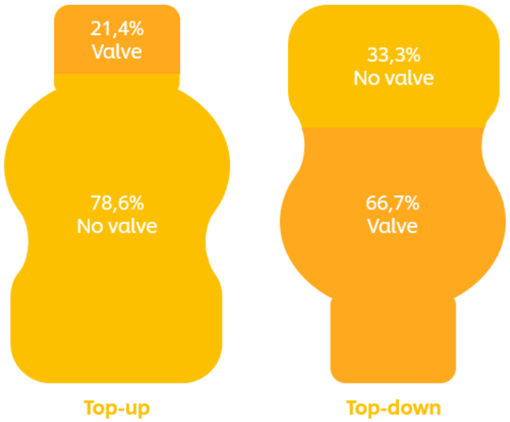


Figure 15. Overview of amount of top-up and top-down bottles

Figure 16. Overview of different closures

The valveless top-down bottles

The 33,3% that are top-down bottles without a valve are mostly from the supermarket brand itself (AH). These three bottles are visible below in Table 5. Two-thirds of these valveless bottles have a 4mm orifice design, this is probably because it reduces the chance of leaking since it is a relatively small opening. Only the closure of the AH "frites saus" is different. This is a orifice that has a 6mm hole and outside tube.
The dosing experience of these bottles; Since these bottles have different bottle neck dimensions, the closures are tested with their own bottle and recipe, Table 5. The information can therefore not directly be compared to MPS squeeze tests. These squeeze tests are just to get a better feeling of the dosing experience of the valveless existing solutions.

Remia frites saus	AH ketchup	AH frites saus
		
		
4 mm orifice	4 mm orifice	6 mm orifice with tube
Works just general, not particularly clean but no problems either.	With ketchup the closure becomes messy. The AH ketchup is really runny.	This closure is interesting, the squeeze experience is great. Clean cut-off, easy to squeeze and clean closure.

Table 5. Overview of valveless top-down bottles

Another observation is the difference between the inside of the closure of valve designs and valveless designs. With valve design the waterproof ring connects to the orifice and with valveless designs the connection is with the pin, Figure 17.

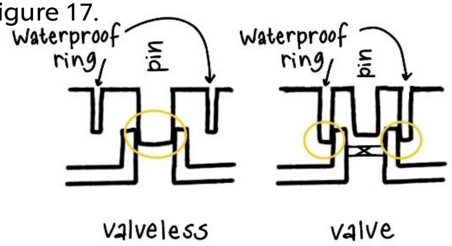


Figure 17. Valveless design: The pin fits the orifice (L). Valve design: The waterproof ring fits the orifice (R).

When looking at the squeeze bottles at the drugstore, all except for one, are top-up bottles (with a regular valve). This is likely in relation to the viscosity of shampoos; this is higher than that of condiments. The exception is the men's shampoo from Dove, this is a top-down bottle with a bridge and hole design orifice, Figure 18. This design is probably chosen to decrease the chance of leaking, without having a polluting valve. The other orifices that are valveless (but are top-up), have the same two-diameter orifice design, Figure 19. Some differ in diameters but still have this two-diameter design.

Figure 18. Bridge with hole orifice.

Figure 19. Two-diameter orifice.

These already existing orifices are an inspiration for the development phase, chapter 5. But before the design and iteration phase can take off, it is important to know how the current MPS cap performs and what variables determine the squeeze force, the cleanness, and the overall dosing experience. In the next paragraph, tests will be performed to understand the squeezing context, which will help formulate the project variables.

Alpla CDC

Alpla, a company that develops innovative plastic packaging solutions, has developed a valveless closure with controlled dosing feature, the CDC. Controlled Dosing Cap, Figure 20. The closure consists of a labyrinth covered by a PP insert. The PP cover helps with decreasing the chance of leaking, since there is no direct contact between the opening and the volume inside the bottle. The product enters the labyrinth on one side and must travel around to meet the opening of the orifice. This controls the dosing of the product, but increases the dosing force immensely.

Figure 20. Controlled Dosing Cap of Alpla (CDC - Controlled Dosing CaP, n.d.).

H. J. Heinz Company

One of the main competitors of Unilever brands is Heinz. Heinz mainly sells ketchup but does have a few mayonnaises and variety sauces. All Heinz ketchup bottles have the same closure, one with a silicone valve, Figure 21. This valve is comparable to the original silicone valve inside the MPS closure. It is considered non-recyclable and pollutes the waste streams.

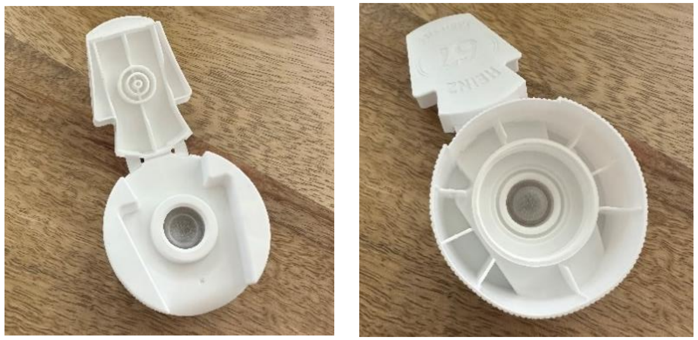


Figure 21. Heinz closure with valve outside (L), inside (R)

Heinz also has a more sustainable closure, a valveless closure with a 4 mm orifice, Figure 22 This closure is only used for the mayonnaises since these products are more viscous, they are less likely to leak. The feature of this closure that stands out is the tube as an orifice. On the outside as well on the inside there is a small tube design.

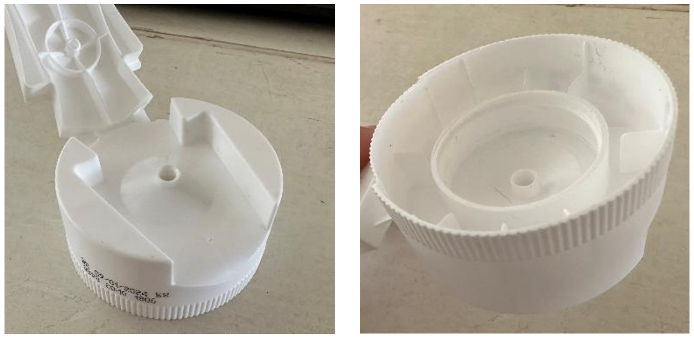


Figure 22. Heinz closure without valve, outside (L), inside (R)

Heinz had thus far only a valveless design for the mayonnaise recipes and not yet one for their large ketchup portfolio. However, Heinz has announced in 2021 that it has designed a valveless 100% recyclable bottle cap that ensures the same dosing experience. It took Heinz 185.000 hours, 45 iterations and 1.2 million dollars to develop (*Heinz Tomato Ketchup Introduces First 100% Recyclable Cap Delivering the Perfect, Eco-Friendly Squeeze!*, n.d.). Heinz announced the new sustainable flip-top cap in July 2021 that would be rolled out in 2022. But in spite of this claim, the cap was nowhere to be found at the beginning of this project in March 2023.

Luckily, the new Heinz closure appeared in the supermarkets at the end of this project. The new Heinz valveless closure for ketchup has like the Alpla CDC a PP insert, Figure 23. Since this new closure appeared relatively late in this thesis project, could this new closure not be used as benchmark during the analyzing and development phase. The 4mm orifice valveless closure of Heinz is used for this. However, the final closure is tested and compared to this new valveless closure of Heinz, in Paragraph 5.13.

Figure 23. The new 100% recyclable valveless Heinz closure for ketchup.

Patents

There are many patents regarding the design of a closure for squeeze bottles. When searching for patents "closure, squeeze bottle, orifice" more than 100.000 results are found. All with a very specific design, and at this stage of the project a bit too early to consider. Research was done, to see what was already patented, to know what already exists, but also to map. Therefore, when there is a clearer view of the final design, a comparison can be made with existing patents, Paragraph 6.5. Below (in Figure 24, 25, 26 and 27) are a few examples of the many patents there are.

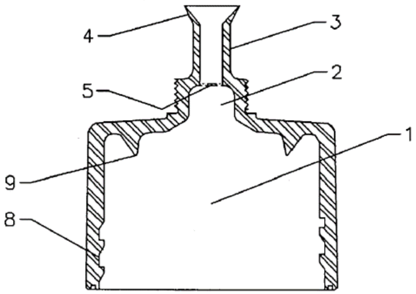


Figure 24. patent US 2004/0129738A1 Flared spout of 30-60 degrees.

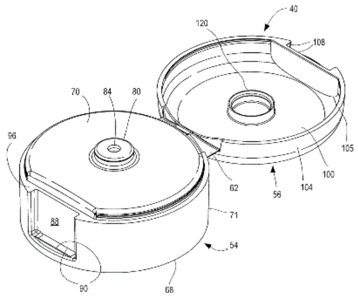


Figure 25. patent US 2020 / 0140152A1 Defines an orifice

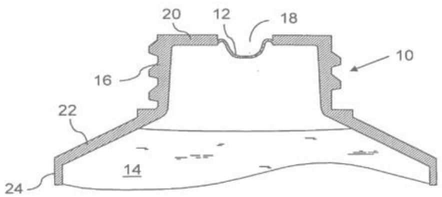


Figure 26. patent US 2007/01 14250 A1 – orifice moulded valve

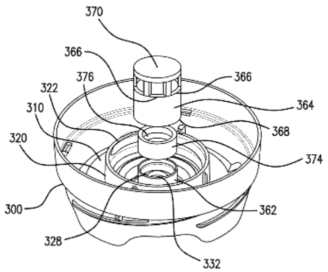


Figure 27. Patent EP 3 261 943 B1 – Dispensing system

2.10 The squeeze test method

Unilever has developed a procedure to test the squeeze-ability and dosing efficiency: the Squeeze test – UMA-6341.02 from the Packaging Method of Analysis (Unilever et al., 2011), more details in Appendix II. The Squeeze tests that are conducted for this project follow this protocol for accurate comparison to earlier tests of Unilever and results.

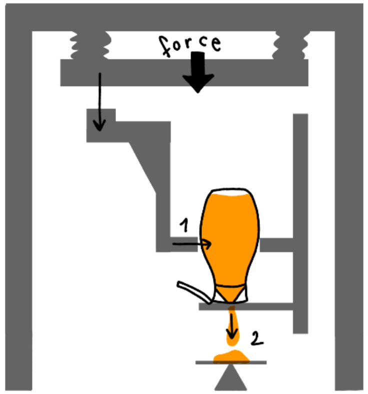


Figure 28. The squeeze test setup. 1= dosing force, 2= dosed serving.

The squeeze test procedure

The setup of the Squeeze tests can be seen in Figure 28. A squeeze bottle is placed in this setup and the force is applied. The squeeze force is the force needed to dose exactly 13 grams of products, for instance, mayonnaise. When too much force is needed (more than 60 Newton, requirement C.012), it could result in negative consumer interaction. However, the difficulty to squeeze could also lead to more leftover products in the bottle. This is also not desired by the consumer, but more importantly, it makes the package non-recyclable. This is because when a package has more than 10% product left inside, the package is too heavy to get blown in the right recycling stream (the PET stream) (Admin, 2021) (Boshart & Unilever, n.d.).

To get reliable results from the Squeeze test, each bottle is squeezed 10 times, the average is calculated to get the squeeze force. In between each squeeze test, the cap is closed, and the bottle is shaken to create a realistic context. After conducting the 10 squeeze tests, the orifice is photographed to analyse the cleanness.

As stated earlier, this squeeze test method is used since Unilever uses this standard. However, it is important to take into account that it is not fully recreating the squeeze testing method of a consumer. The Zwick machine used for these squeeze tests will apply the force more constantly than a user could do, the measured squeeze force could differ from the reality. Another factor that influences this is the areas that apply the pressure onto the bottle. Normally this would be done with your hand or hands. Research concluded that from the three squeeze grip styles, grip style a (Figure x) is the most used (Yoxall et al., 2010b).

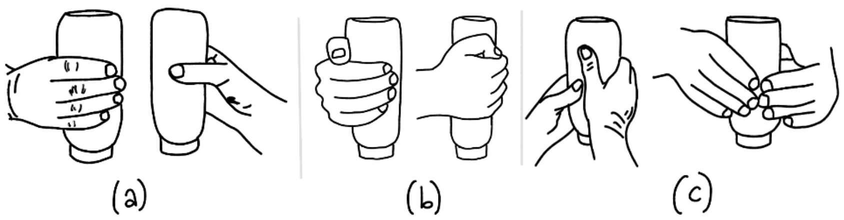


Figure 29. Grip styles for squeezing a bottle

This grip style (a) is most comparable to the squeeze test method setup. The thump is represented by part 1 (Figure 29), only the other four fingers are less represented since part 1 is the same on the other side of the bottle.

2.11 The first squeeze tests

The four closures

To get an understanding of the current dosing experience of the MPS bottles and the French recipes, the combinations are tested. Besides these recipes and the MPS caps, three other caps were also tested. The three other closures are the Interkap closure, the Latam closure, and the 4 mm orifice. The Latam and Interkap are produced by suppliers of Unilever and fit the MPS bottles. These closures were chosen by Unilever, besides that these are closures that Unilever is interested in, the MPS bottle neck is very specific, no other closures fit these dimensions.

The Interkap closure is designed in Turkey and has a star orifice, this orifice should ensure clean dosing, Figure 30. The Latam closure is designed in Latin America by the supplier Plastek. The Latam cap has a bridge design orifice to prevent leaking. As mentioned earlier, the 4 mm orifice is the most common diameter used in flip-top caps for squeeze bottles. This is thus interesting to test in the first round of squeeze testing. To create this 4 mm orifice cap, the Latam cap is altered. The bridge was

Figure 30. Interkap closure, Latam closure, 4mm orifice closure (L to R).

The benchmark closure

As mentioned earlier, the newly announced valveless closure of Heinz was not yet on the market during this phase of the project. The other valveless Heinz closure with a 4 mm orifice will be the benchmark closure during these tests. Since it is important to know how the competitor closure performs regarding the squeeze force and cleanness.

Negative pressure inside the bottle

After squeezing the bottle 10 times to measure the average squeeze force for dosing 13 grams of mayonnaise, the bottle was squeezed by hand to experience the bottle, closure recipe combination. During the first squeezes the importance of the negative pressure was discovered.
The negative pressure inside a bottle is created by squeezing the bottle, during this the bottle deforms, decreasing the volume inside (1). This creates pressure and causes the product to be squeezed out of the bottle (2). When the pressure on the bottle is relieved, the bottle expands causing the dosing to stop (3). During this step, the negative pressure is created, resulting in sucking the product a bit inwards (4). These steps are visualised in Figure 31.

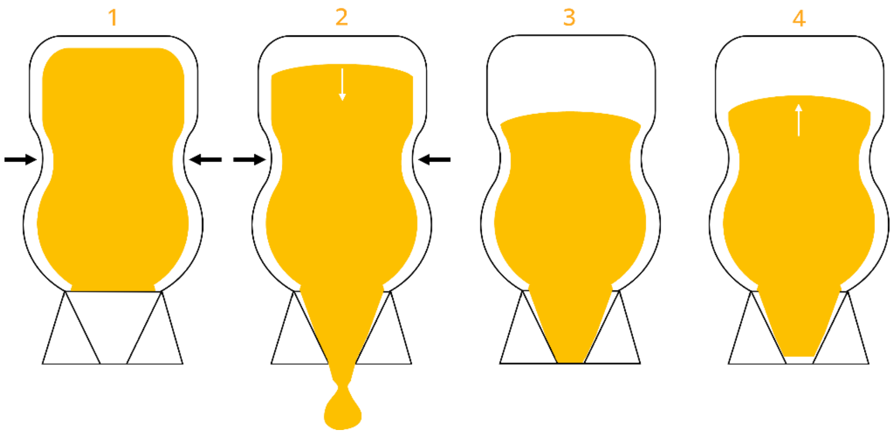


Figure 31. The steps of negative pressure inside a squeeze bottle.

The first squeeze test results

To make an overview of the many squeeze test results, the C-box method was used. This is normally used to generate an overview of a multitude of ideas (*DELFT DESIGN GUIDE*, 2011), but can also be used to plot data. The C-box is a 2x2 matrix. The two axes usually represent criteria fitting the ideas generated, but in this case, the cleanness and dosing force will be used. The C-box normally has four quadrants, since axis with a typical C-box does not have a scale. But in order to plot the data in the most useful way the c-box has a scale for the dosing force and one for the cleanness, instead of low force, high force and clean, messy, Figure 32.

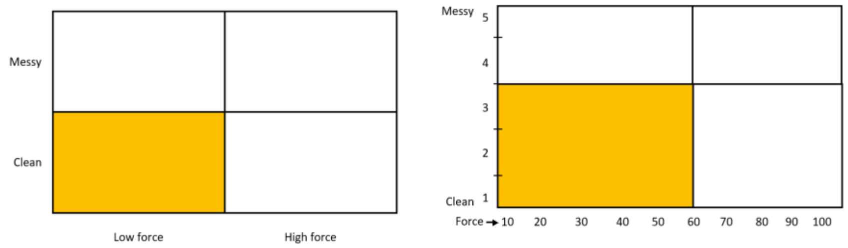


Figure 32. Normal C-box, desired area left bottom (L), Used C-box, desired area left bottom (R).

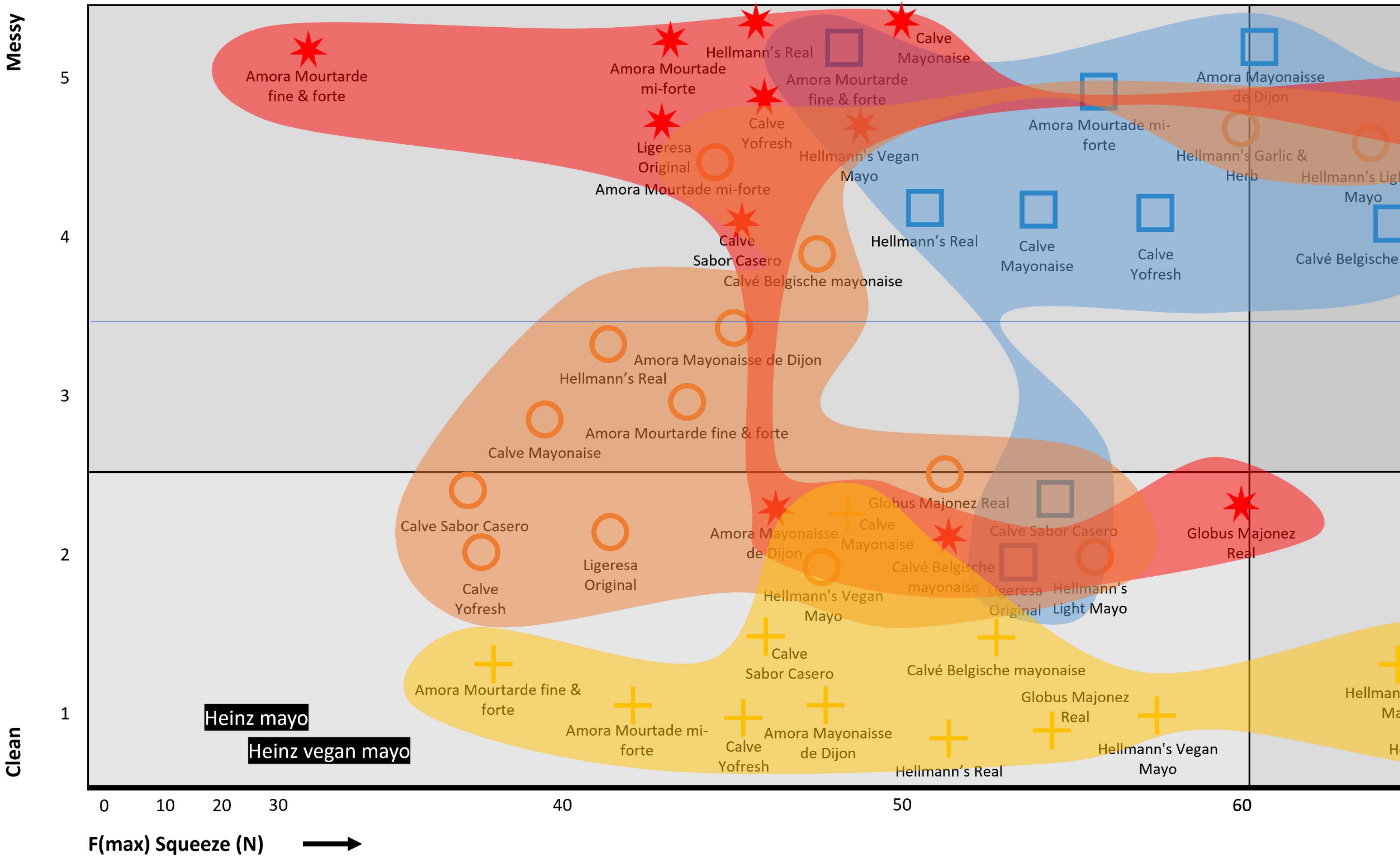
As can be seen in Figure 32, the left bottom corner is the desired spot for the to-be-designed closure. As Requirement C.012 claims, the dosing force should be lower than 60 Newton and as explained in Paragraph 2.8, the cleanness should be a maximum of 3 with the developed cleanness scale. This leaves the top right corner as the most unwanted place.

Plotting the dosing force in the C-box overview is straightforward, and plotting the cleanness on this scale is less. As described in Paragraph 2.7, each scale step of the cleanness scale has its own requirement of what is allowed to have residue. Something that is developed as a strict requirement is in practice less objective. Since the amount of residue matters. To give a better visual inside of this, some cleanness results are discussed below in Table 6.

Picture of the orifice after dosing	Cleanness scale number
	1 The whole closure is clean, there is not residue on the body or lid.
	2 The pin is covered in residue, and only a small dot on the orifice, this is neglected.
	2 Only a small dot on the orifice, not clean but not messy.
	3 The pin is covered in residue, and there is some traces of product on the orifice.
	4 The pin and orifice are covered in residue.
	4 The pin and orifice are covered in residue.
	5 Everything is covered in residue.

Table 6. Examples of each cleanness scale number

In Figure 33, the overview of the squeeze test results is visible. The individual squeeze results and data can be found in Appendix III. As explained, the results are plotted along two axes, the horizontal axis shows the average amount (out of 10 squeezes) of force needed to dose the 13 grams of product, and the vertical axis shows the cleanness of the orifice after dosing ten times. The desired spot on this overview is the bottom left corner.



Messy
Clean
5
4
3
2
1
0
10
20
30
40
50
60
F(max) Squeeze (N)
Amora Mourtarde fine & forte
Amora Mourtade mi-forte
Hellmann’s Real
Calve Mayonaise
Amora Mourtarde fine & forte
Amora Mayonaisse de Dijon
Amora Mourtade mi-forte
Calve Yofresh
Ligeresa Original
Hellmann's Vegan Mayo
Hellmann's Garlic & Herb
Hellmann's Ligl Mayo
Amora Mourtade mi-forte
Calve Sabor Casero
Calvé Belgische mayonaise
Hellmann’s Real
Calve Mayonaise
Calve Yofresh
Calvé Belgische
Amora Mayonaisse de Dijon
Hellmann’s Real
Amora Mourtarde fine & forte
Calve Mayonaise
Calve Sabor Casero
Calve Yofresh
Ligeresa Original
Amora Mayonaisse de Dijon
Globus Majonez Real
Calve Mayonaise
Calve Sabor Casero
Calvé Belgische mayonaise
Ligeresa Original
Hellmann's Light Mayo
Hellmann's Vegan Mayo
Globus Majonez Real
Calve Sabor Casero
Calvé Belgische mayonaise
Amora Mourtarde fine & forte
Amora Mourtade mi-forte
Calve Yofresh
Amora Mayonaisse de Dijon
Hellmann’s Real
Globus Majonez Real
Hellmann's Vegan Mayo
Heinz mayo
Heinz vegan mayo

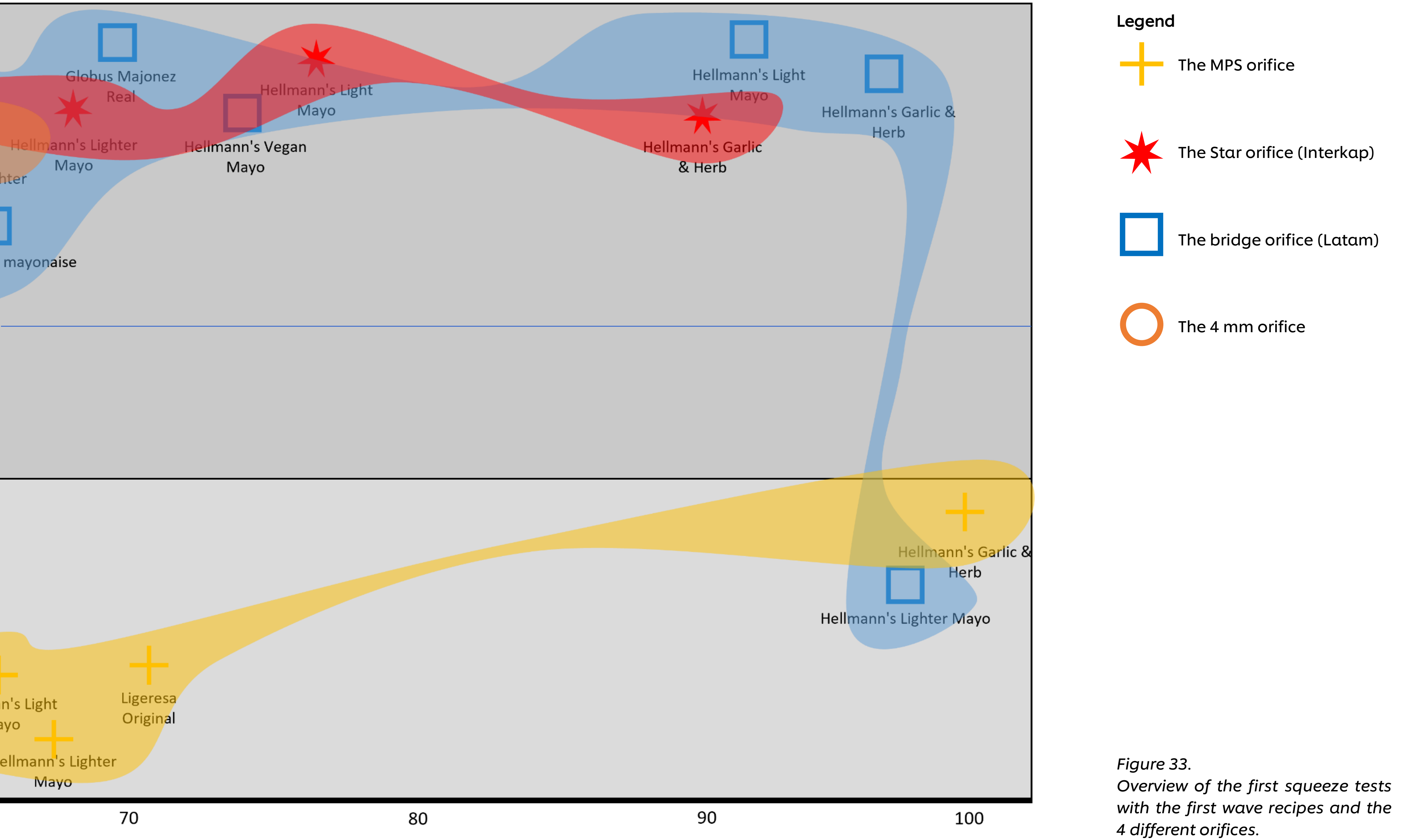


Figure 33.
Overview of the first squeeze tests with the first wave recipes and the 4 different orifices.

2.12 Observations

The average results of the squeeze tests is that the Latam closure requires the most squeeze force, the MPS closure only with some recipes and the 4 mm orifice the least, Table 7. But the MPS closure is the cleanest, something that should be improved with the 4 mm orifice. The star and Latam closure are obviously the messiest, Figure 34.

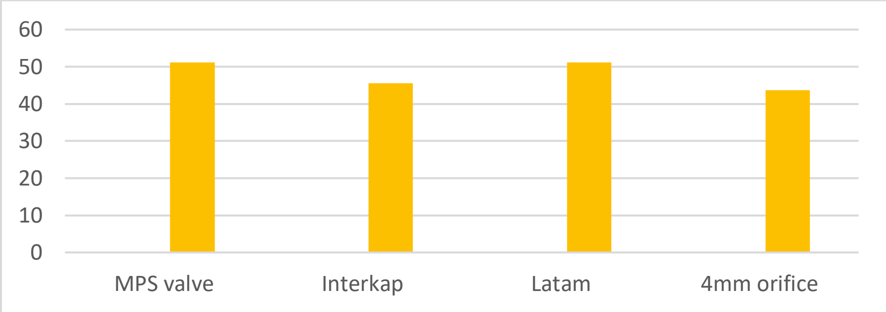


Table 7. Average dosing force with Hellman's real recipe

Figure 34. Cleanness inside the closure after squeezing (L-R, MPS=1, Interkap=5, Latam =4, 4 mm orifice = 3.)

The cleanness and dosing force

During the squeeze tests, it was clear that the Latam cap with the bridge design, was not performing up to standards. It took overall way more force to dose the right amount, was often leaking a bit of product after dosing and scores with most recipes a negative score in case of cleanness (average score 4 or 5 = messy).

After these tests, it was clear that the negative pressure that is created (explained in Paragraph 2.11) and a clear pathway from the orifice to the inside of the bottle that will be used with that negative pressure is an important variable. This is because the bridge is blocking the path for the product to be sucked back inside by the negative pressure, Figure 35. This residue will increase the chance of leaking, decrease the cleanness and when dried can cause a blockage. Hindering the path from the orifice to the inside of the bottle is thus unwanted.

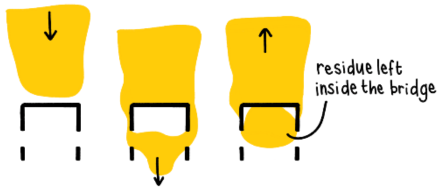


Figure 35. Residue stays in the bridge design.

The Interkap star orifice has also not the desired dosing experience. Although the required dosing force is more acceptable, the cleanness is not. This is because the star orifice contains more surface area for the product to stick to, causing an unclean pin and orifice. The 4 mm orifice is interesting when considering the dosing force. On average less force is needed than with the current orifice, the silicone valve. However, the cleanness of the 4 mm design, is not yet up to standards, most test results score a cleanness of 3 and higher, which is not desired.

Another observation is that the cleanness of the orifice is determined by the cleanness of the pin and waterproof ring when shaking and standing on top of the cap.

While performing the squeeze tests, it was noticed that the orifice got dirty because, during the shaking of the bottle, the product leaked onto the pin. When after dosing the cap is closed, the residue gets onto the orifice, resulting in an unclean orifice when the cap is opened next time, Figure 36. This means that besides the design of the orifice, the design of the pin is an important variable. More specifically, the way the pin fits into the orifice, to prevent leaking while standing on its cap and during the shaking.

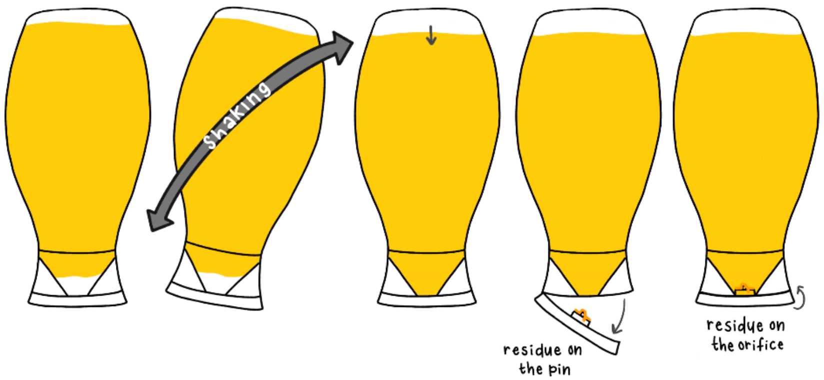


Figure 36. The residue on the pin makes the orifice dirty.

Another observation is that the cleanness of the orifice is determined by the cleanness of the pin and waterproof ring when shaking and standing on top of the cap. When the pin and/or waterproof ring are covered in product, it gets transferred to the orifice when the cap is closed.

The valveless Heinz closure

As mentioned earlier, the Heinz valveless closure was also tested as a benchmark. The Heinz valveless closure with a 4 mm orifice is tested with the Heinz bottle and Heinz mayonnaise and Heinz vegan mayonnaise. In the overview in Figure 33, it is clear that the valveless Heinz closure is a competitor to the wanted result, it is in the far left bottom corner. The closure results in a low dosing force with good cleanness inside the closure after squeezing. The question is, what is the difference between the MPS and the valveless Heinz closure?

The first difference can be seen in the plotted graph of the squeeze results. The squeeze tests are performed with a Zwick machine, this software plots a graph of the stress (N) distributed over the squeezing time (s). Closures with a valve have a different graph than those with a valveless design. Valved closures have a graph with a peak at the moment that the valve is opened, Figure 37. These lines have a lot of wobbles in them, this is the result of air being dosed.

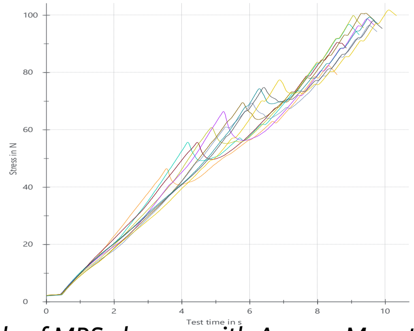


Figure 37. Graph of MPS closure with Amora Mourtarde fine & forte

The valveless Interkap closure with the star orifice, experiences the same wobbles due to air bubbles, but does not have the high peak at the moment of starting to dose. This is due to the fact that this closure is valveless, Figure 38.

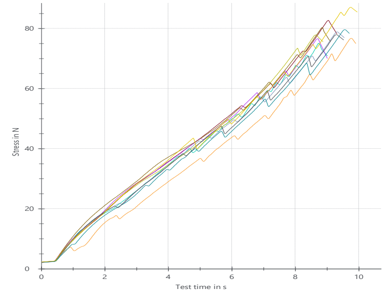


Figure 38. Graph of Interkap closure with Amora Mourtarde fine & forte

The valveless Latam closure with bridge orifice experiences a lot of small wobbles in the dosing graph. This is the result of the product that has to move around the bridge, Figure 39.

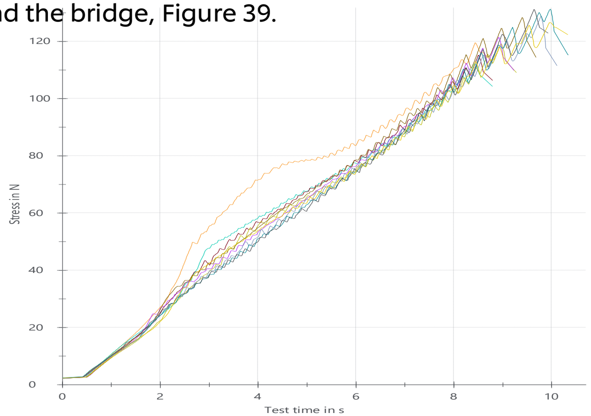


Figure 39. Graph of Latam closure with Amora Mourtarde fine & forte

The valveless closure with 4 mm orifice has a similar graph to the Latam closure, this is probably the reason of having the same closure only a different orifice, Figure 40.

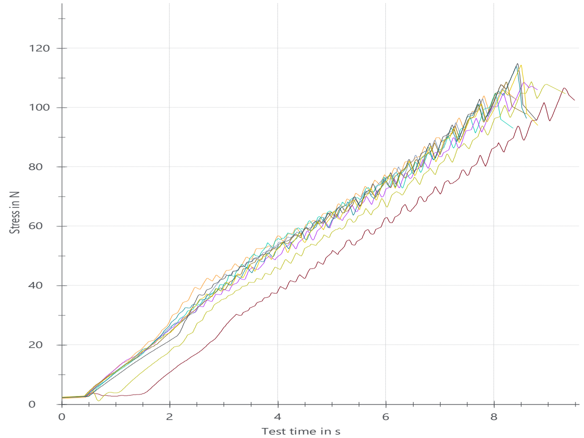


Figure 40. Graph of 4 mm orifice closure with Amora Mourtarde fine & forte

The valveless closure of Heinz does not have these, these graphs are straight lines with a little peak at the end of the squeeze, Figure 41.

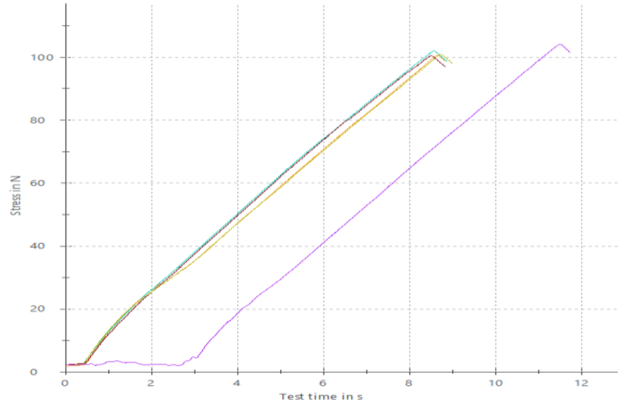


Figure 41. Graph of valveless Heinz closure with Heinz mayonnaise

In Figure 40 and Figure 41, can be seen that one line is more to the right in the graph than other lines. This can be detected in multiple graphs. The reason for the delay of one line is the result of air inside the bottle. When the bottles is shaken improperly, the Zwick machine is squeezing for some time before product is coming out. This is the delay that can be seen in the graphs.

Another difference between the MPS and the valveless Heinz closure is the looks of the inside of the closure after squeezing. The MPS closure has residue all over de valve, Figure 42. Whereas the valveless closure of Heinz has residue mostly around the orifice, but not on top of the orifice.

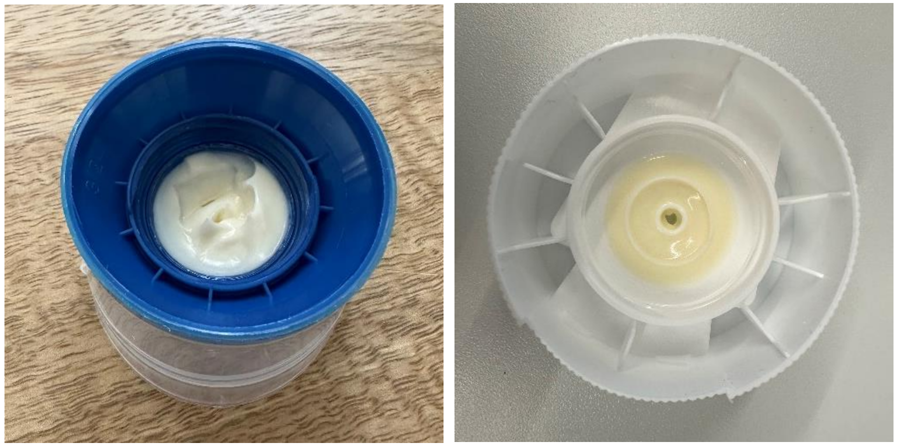


Figure 42. looks inside the closure after squeezing (MPS Left – Heinz Right)

It is likely that the inside design of the valveless Heinz closure is the reason for this. But the question is, is this the reason for the good cleanness inside the closure after squeezing? Or why else is this feature added? This is researched in Chapter 5.

2.13 Conclusion

The first squeeze tests

From the first squeeze tests can be concluded that the 4 mm orifice is a promising orifice design since the dosing force of this closure is in the desired range. A round orifice is probably preferred since it has least wall area inside the orifice (circumference) in relation to the surface area (the opening of the orifice). Less amount of wall area will decrease the chance of leaking. However, this 4 mm orifice does not score that great in case of cleanness since the lid design is not yet sufficiently designed. This means that a round orifice design will only be a viable solution if the cleanness of the inside of the cap can be improved. This is something that should be researched in the development phase.

The Heinz valveless closure

The Heinz 4 mm orifice bottle with Heinz mayonnaise and vegan mayonnaise has been tested as competitor benchmarking. Important to keep in mind that this test cannot be completely compared to the other tests since there is all variables are different. Different closure, bottle, and recipe. At this stage of the project it was done deliberately, to know how the competitor scores in relation to the tested closures. When mapped with the test results, the Heinz 4 mm orifice design, does not only require a light dosing force, but it also has a good cleanness score. This Heinz valveless orifice design will be further analysed in Chapter 4, develop.

The dosing graphs

As mentioned earlier, all dosing graphs are very different, but the largest difference is with the Heinz valveless closure. The lines are more straight and with less wobbles. Since the test results of the Heinz closure are desired, it could be promising to design a closure that will result in a graph line comparable to the Heinz valveless closure ones.

These research steps are important steps towards the final design scope. Initially thought that designing an orifice with the right dosing force will be the challenge, however designing one that maintains cleanness will be more challenging. To finalise the design scope, the project's important variables are mapped in the next Paragraph.

03

Define

Scoping the boundaries of this project.

In this chapter the variables that influence the dosing experience are determined and the challenges linked to these variables are explained. These are important to adjust the scope, finalize the assignment and understand the possibilities for the next phase, Develop.

3.1 The variables influencing the dosing experience of flip-top closures

There are four main variables that determine the dosing experience, which include the cleanness after dosing and the required dosing force:

1. The design of the bottle
2. The recipe inside the bottle
3. The design of the orifice (inside and outside)
4. The design of the pin

The design of the bottle

The design, material, and thickness of the bottle determine the amount of negative force that can be created after squeezing to suck back the product to prevent leaking. It also has an influence on the dosing force, when the packaging is easier to squeeze the required dosing force will be less. However, redesigning the bottle is not the initial scope of this project. When other variables are not realising the wanted results, the design of the bottle could be an opportunity. Until then, this variable is fixed.

The recipe inside the bottle

The recipe inside is fixed, but important to include because it determines certain aspects of the dosing experience. The first wave of recipes differs from each other regarding density, viscosity, in some cases syneresis and chunks, as described in Paragraph 2.5. The density is the amount of mass per unit of volume, a higher density means that the same amount of volume will be heavier. It is likely to suspect that higher-density products are more likely to leak since there is more pressure on the bottom.
As previously described, viscosity is the unit to announce how viscous a liquid is. Viscosity is directly related to the chance of leakage. Since a more watery product is more likely to leak. This is why products with syneresis are challenging, since they separate water with a very low viscosity.

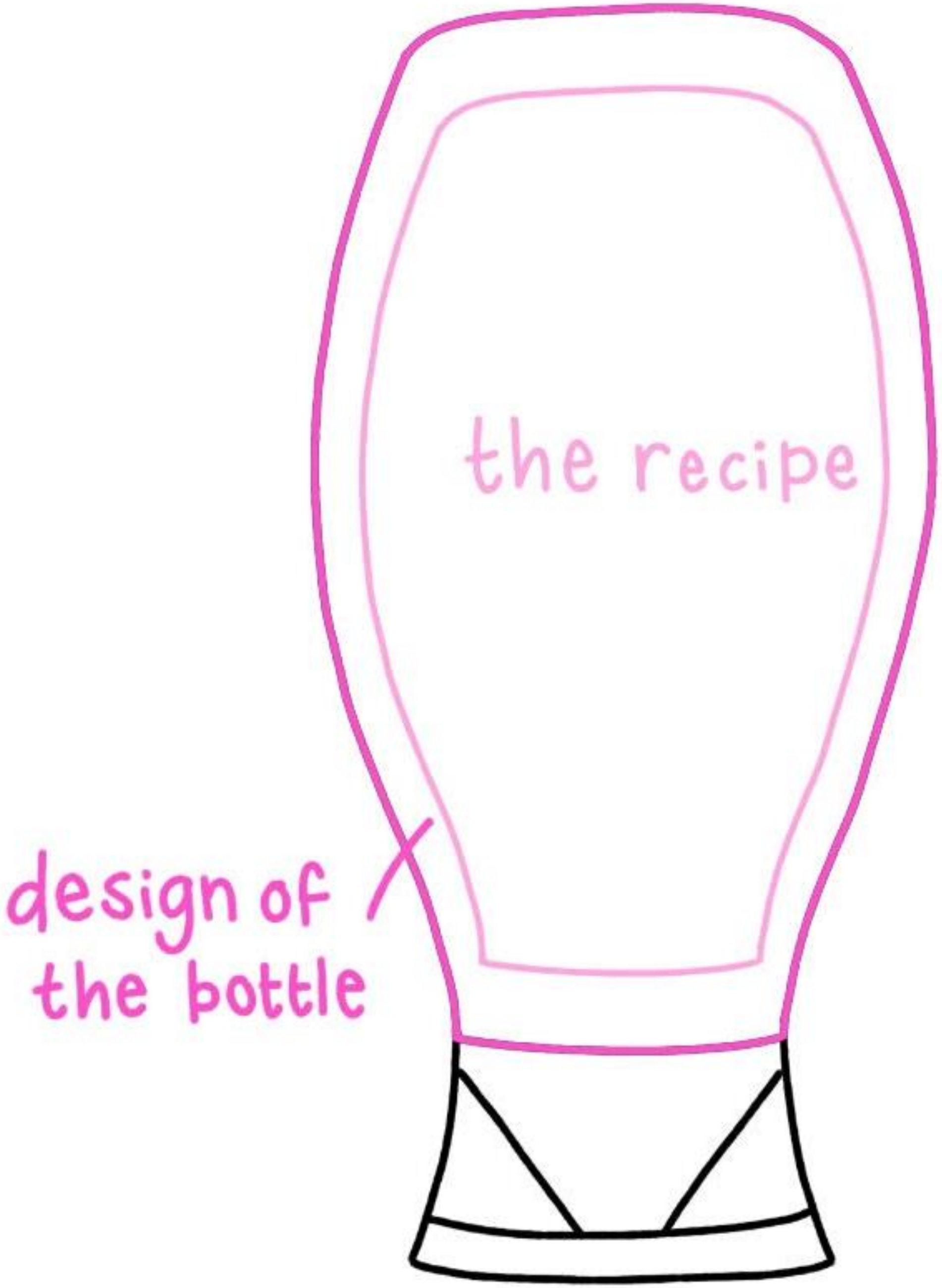


Figure 43. Variable 1 and 2

The design of the orifice

The design of the orifice will impact the required dosing force and cleanness after dosing. The three aspects of the orifice that are influencing this are the shape of the orifice, the width of the orifice, and the length of the orifice. When the shape of the orifice is changed to one with more surface area, the cleanness after dosing will decrease and the required dosing force will increase. When a larger diameter orifice is used the amount of required dosing force will decrease and the chance of leaking will increase. When the length of the orifice is increased, the required dosing force will increase, but the cleanness will also increase. This is because the product will have more resistance to overcome. This is further explained and researched in Chapter 5. Therefore, the design of the orifice consists of multiple aspects:

1) The shape of the orifice.
2) The diameter/dimension of the orifice.
3) The length of the orifice, this can be more than just the wall thickness of the closure.

The design of the pin

The design of the pin will determine the cleanness of the orifice after dosing. The shape of the pin itself is not the most important, but the way that the pin will fit into the orifice is crucial. This will directly influence the cleanness inside the cap. What is related to this part is the waterproof ring, this ring helps minimize the leaked product. If some residue will escape the pin, the waterproof ring makes sure that the leaked product will not move outside of this area. Thus controlling the cleanness inside the closure.

As mentioned in paragraph 2.6, in a closure with a valve, the orifice connects to the waterproof ring. Whereas a closure without a valve the orifice is connected to the pin. Designing these to work together could ensure cleanness inside the closure after dosing.

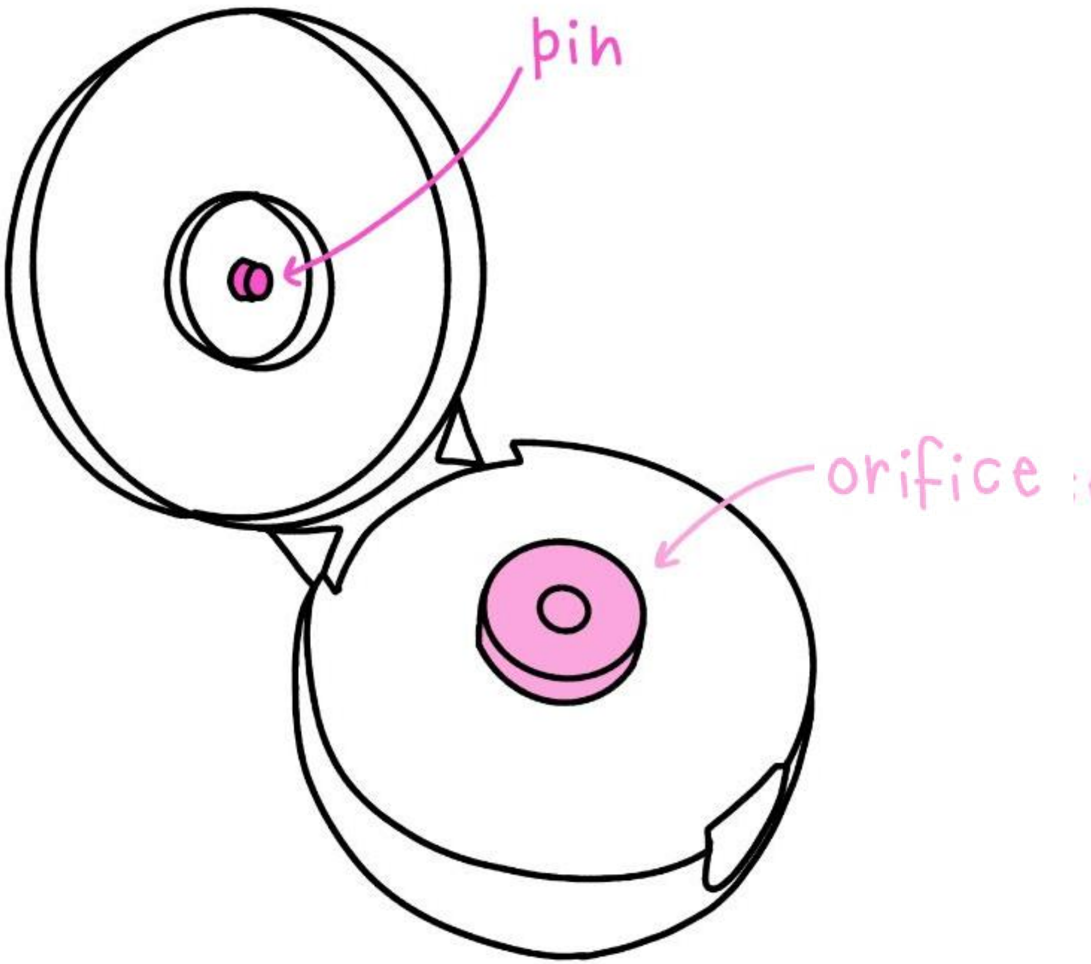


Figure 44. Variable 3 and 4

The four mentioned variables are not all open for optimization. The first two of these variables are preconditions, the design of the bottle and the recipe inside the bottle are fixed. The second two variables are the design space, these two variables need to be changed to find a balance that will suffice the given problem.

As mentioned, the variables have an influence on the dosing experience, which can be split into the dosing force and cleanness inside the closure after squeezing. Below is an overview of the variables and the influence that they have on the dosing force or cleanness.

	Part/feature	Variation	Cleanness	Dosing force
Preconditions	Recipe	Low density	Increase	Decrease
		High density	Decrease	Increase
		Low viscosity	Decrease	Decrease
		High viscosity	Increase	Increase
		With syneresis	Decrease	Decrease
		With particles	Increase	Increase
The design space	Orifice	Small diameter	Increase	Increase
		Large diameter	Decrease	Decrease
	Pin	Tight tolerances	Increase	-
		With cavity	Decrease	-
	Path to the bottle	The path is clear, no blockage	Increase	Decrease
		The path is blocked (bridge design)	Decrease	Increase

Table 8. Overview of variables and their influence.

Most variables have a different effect on the cleanness and dosing force. When one is improved, the other one is worsened. This is a challenge. What will be the right division between those, to ensure a good dosing force, while maintaining the cleanness inside the closure?

Clean cut-off

An aspect that was concluded important to the cleanness inside the closure is a clean cut-off. This means that the product flow stops immediately after the dosing stops, and the product stops with a clean orifice. Meaning there is no residue blob left at the orifice. The clean cut-off is explained in Figure 45.

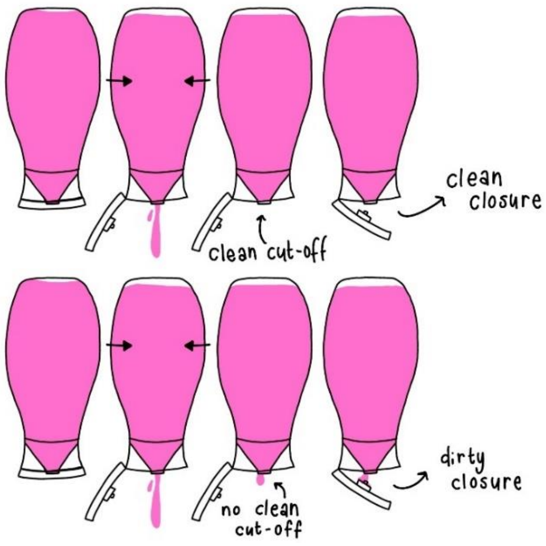


Figure 45. Explanation of the clean cut-off (top) and no clean cut-off (bottom).

When a closure does not have a clean cut-off, there is a larger chance of a dirty inside closure. Since the blob that will be at the orifice will make the pin and maybe more parts inside the lid of the closure dirty.

Spattering

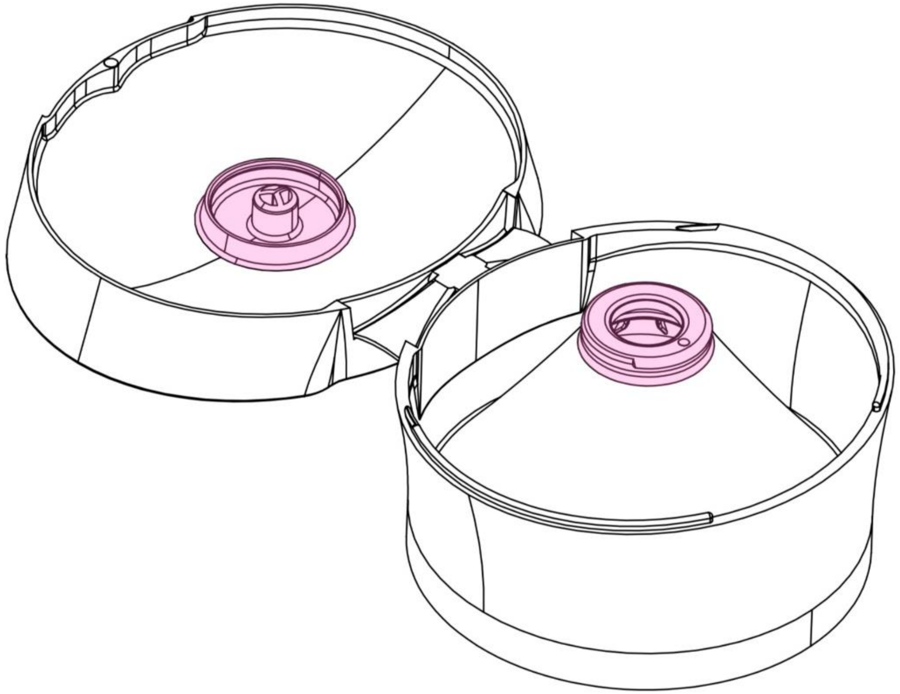
Another thing that is related to the variables, is spattering. When air first escapes the closure, the product will experience spattering. Spattering also decreases the cleanness inside the closure after dosing.

3.2 The design project scope

The scope of this design project is to design a closure for the Marco Polo Squeeze bottles of Unilever that is fully recyclable in line with the new European Packaging and Packaging Waste regulations for 2030 (*Packaging Waste*, 2023), and more specifically in line with the French and English legislation for 2025 (*LOI N° 2020-105 Du 10 Février 2020 Relative À La Lutte Contre Le Gaspillage Et À L'économie Circulaire - Dossiers Législatifs - Légifrance*, n.d.) (King's Printer of Acts of Parliament, n.d.). This solution should be achieved without changing the bottle, the outside dimensions of the closure, the aesthetics of the closure, the cleanness, and the dosing experience. The new closure should be compatible with all Unilever dressings recipes, but mostly the French recipes since this is the first scope for Unilever. These recipes are ranging from mayonnaises and Dijon mayonnaises to mustards. The specific recipes can be found in Appendix V. Firstly, the scope of this project was without ketchup, but later the Investor Board of Unilever was interested in also adding ketchup to the scope, this can be found in paragraph 5.11. Because of the set design project and restrictions, the design space of this assignment is small. In Figure 46 can be seen that the design space in the first scope is only 0.65 cm^3, if the desired result cannot be achieved, the design space could be extended after consultation.

The opportunities

Certain results from the first round of Squeeze tests relate that there are possibilities to achieve the desired solution. Although the current MPS closure does not suffice the new PPWR 2030, it does fit all the requirements set by Unilever. However, the squeeze force is on the higher side, as can be seen in Figure 33. This redesign gives the opportunity to reduce the average squeeze force. As described in paragraphs 2.11 and 2.12, two main observations are in need of further research: 1. The shape of the orifice should be round, this shape has the least wall surface (circumference) compared to the surface area. This helps with reducing the chance of leaking. 2. The path from the exit spot, the orifice, to the inside of the bottle should be clear. When this is blocked, the chance of leaking is higher.



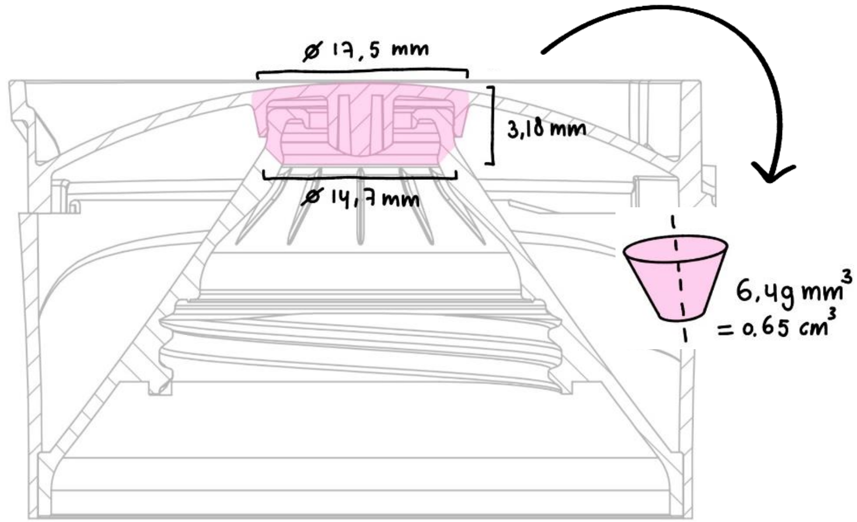


Figure 46. The design space

3.3 The project brief

Paragraph 1.4 has mentioned the assignment as given, since then the current closure, the three other closures (Interkap, Latam and 4 mm orifice), and other closures on the market are researched. This helped to map the variables, but more importantly, helped to understand the assignment and thus the problem better. This has resulted in an assignment as perceived.

The main challenge is not just designing a closure that is completely recyclable, with a similar dosing experience and lower dosing force, but also maintaining cleanliness inside. Removing the valve can decrease the dosing force and enhance the dosing experience, but the focus should be on creating a 100% recyclable closure with a similar dosing experience and most importantly focusing on the cleanliness inside.

The research up till now has led to the final assignment: to design a new sustainable closure for the Marco Polo Squeeze bottles of Unilever, that is compatible with the first wave recipes, ensures the same dosing experience without changing the outside dimensions and aesthetics of the current closure.

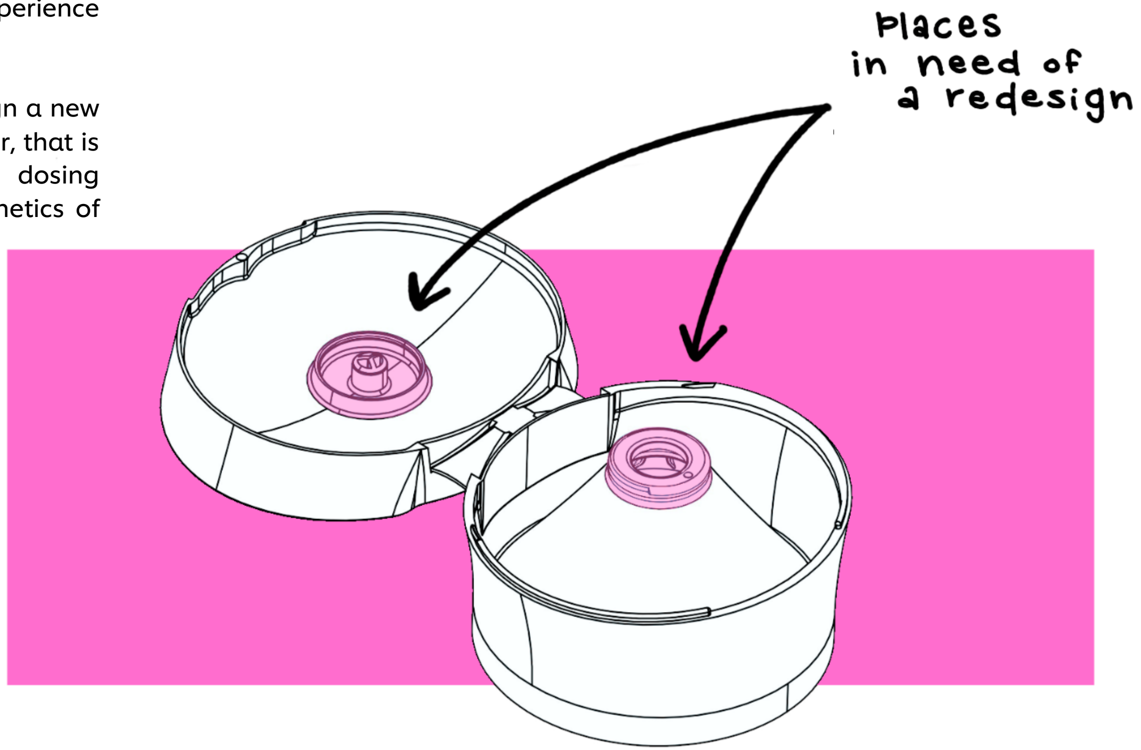


Figure 47. Places in need of a redesign highlighted

04

The project overview

This chapter shows an overview of the project process to develop the new sustainable valveless closure for Marco Polo Squeeze bottles. The process is a structured process, each time multiple variations are tested and a new feature can be determined until the new closure is fully developed.

4.1 The challenge

As mentioned in paragraph 1.4 and paragraph 3.2, the desired design has a lot of limitations, because of set requirements. But as mentioned earlier there is also room for some improvements. These opportunities are important to consider in the design process. The mentioned limitations are challenging, they restrict the design process and possibilities.

The biggest challenges are 1) not changing the outer dimensions and aesthetics of the current closure. This means that, as noted in paragraph 3.2, the design space is only 0.65 cm^3. 2) In combination with Requirement A.022, that the new to-be-designed closure should fit with "all" recipes of Unilever, is provocative.

In this chapter, the challenge is tackled. By using a structured design process, ruling out solutions that will not work, fluid dynamics, and iterating with prototypes the desired solution is developed.

4.2 The design process

As stated above, the design process was not a creative process. The process is constructed of multiple iterations, all with its own challenge to tackle. With each iteration, a design is chosen that fits the set requirements best, and more importantly, designs that will not work are excluded. Figure 48 is an overview of these iterations and it is visible what is chosen in which iteration. The overview can be read as a Morphological chart.

On the next two pages, the design path is made visible, Figure 49. Each step is explained with which test method is tested, what conclusions were drawn, what important observations were made, and what part of it, is a feature in the final design.

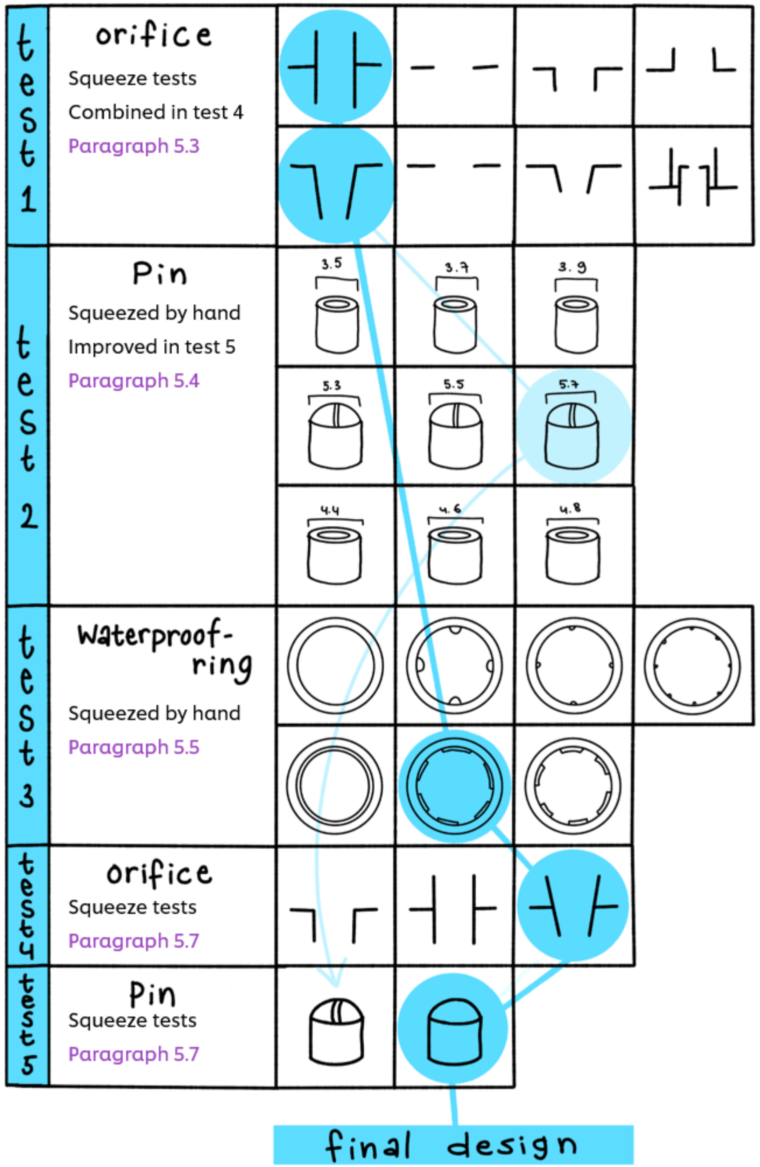


Figure 48. Morphological chart of the iterations

Paragraph 2.9

Market research

- Mapping existing closures
- A design inside the closure
- Larger diameter

Paragraph 2.11

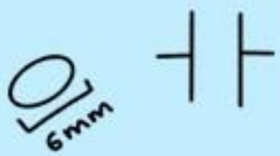
The four closures

- UMA-6341.02 – Squeeze test
- Round orifice
- A clear path to bottle
- Importance of pin design
- A design inside the closure
- Round orifice

Paragraph 5.3 (Test 1)

3D-printed inserts

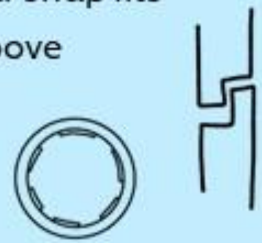
- UMA-6341.02 – Squeeze test
- Tube decreases the chance of leaking
- Tube increases the dosing force
- Larger diameter decreases the dosing force
- Tapered design improves the clean cut-off
- A tube as part of the orifice design
- Diameter of the orifice – 6mm



Paragraph 5.5 (Test 3)

Pin designs

- Squeezing by hand
- Having the right tolerances is important
- Annular snap fits
- Lip-groove



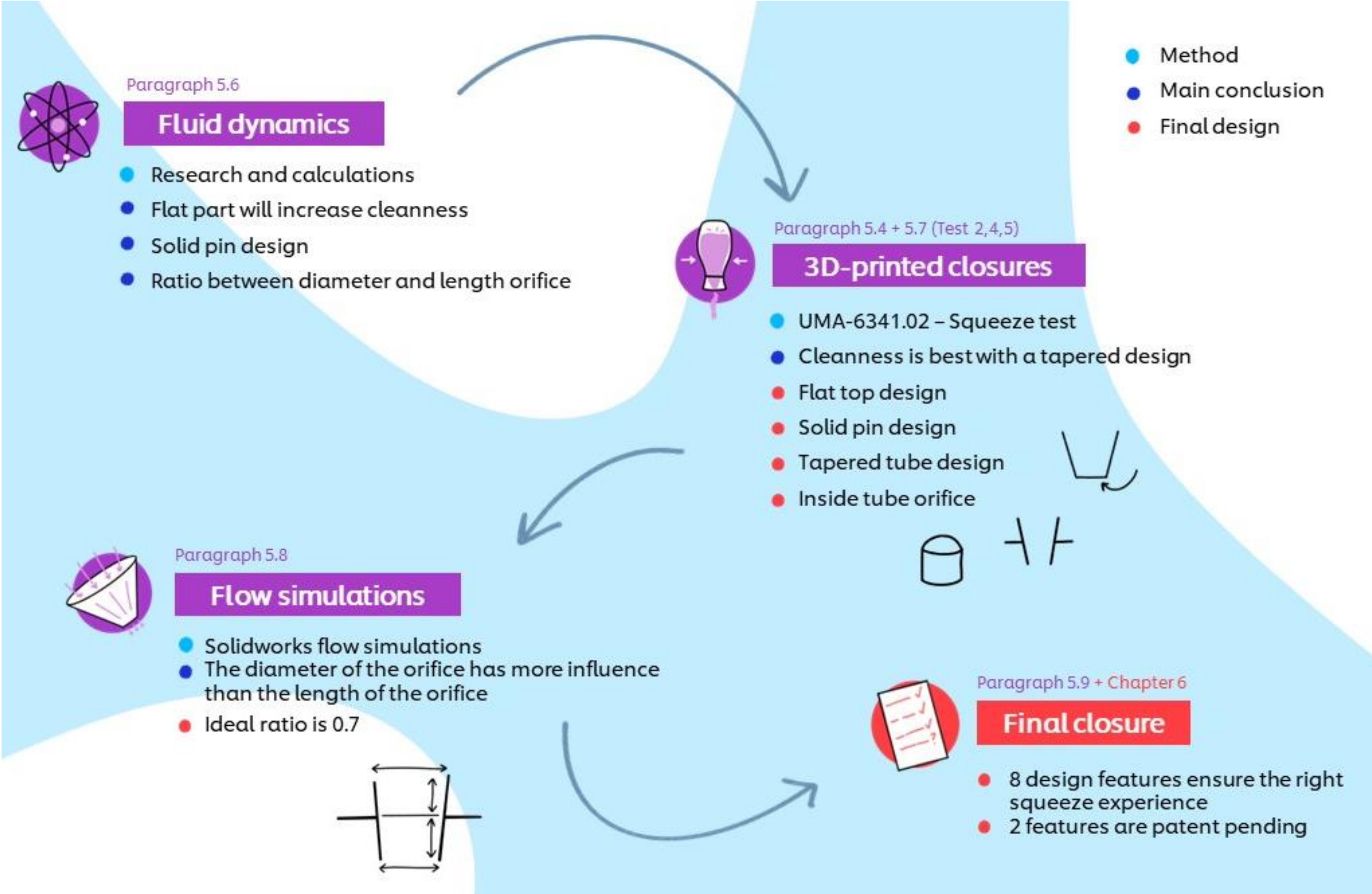


Figure 49. Project overview

05

Develop

This chapter explains the design project of developing, testing, and iterating the new valveless closure for the MPS bottles.

5.1 Injection moulding

Besides having a small design space, the production technique and material are also fixed. Thus reducing the possibilities. The new valveless closure should be designed so it can be injection moulded. This means the design should follow the injection moulding rules. The most important one to take into account while designing is that the design should be drafted. So it will come out of the mould. Standard injection moulding uses two moulds (the core and the cavity) to make a part, one part moves away and the design is ejected with an ejector bar, Figure 50.

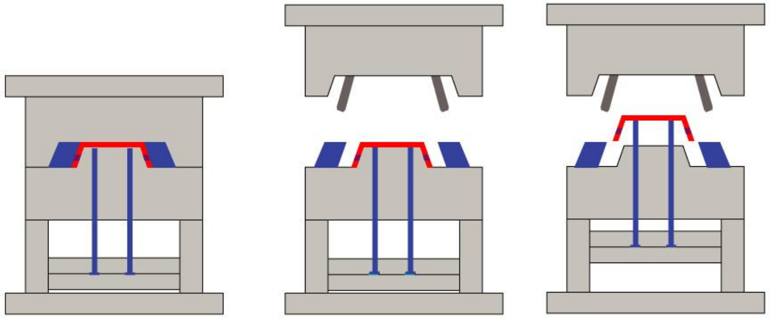


Figure 50. Injection moulding (Een Spuitgietproduct Ontwerpen | Hoe Doe Je Dat? | Flow Products, 2021)

Usually, the design is optimized for a particular production technique after the design is finalized. Considering all these rules can reduce the creativity or be overwhelming because of the number of rules. But because of a background in Industrial Product Design – Rotterdam, injection moulding is a familiar technique. Most rules are therefore naturally taken into account during the coming design phase. This influences the design positively, knowing that a design that will work after testing can also be produced. There will still be some altering needed, but no drastic changes.

Besides making sure the design can be ejected from the mould by having it drafted, it is also important that the design doesn't have an undercut, Figure 51. Something that is not always easily changed. An undercut in the design will result in a product that is not able to be removed from the mould.

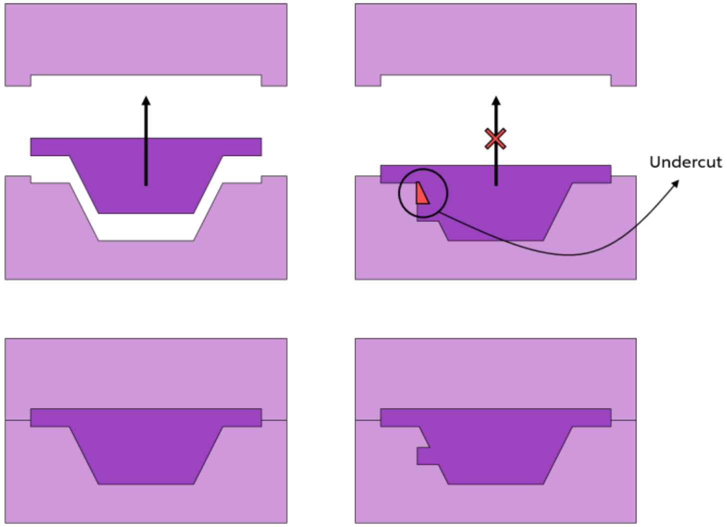


Figure 51. Ejection is restricted due to an undercut

An undercut can sometimes be solved, by creating an extra hole to make sure the part can be demoulded, Figure 52. But this is not always possible, therefor it is preferred to have a design without large undercuts.

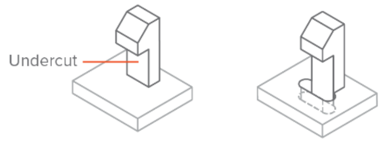
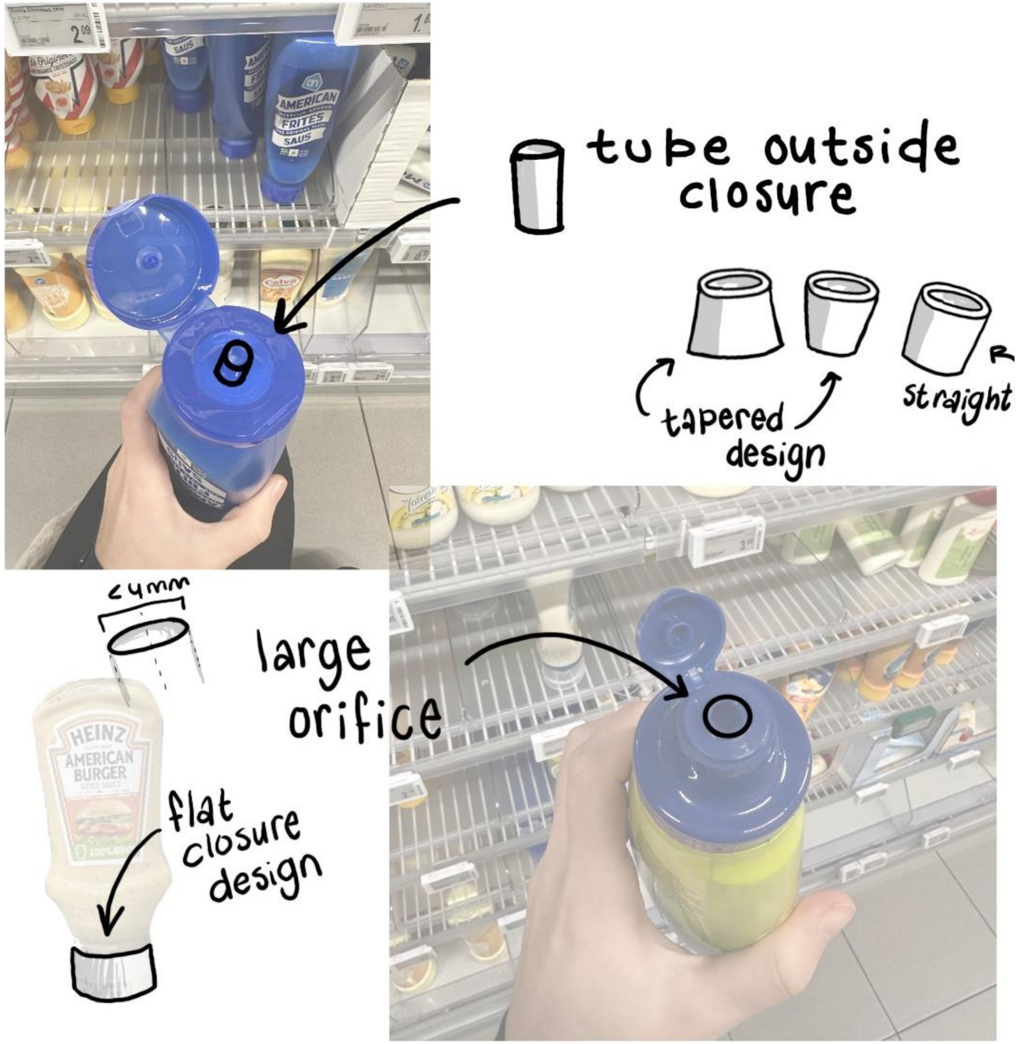


Figure 52. Solving an undercut (FACFOX,INC., 2020)

5.2 Inspiration

As mentioned in paragraph 2.9, there are many different caps on the market, all with their own orifice, pin, and waterproof ring design. The combination of these three is important for the dosing experience and cleanness. In this chapter, a fitting solution will be designed, these next two pages are inspiration for this design process.



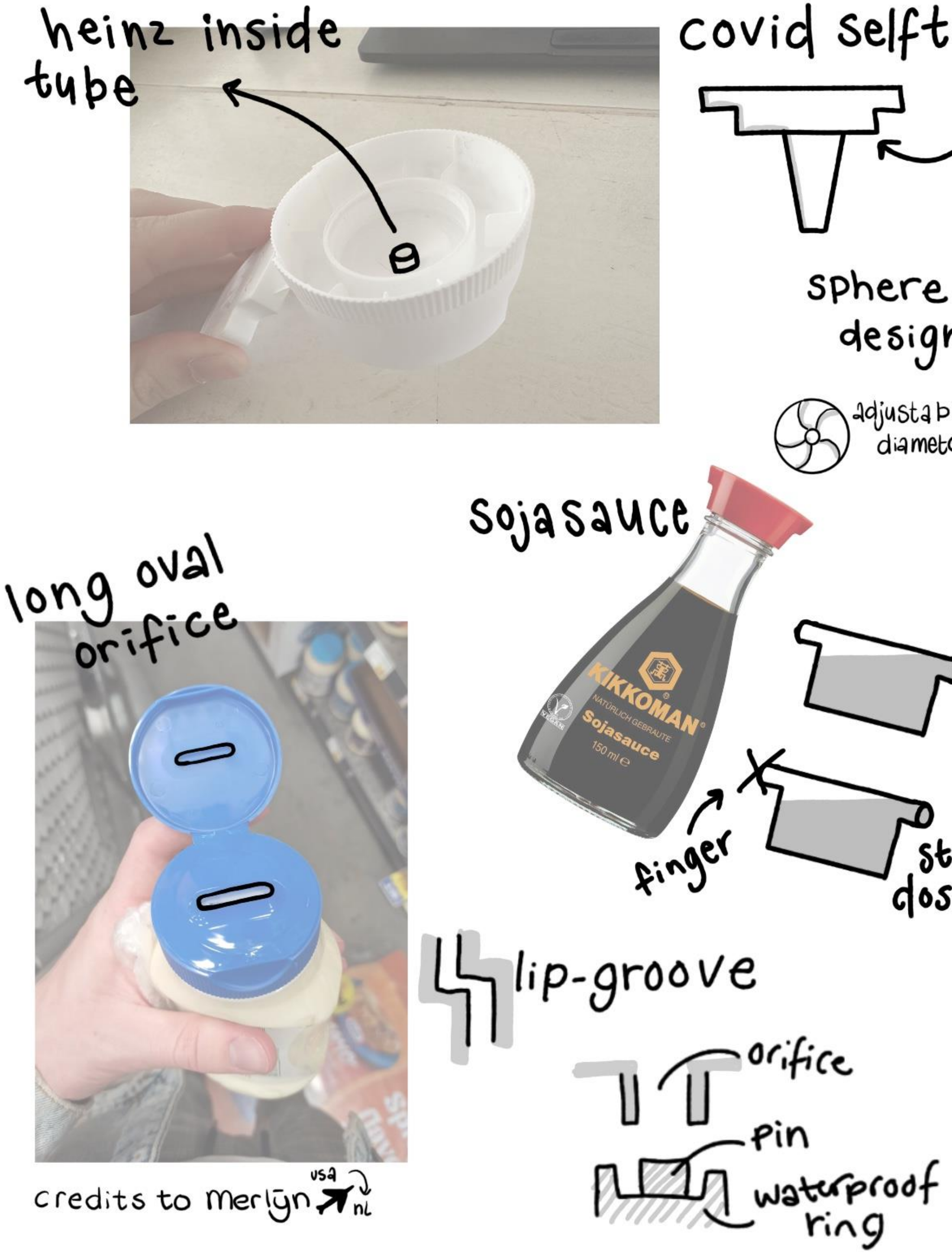
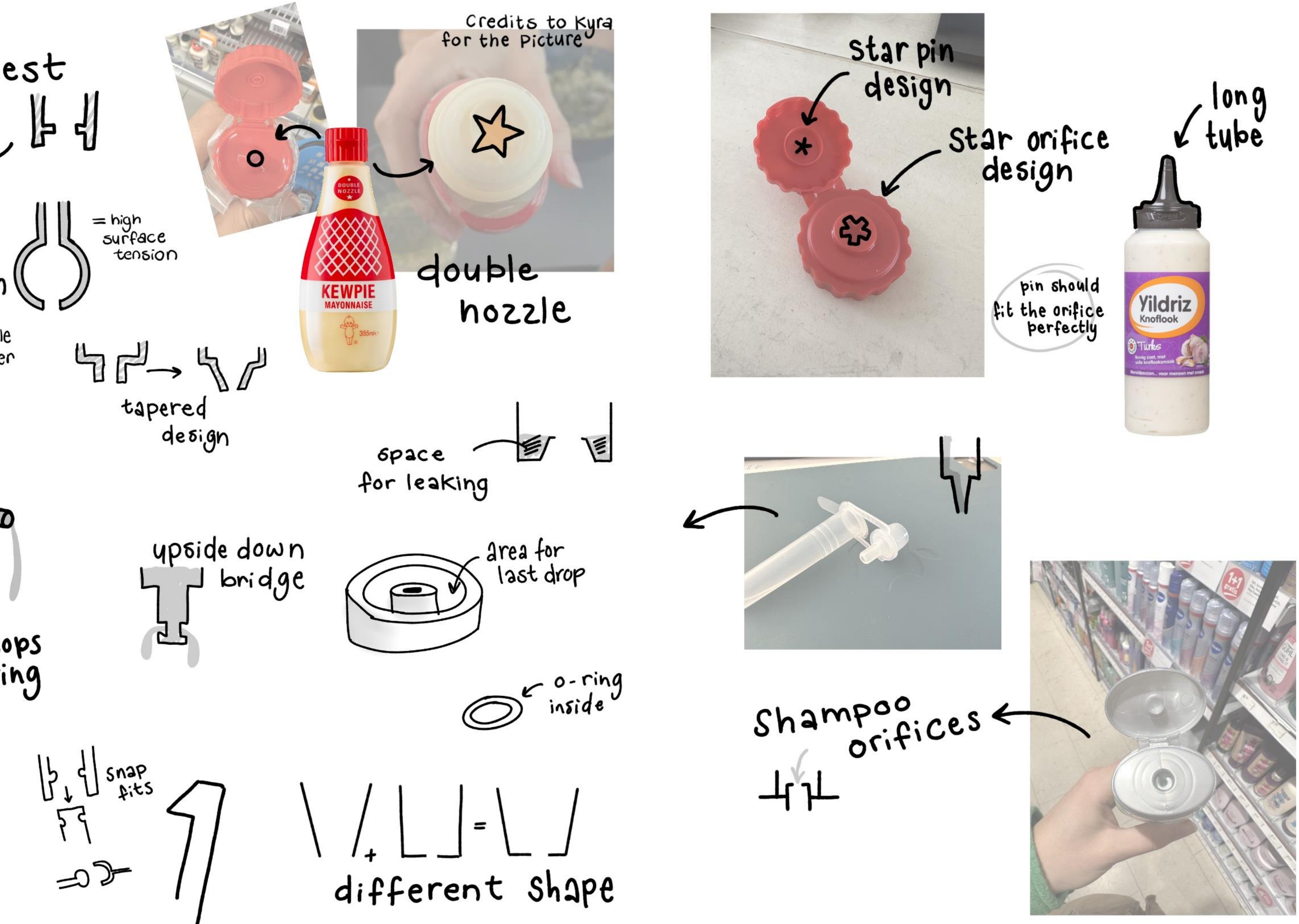


Figure 53. Inspiration overview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KEWPIE
MAYONNAISE
355ml
double nozzle
tapered design
star pin design
Star orifice design
pin should fit the orifice perfectly
long tube
Yildriz
Knoflook
Turks
space for leaking
upside down bridge
area for last drop
o-ring inside
ops
ing
snap fits
different shape
Shampoo orifices

5.3 Prototyping and testing new orifices

An important observation during the first squeeze tests was that the inside of the Heinz closure looks different after squeezing than that of the MPS closure, as described in paragraph 2.9. The MPS closure has a tapered design whereas the Heinz closure has a flat design. The Latam closure has the same flat design as the Heinz closure. To be sure of the influence of this difference, the same orifice inserts are designed for the MPS closure and Latam closure.

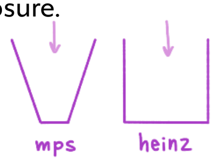
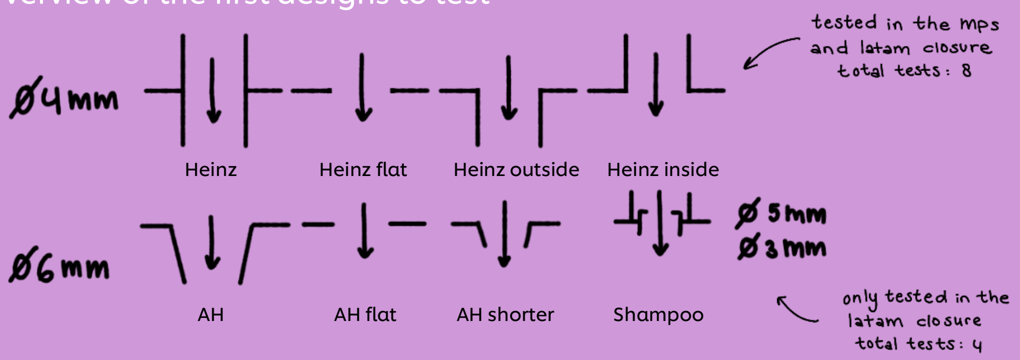


Figure 54. Tapered MPS design (L), flat Latam design (R).

As can be seen in Figure 33 in Paragraph 2.11, the Heinz closure scores impressively well regarding the required dosing force and cleanness. The question is, what part of the Heinz orifice design ensures this? Does this regard the diameter, the flat closure design, or the inside tube? By testing variations of the Heinz design in the MPS and Latam cap, this can be determined. When analysing existing closures, two closures that are on the market stood out. 1) The Albert Heijn's closure used for frites sauce and 2) the orifice used in most closures used for shampoos. To test these designs on dosing force and for the AH orifice specific, regarding the influence of the tube on the dosing force. These are modulated as inserts only for in the Latam closure since the diameter of the design was too large to fit as an insert into the MPS closure.

Overview of the first designs to test



The dimensions and specifics of the designs can be found in Appendix VI.

The key information

Research questions and goal: Finding out what the influence of these variables are on the dosing force. 1) What influence has a tube as part of the orifice on the dosing force? 2) What is the influence of a tapered design closure in comparison to a flat design?

Method: Squeeze test UMA-6341.02
Recipe: Amora mayonnaise de Dijon
Prototype: 12 closures with designed inserts

Observations:

- Since the inserts are glued into the closures, some measurements were less accurate, since the inserts could come loose after some testing.
- With the large diameter variations (AH, AH flat, and AH shorter) the cut-off was cleaner.

Conclusions:

- Having a tapered design improves the clean cut-off.
- Having a tube as part of the orifice design helps with increasing the resistance. This also increases the dosing force, but decreases the chance of leaking.
- Having a larger diameter, 6 mm instead of 4 mm, reduces the dosing force.

Final feature: A feature of the final design of the orifice should be 1) a large diameter to reduce the dosing force and improve the clean cut-off. 2) a tube as part of the orifice design to improve the cleanness.

Next steps: Prototyping pin designs to test with these orifices.

Figure 55. tested prototype inserts in the MPS closure (Heinz designs)

Figure 56. tested prototype insert in the Latam closure (Heinz, AH and shampoo)

Summary of the test data

Below in Table 9 and Table 10 is the summary of the squeeze data visible.

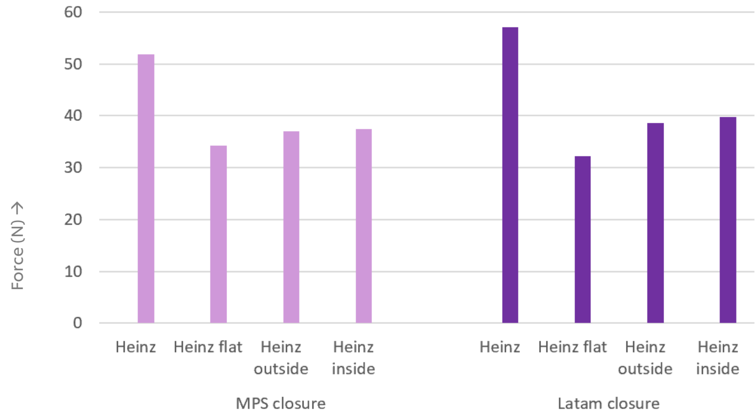


Table 9. Squeeze data of Heinz orifice designs in MPS (L) and Latam (R).

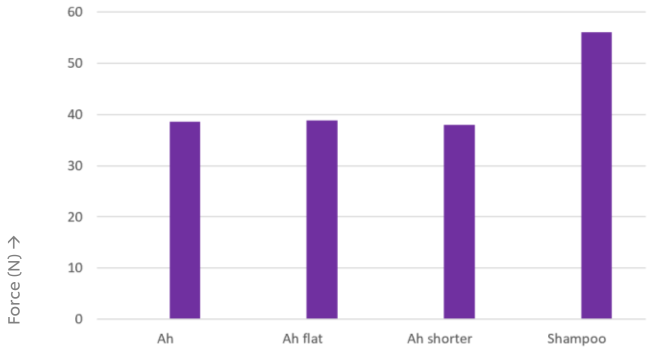


Table 10. Squeeze data of Ah orifice design and shampoo design in Latam.

5.4 A leakproof design part 1

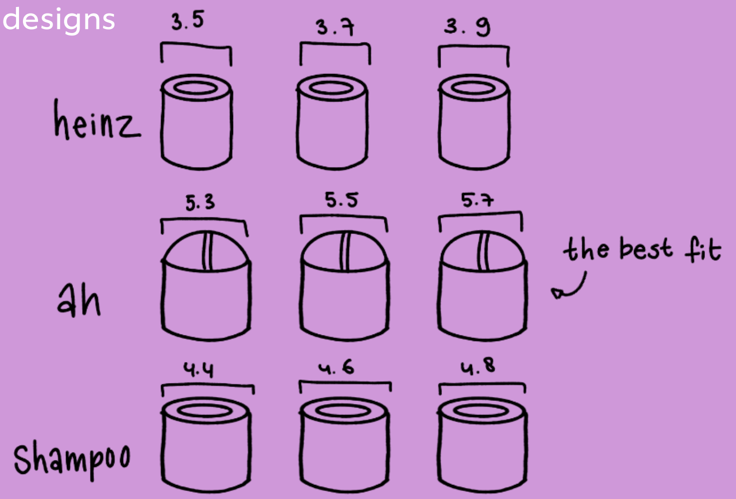
Pin designs

The previous prototypes of orifices were designed to test the difference in dosing force between these different variants. It can be concluded that reducing the dosing force is not the biggest challenge, enlarging the orifice diameter will do the trick. The more challenging is the cleanness inside the closure after squeezing. Besides the design of the orifice, the design of the pin, and especially the way that this fits into the orifice determines the cleanness of the inside of the closure after squeezing.

As mentioned in Figure x, most pin designs are the same of valveless closure. They fit inside the orifice and do not have a unique feature. To ensure a leak-free closure, a unique new design is needed. To test these in the already 3D-printed orifices, multiple variations were printed with all different dimensions, to see what would be the best fit. Since the more accurate the fit, the less chance of leakage.

The different pin designs

In mm.



The dimensions and specifics of the designs can be found in Appendix VI.

The key information

Goal: Designing a leakproof closure

Research question: What pin design ensures cleanness inside the closure after testing?

Method: Squeezing by hand (shaking with a closed cap in between squeezes)

Recipe: Amora mayonnaise de Dijon

Prototype: 3 different pin designs, 3 variations of dimensions for validating the right fit.

Observations:

- Designing the pin with the right tolerances for the orifice is important. When this is not the case, there is a lot of residue on the outside of the pin.

Conclusions:

- The cross design with the four cavities works the best. Liquid always wants to leak somewhere, now it is controlled where it will leak -> into the cavities.

Final feature: A pin design with chambers

Next steps: Design a waterproof ring for this new leakproof closure.

Figure 57. Pin designs as inserts for in MPS or Latam lid
Figure 58. Example of a pin design in Latam closure with orifice insert

Summary of the test data

Below in Table 11 is an overview of the cleanness of the pin after squeezing by hand. The cleanness scale is the same as used with the first squeeze tests, where 1 is clean and 5 is messy.

Closure	Orifice	Pin design	1x squeeze	5x squeeze	10x squeeze
MPS	Heinz	3.9 mm	2	3	5
Latam	Heinz	3.9 mm	2	3	3
Latam	AH	5.7 mm	1	2	2
Latam	AH	5.7 mm with Cross	1	1	2

Table 11. Overview of cleanness inside the pin after squeezing.

Figure 59. Design with unsuitable dimensions (L), design with right dimensions (R)

5.5 A leakproof design part 2

Waterproof ring

The waterproof ring around the pin is meant to be a safety barrier for residue that does escape the pin. Normally, the waterproof ring is not connected to the orifice in a valveless design. This is an opportunity to improve since the barrier of the waterproof ring will be enhanced if this is the case.

A standard feature used to connect two plastic injection moulded parts is with a lip-groove, Figure 60 (Hoonkai, 2015). A lip-groove feature is used to join two parts precisely at the parting line along the walls (*Autodesk*, 2023). When used together with snap fits, Figure 61, a watertight seal can be made. Snap fits are a type of mechanical connection commonly used in plastic parts, where one part "snaps" into another part, creating a secure and tight fit (Dwivedi, 2023). There are a lot of different types of snap-fits: Cantilever, L-shaped, U-shaped, Torsion, and Annular. Some are designed to be permanent and some are non-permanent. Those temporary snap-fits are designed to be used multiple times, for parts that need to be opened and closed. This is also wanted for the waterproof ring in the to-be-designed closure.

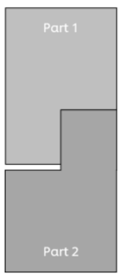


Figure 60. Lip-groove

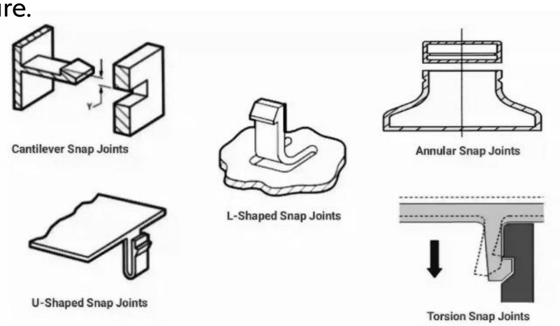


Figure 61. Types of snap-fits (Dwivedi, 2023)

Temporary snap-fit joints can be designed in two ways. 1) The beam of the snap-fit must be bent back in order to have the snap-fit released. 2) The friction of the snap-fit is minimal, with some tension in the opposite direction, the snap-fit will release. These second types of non-permanent snap-fits are commonly used in two shell parts, that are often connected and disconnected, for instance, a pen. The inside of the cap of the pen has annular snap-fit joints, so the cap will stay on the pen but can be easily removed, Figure 62.

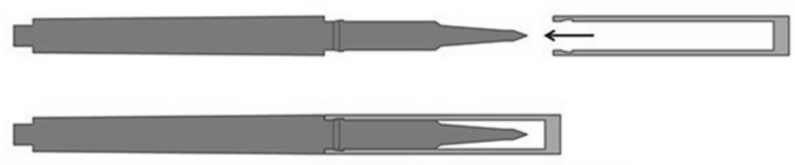


Figure 62. Annular snap-fits inside the cap of a pen (*Jourden's Classroom Website / Snap Fitting Samples*, 2022)

A similar solution could also work for the waterproof ring. To research what would be the best solution, multiple variations are modelled and 3D-printed to be tested. The dimensions and specifics of the variations can be found in Appendix VI.
The variations, Figure 63:

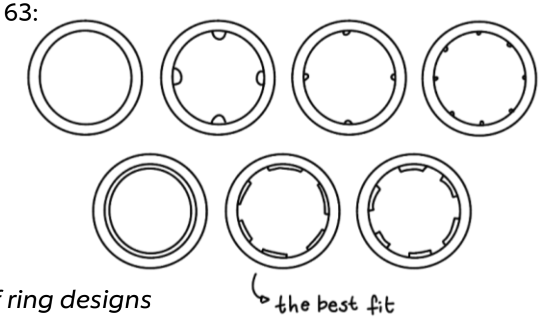


Figure 63. Waterproof ring designs

Most variations have just different tolerances to test what would be an accurate fit. You want the connection to be fixed, but not too fixed, and the same goes for not too loose. The connection should be fixed enough, the two parts stay together, but loose enough, that a consumer can easily disconnect and connect them, i.e. open and close the bottle.

The key information

Goal: Designing a leakproof waterproof ring.

Research question: What is the best way to design a leakproof - waterproof ring?

Recipe: Amora mayonnaise de Dijon

Method: Squeezing by hand (shaking with a closed cap in between squeezes) + feeling which design closes and opens the best.

Prototype: 3 lip designs and 10 groove designs + annular snap-fits designs.

Observations: The annular snap fit gradually placed around works the best, the fit feels right.

Conclusion: Combining the pin of Paragraph 5.4 inside this waterproof ring. The pin will make sure that there will be less residue inside the waterproof ring.

Final feature: Annular snap fit joints inside the waterproof ring

Next steps: Testing the new designs in a fully 3d-printed closure.

Figure 64. Pin designs as inserts for in MPS or Latam lid

Figure 65. Example of a pin design insert in Latam closure

5.6 Fluid dynamics

After these three tests iterations, it was clear that certain information is still missing to understand why certain designs work or not work. In order to validate but also predict which designs could be suitable for this new closure, it was necessary to understand the fluid dynamics of mayonnaises and closures. First, this information is gathered by having an interview with Dr. J. H. Boyle. He is an assistant Professor with the Materializing Futures section, Department of Sustainable Design Engineering of the faculty of Industrial Design Engineering within the Technical University of Delft. Furthermore, information was retrieved by searching for relatable academic papers.

Non-Newtonian fluid

An important fact is that mayonnaise is not a standard liquid, mayonnaise is a non-Newtonian fluid (Boyle, 2023) (Chhabra, 2010). A non-Newtonian fluid is a fluid that does not follow Newton's law of viscosity. This means that the fluid does not flow smoothly, but gradually flows (Wilson & Thomas, 1985). Not only mayonnaise, but also ketchup, variety sauces, and mustards are non-Newtonian fluids. More specifically, they are Bingham plastic shear thinning non-Newtonian fluids. The viscosity of a shear-thinning fluid decreases with increasing shear rate, whereas with low stress, the material behaves like a rigid body. This results in the fact that standard fluid dynamics cannot be applied to mayonnaises.

Possible complications

Since non-Newtonian fluids have elastic connections, which means that it will hold itself up (Boyle, 2023). This validates earlier observations, that designs with less wall surface, decrease the chance of leaking, since the more wall surface, the more material can stick to it. This is a confirmation that a round orifice is preferred, as concluded in paragraph 2.11 and 2.12.

Opportunity

An opportunity to make use of these non-Newtonian fluid properties is designing a closure that amplifies the ability of the negative pressure. The negative pressure inside the bottle moves the product back inside the bottle. This helps with a clean cut, but mostly with reducing the chance of leaking, since a non-Newtonian fluid acts like a solid in low stress. If the product is higher inside the bottle, the chance of leaking inside the closure while standing in the fridge is decreased. An opportunity is thus, to design a closure that improves the movement back into the bottle. The question is how can this be achieved without changing the shape and material of the bottle?

Equation 1: $P_1 + \frac{1}{2}\rho v_1^2 + pgh_1 = P_2 + \frac{1}{2}\rho v_2^2 + pgh_2$

Bernoulli's equation (1) shows that the energy transferred to raise the pressure inside the bottle would be transferred into the kinetic energy of the fluid leaving through the nozzle. The pressure in vs. out is constant, but the energy required is different.

It takes more energy to go from a large area to a small area than it takes to go from a small area to a large area, Figure 66. Adding this phenomenon to the design of the closure could give the wanted result, of creating a closure that amplifies the ease of moving back into the bottle.

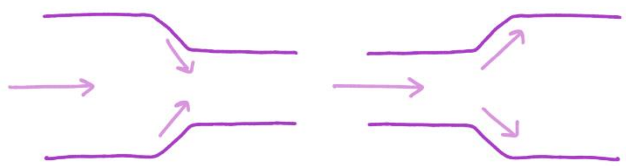


Figure 66. Flow from a large area to a small area (L), flow from a small area to a large area (R).

It is expected that when the tube as part of the orifice design, has a tapered design towards the outside, more dosing force is needed to dose the same amount of product, than having a tapered design towards the inside or a straight tube design, as earlier tested and explained in Figure 52. Since mayonnaise is a non-Newtonian fluid with elastic connections. It is plausible that the cleanness inside the closure will be improved if there is less product leaking, or still inside the orifice. When the product is higher inside the bottle after squeezing due to negative pressure, there is less change of the products moving downwards. Having the tapered design towards the inside may increase the dosing force, but will reduce the change of leaking. Since the ease of moving back into the bottle is better, Figure 67. These variations are tested in paragraph 5.8.

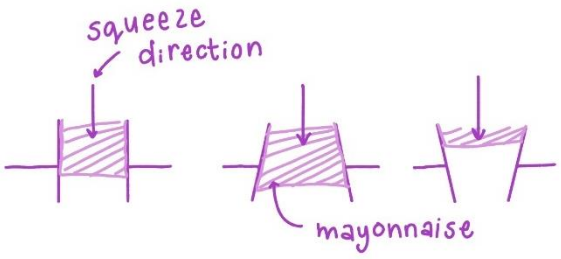


Figure 67. Straight design (left), tapered design inwards (middle), tapered design outward (right)

Syneresis

As mentioned in paragraph 2.5, some recipes experience syneresis. The water or oil that is separating from the formula is a standard liquid, and thus a Newtonian fluid. This means that the closure should be compatible with non-Newtonian and Newtonian fluids. This is an important fact to consider with developing the new closure. The closure should have a feature, that reduces the chance of leakage when a product experiences syneresis, there should be a place for the separated water or oil to go to.

As earlier pointed out, the mayonnaise closure of Heinz has an inside tube. Such a tube can also be used to create a space for the separated liquid.

The original MPS closure has a cone design, this helps with guiding the liquid to the orifice, but could also be a reason that the leakage of the MPS without a valve is higher in comparison to other flat design closures. One could think that there is more pressure on the orifice with a cone design than with a flat design, but this is not the case. As can be seen in Figure 68 and the equation: $P = \rho g h$, the pressure on the orifice is determined by the height, not by the area. Since these are the same, the pressure is also the same.

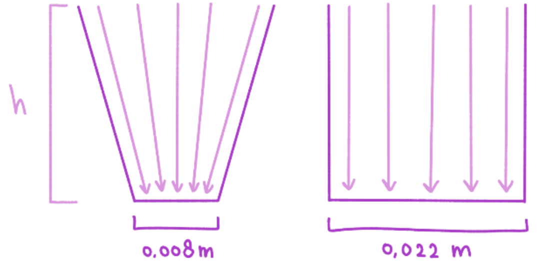


Figure 68. Pressure on the orifice

However, there is a pressure difference when a recipe is experiencing syneresis. In the cone design closure, the same amount of water will be higher than in the flat design closure, Figure 69. This will create a pressure difference, with more pressure on the orifice in the cone design closure.

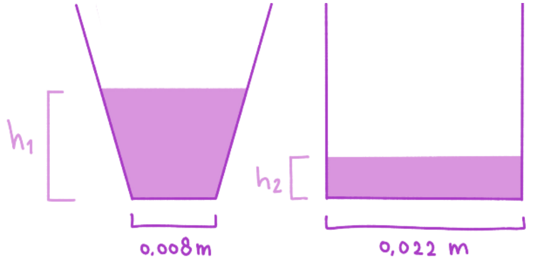


Figure 69. Same amount of liquid in cone design (L) and flat design (R)

As concluded before, the cone design does have a positive influence on the required dosing force, since it helps guide the product to the orifice. Combining the cone and flat design, as shown in Figure 70, could be a viable solution.

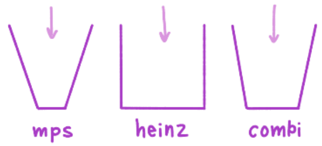


Figure 70. Different designs of the closure.

An inside tube, as seen in the Heinz closure and earlier tested with, can ensure a cleaner closure, since less amount of liquid is able to leak.

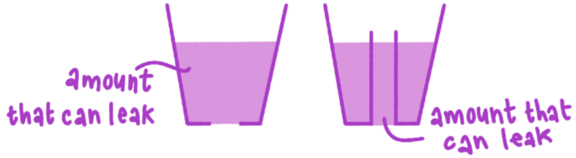


Figure 71. Inside tube will decrease the chance of leaking.

Paper – squeezability

S. Blakey, J. Rowson, R. A. Tomlinson, A. Sandham and A. Yoxall wrote two papers regarding the squeezability of mayonnaise squeeze bottles (Blakey et al., 2009). The papers are focused on researching the variables influencing the performance of squeeze bottles, especially upside-down squeeze bottles. The first paper concludes that the bottle material, shape, and shape of the orifice are influencing the squeezability and access to bottle contents.

This paper is a follow-up on the research of Van Satvilliet and Ludwig research towards the influence of the design of a dropper tip (Yoxall et al., 2010). They conclude that the diameter of the nozzle of a dropper bottle has a major impact on the force required to dispense the contents.

It starts with a fundamental analysis of squeeze bottles and validate the reference of Van Satvilliet and Ludwig with the following equations.

Equation 2: $Wpress = \int p\mathrm{dV}$

P is the bottle pressure and V is the bottle volume. This equation (2) simply shows that the Work inside the bottle is related to the pressure inside the bottle and the bottle volume.

Equation 3: $\int F\ \mathrm{dx} = \int kx\ dx + \int p\ \mathrm{dV}$

This equation (3) means that the increase in the bottle pressure due to a change in volume will lead to a pressure differential between *p* and the ambient surroundings, resulting in fluid flow.

The liquid pressure and the resulting flow are related by the following equation $\dot{V} = C_{\mathrm{d}} A_{nozzle} \sqrt{\frac{2\mathrm{p}}{p}}$ validating as probably expected intuitively, that there is a relationship between the force required to dose, the bottle stiffness and the geometry of the nozzle. The geometry of the nozzle is especially interesting for this design project.

Although mentioned earlier, that the pressure in is constant to the pressure out. Because the liquid is forced through the orifice, there is a loss of some energy. This energy loss comes due to the fact that the orifice has a smaller diameter than the bottle or bottle's neck, this is called venga contracta. This energy loss is called the discharge coefficient C_d and can be calculated:

$$C_d = \frac{Area\ of\ vena\ contracta\ x\ actual\ velocity}{Area\ of\ orifice\ x\ ideal\ velocity}$$

The paper describes "normal" round orifices as sharp-edged orifices. Those orifices typically have a discharge coefficient between 0.6 and 0.65. Since the C_d represents the resistance of the orifice, a lower C_d will result in easier flow and is thus wanted.

S. Blakey, J. Rowson, R. A. Tomlinson, A. Sandham and A. Yoxall (Blakey et al., 2009) found a relationship between the C_d, ease of flow and orifice design. As known, the orifice can have a length, the paper calls this length the Borda length of an orifice. They tested multiple orifice designs, with multiple recipes (different Re, Reynolds numbers), and plotted the results in Figure 72.

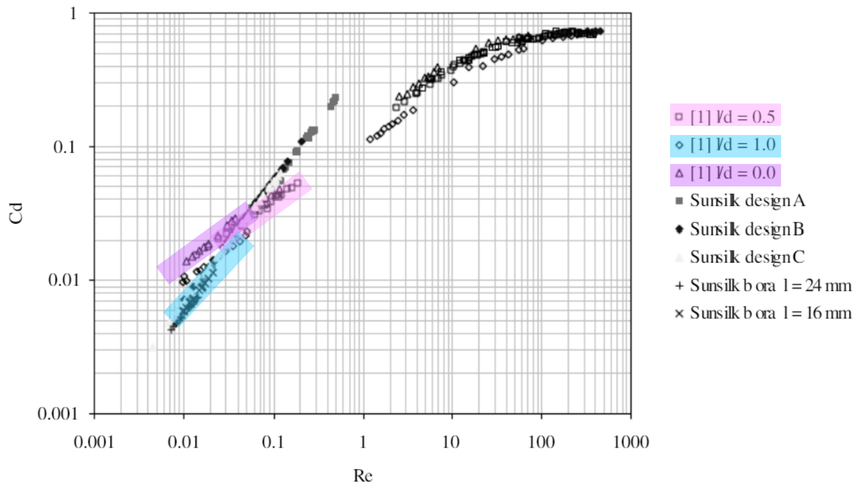


Figure 72. Results of testing by S. Blakey et al

In the legend on the right in Figure 57, the different orifice designs are noted. When looking at the results, it is clear that orifice design l/d = 1.0 has a lower C_d than l/d = 0.5 and l/d = 0.0. Suggesting that a ratio of 1.0 between orifice diameter and orifice (Borda) length is needed for optimal flow.

S. Blakey et al conclude that "the length of the Borda has quite a clear effect on the flowrate; the longer the Borda, the lower the flowrate for the same initial energy Wpress. This indicates that applications of squeezy bottles requiring low or closely controlled flowrates may benefit from the use of a Borda and ration l/d = 1.0. "

This results in the following question: is a ratio of l/d = 1.0 optimal for the to-be-designed closure and set requirements? Since the wanted flow rate is not too slow or too controlled.

As the follow-up paper summarizes, the squeeze forces is determined by three design related features: 1) Bottle material. 2. Bottle shape 3. Orifice shape (Yoxall et al., 2010). Verifying the set variables in Chapter 3. Since in Chapter 3 the four variables were determined, the design of the bottle, the recipe, the pin design and the design of the orifice. Where only the design of the bottle, the recipe and the design of the orifice influence the dosing force, the pin design is related to the cleanness. This is in line with the features determined by the paper.

Conclusion

This research helped iteration new variations to test for the design of the closure and the orifice. But also to validate the ratio of the orifice.
The new design to test is one with a tapered designed tube partly inside, to improve the suck back of the product and reduce leaking due to syneresis, and with an combination of a cone and flat closure design, to still have the perks of guiding the product with the cone design towards the orifice, but also having the flat part in combination with the tube to reduce the leaking of syneresis. Figure 73 shows an overview of these new features. In Paragraph 5.7, these new suggestions of the orifice design are tested.

Figure 73. Overview of the new orifice features to test

As the paper suggested, there is an optimal ratio between the diameter of the orifice and the length of the orifice for optimal flow. In Paragraph 5.8 is researched what the optimal ratio for this new closure is.

5.7 3D-printing new closures

The first designs were tested as inserts in already existing closures. Since these closures were glued into the closure, the test results are less accurate. This is a reason to test the next designs in fully 3D-printed closures, in Figure 75, the first 3D-printed closure can be seen.

3d-printing

When 3D-printing the closure, it is important to consider the design rules of this prototyping technique. The closures will be FDM 3D-printed with PLA material, like the inserts since this is the easiest available and suitable for the type of tests. However, the PLA material is not suitable for printing the hinge of the closure, this is not a problem because this is not a feature that needs to be tested, since it stays the same.

The inside dimensions after 3D-printing are smaller than modelled in Solidworks, whereas the outside dimensions are larger, this is because the nozzle dimensions translate to the print dimensions. The FDM Ultimaker printers at the PMB in the Industrial Design Faculty have a nozzle of 0.4 mm, when printing a square, the inside dimensions are 0.4 mm smaller and the outside dimensions are 0.4 larger, Figure 74.

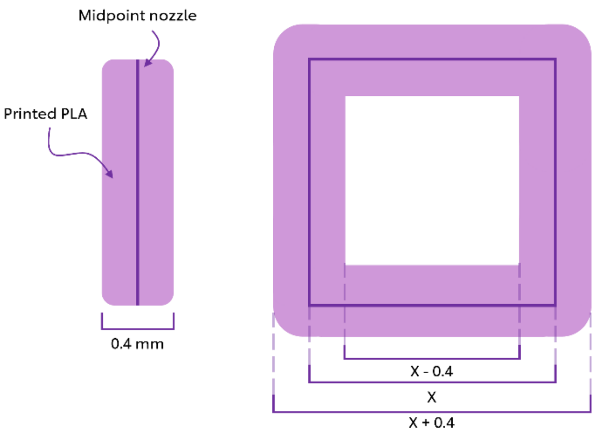


Figure 74. 3D-printing dimensions

Figure 75. 3D-printed closure

The designs of the 3D-printed closures for testing

In paragraph 5.6, multiple ideas for improving the closures required dosing force and cleanness were created. In the next variations, those designs are tested. The difference between the designs can be seen in Figure 76, the first design does not have an inside tube, the second has a straight inside tube and the last design has a tapered inside tube. The dimensions and specifics of the designs can be found in Appendix VI.

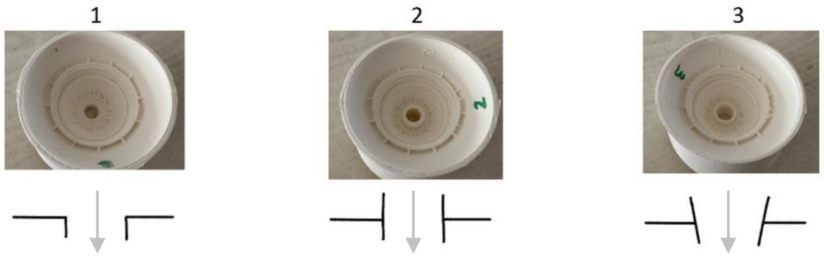


Figure 76. The variations of closures to test (No tube, straight tube, tapered/cone tube (L-R))

Summary of the test data

Below, in Table 12, the average required dosing force of the Squeeze test is visible. The three designs are compared to three already existing closures, the original MPS, the Interkap closure with star orifice (Unilever sees this closure as a possible replacer for the MPS because of the short implementation time), and the Heinz 4mm closure. The MPS, Interkap and Heinz 4mm closure previous test data (Chapter 2) is used for this comparison.

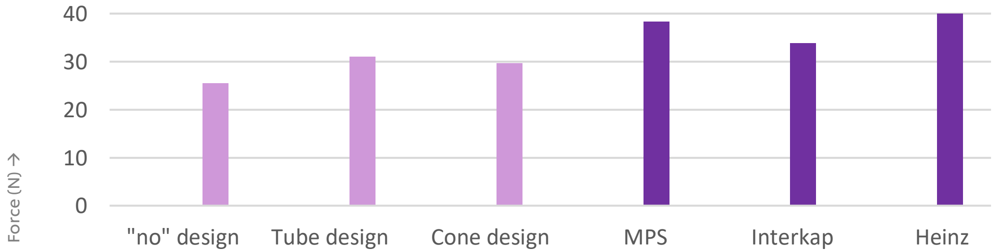


Table 12. Squeeze tests results

The key information

Goal: Concluding the design direction for the to-be-designed closure.

Research question: Which of the prototyped caps fits the requirements bests?

Method: Squeeze test UMA-6341.02

Recipe: Ligeresa Original Mayonnaise

Prototype: 3 variations of closures

Observations:

- No difference is noticed when squeezed by hand
- The product gets sucked back into the packaging the easiest with the cone design.
- The cleanness scores better with the cone design

Conclusions:

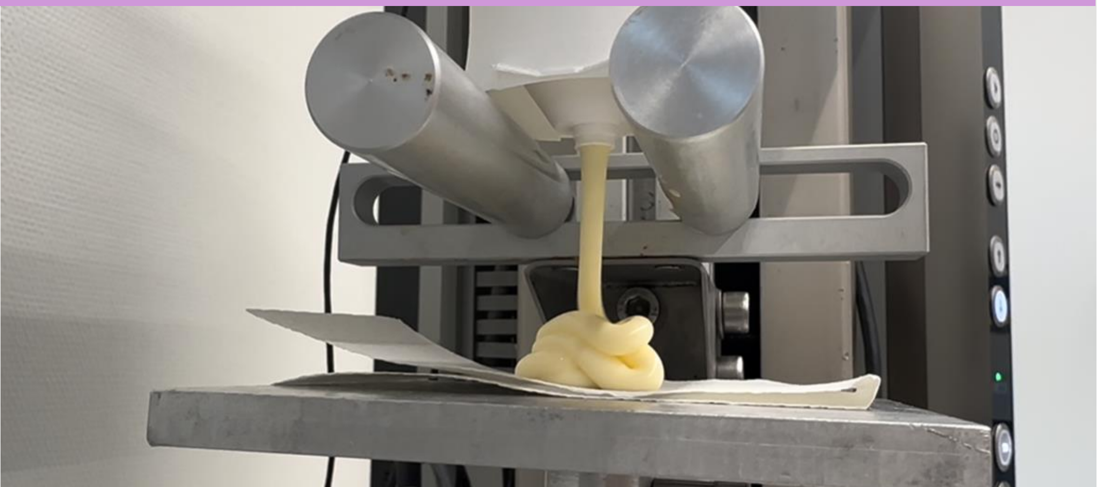
- Cone design requires a bit more Newton than the *no design*, but still in the optimal range (less than 60 N).
- The pin design (designed and chosen in Paragraph 5.4) works well, but there is still room for improvement.

Final feature: Inside tube, cone-design, flat part, and solid pin

Next steps: verifying the ratio of l/d of the designed closure

Individual squeeze data in Appendix: VII

Figure 77. Squeeze test of a MPS bottle with the designed and 3D-printed closure
Figure 78. The 3D-printed closure dosing mayonnaise



Next to the required dosing force, the cleanness inside the cap is important. Below in Table 13, the overview of pictures of the inside of the tested closures after testing is visible. These orifice designs are all tested with the four chamber pin design chosen in Paragraph 5.4.

No design	Tube design	Cone design
		
Cleanness 3	Cleanness 3	Cleanness 2
MPS	Interkap	Heinz 4mm
		
Cleanness 1	Cleanness 5	Cleanness 2

Table 13. Overview of cleanness after squeezing (New design, MPS (valve), Interkap and Heinz results from previous tests).

The tapered/cone design closure requires a bit more dosing force than the “no” design closure. But still very acceptable (less than 60N). Out of the three designs, Table 13, the cone design has the best cleanness inside the closure after dosing.

Since the cone design is the most promising, other recipes were tested to compare the cone design closure to the MPS and Interkap closure. The Interkap closure is used to compare to because this closure is seen as a promising valveless alternative for the MPS by Unilever. In Table 14, is the result of those Squeeze tests.

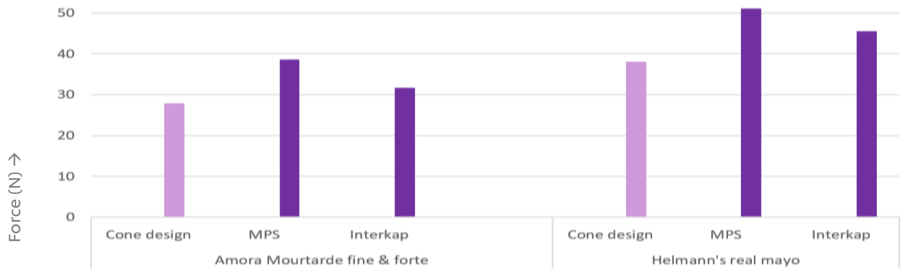


Table 14. Squeeze test results of Amora Mourtarde fine & forte (L) and Hellmann's real mayo (R)

As can be seen in Table 14, the cone design closure has the lowest average required dosing force. This is an improvement in comparison to the original MPS closure. When looking at the cleanness after squeezing these tested closures and recipes in Table 15, it is undoubtedly that the MPS closure (with valve) is still the cleanest. However, the cone design closure is much cleaner than the Interkap closure with both recipes.

	Cone design	MPS	Interkap
Amora Mourtarde fine & forte			
	Cleanness 3	Cleanness 1	Cleanness 5
Hellmann's real mayo			
	Cleanness 2	Cleanness 1	Cleanness 5

Table 15. Overview of cleanness after squeezing Amora Mourtarde (top) and Hellmann's real (bottom)

The chambers in the pin design work, but the downside is that a lot of residue gets into those chambers. This makes it look messier than it actually is, the residue still goes where it is acceptable to go. It only goes inside the waterproof ring and not outside of it.

Advice from Dr. Boyle, J. H. regarding the pin design: the design will only work until the chambers are full of residue. When the residue dries, this feature will not work as predicted anymore. Since there are then no chambers for the residue to go to. A solid pin design is therefore preferred after validating this with tests. With the new solid pin design, there is less place for the residue to go, this improves the cleanness inside the lid of the closure, and the amount of residue is lower.

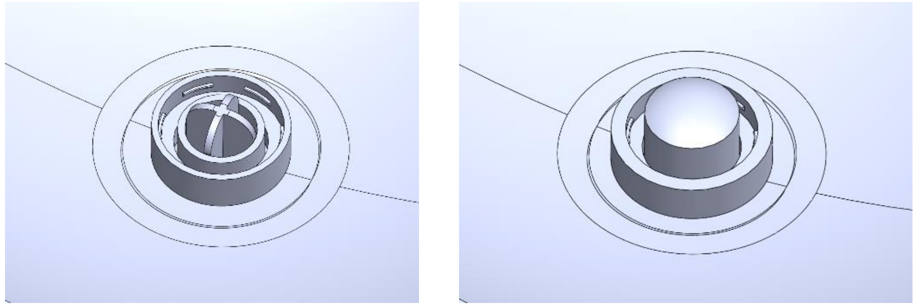


Figure 79. Previous pin design with chambers (L) new solid dome pin (R)

Figure 80. Cleanness of the previous pin design (L) and new design (R).

5.8 Solidworks flow simulations

As explained in paragraph 5.6, there is a relationship between the length of the orifice and the diameter of the orifice. S. Blakey et al. (Blakey et al., 2009) concluded that a ratio of 1.0 is required for optimal flow. The question however is, is optimal flow wanted for the new closure? Ease of flow should be part of it, but it should not flow too easily, as this will increase the risks of leaking. The design so far has a top ratio of 0.7, and also bottom ratio is 0.7, Figure 81.

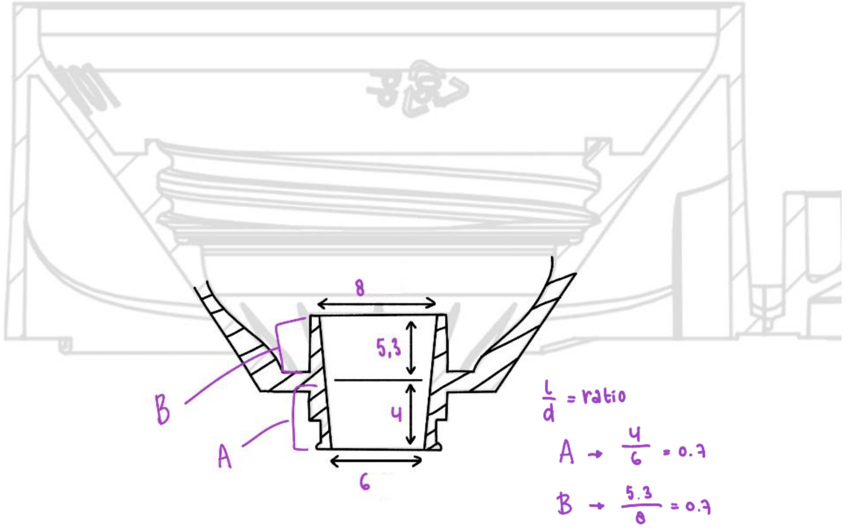


Figure 81. The ratio between the length of the orifice and the diameter of the orifice in the newly designed closure.

This ratio is lower than the mentioned ratio of 1.0 (Blakey et al., 2009), and is the result of structured testing. The question is, is there another ratio that would fit the set requirements better?

Flow simulations Solidworks

Goal: Validating the ratio of diameter and length of the orifice.
Research question: What is the optimal ratio for the new valveless closure?
Method: Flow simulations Solidworks.

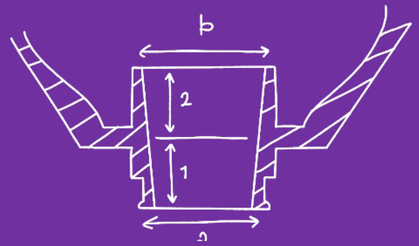


Figure 82. Overview of ratio components

Nr.	Name	a in mm	1 in mm	Ratio top (l/d)	b in mm	2 in mm	Ratio bottom (l/d)
1	MPS	-	-	-	-	-	-
2	New closure	6	4	0.7	8	5.3	0.7
3	Larger 1	6	6	1	8	5.3	0.7
4	Smaller a	4	4	1	8	5.3	0.7
5	Smaller b	6	4	0.7	6	5.3	0.9
6	Larger 2	6	4	0.7	8	8	1

Table 16. Overview of tested variations.

Conclusion:

- Changing the dimensions to create another ratio will change the velocity and inside pressure negatively.
- Ratio 0.7 behaves similar to the current MPS closure.

Final feature: The top and bottom parts of the orifice have a ratio of 0.7.
Next steps: Testing the new closure with the first-wave recipes.

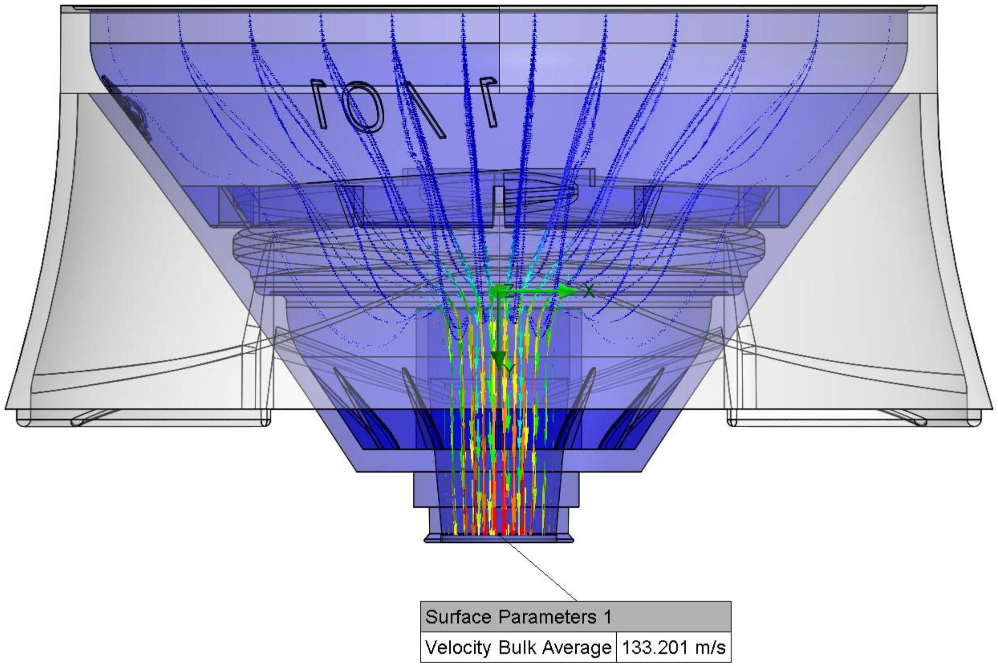
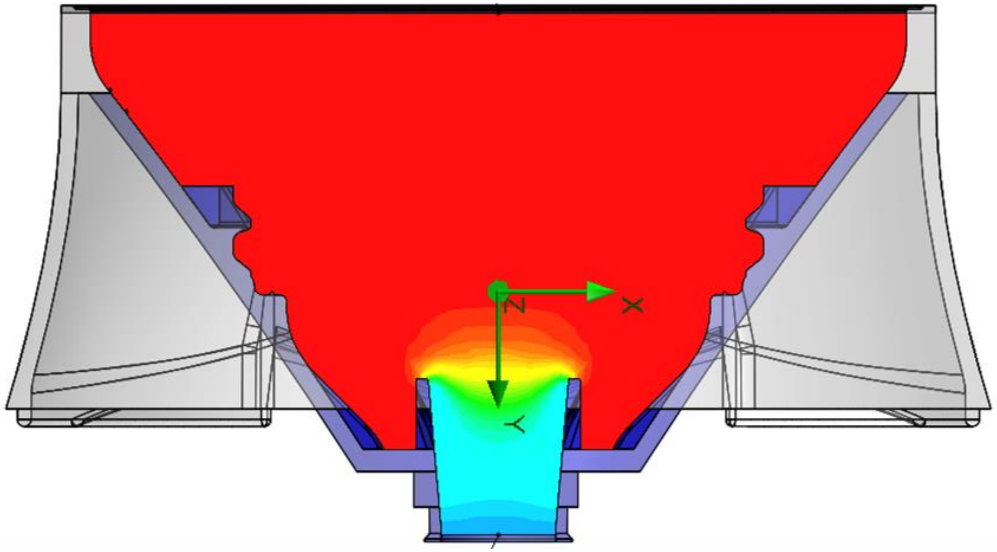


Figure 83. Outlet velocity of the new closure with an inlet velocity of 2.5 m/s
Figure 84. Pressure distribution inside the new closure



Flow simulations Solidworks settings

Inlet velocity: 2.5 m/s (set as an example)
Fluid properties: Material type: non-Newtonian; Density: 910 kg/m^3 (*Mayonnaise, Traditional Density*, n.d.); Specific heat: 335000 J/(kg*K) (Bicanic et al., 1992); Thermal conductivity: 0.2 W/(m*K) (Bicanic et al., 1992); Consistency coefficient: 77 Pa*s (Бредихин et al., 2023); Yield stress: 59.6 Pa.
Gravity: Y-component -9.81 m/s^2
Flow type: Laminar flow
Lid 1: Bottle's neck and Lid 2: Orifice

Overview of the test results

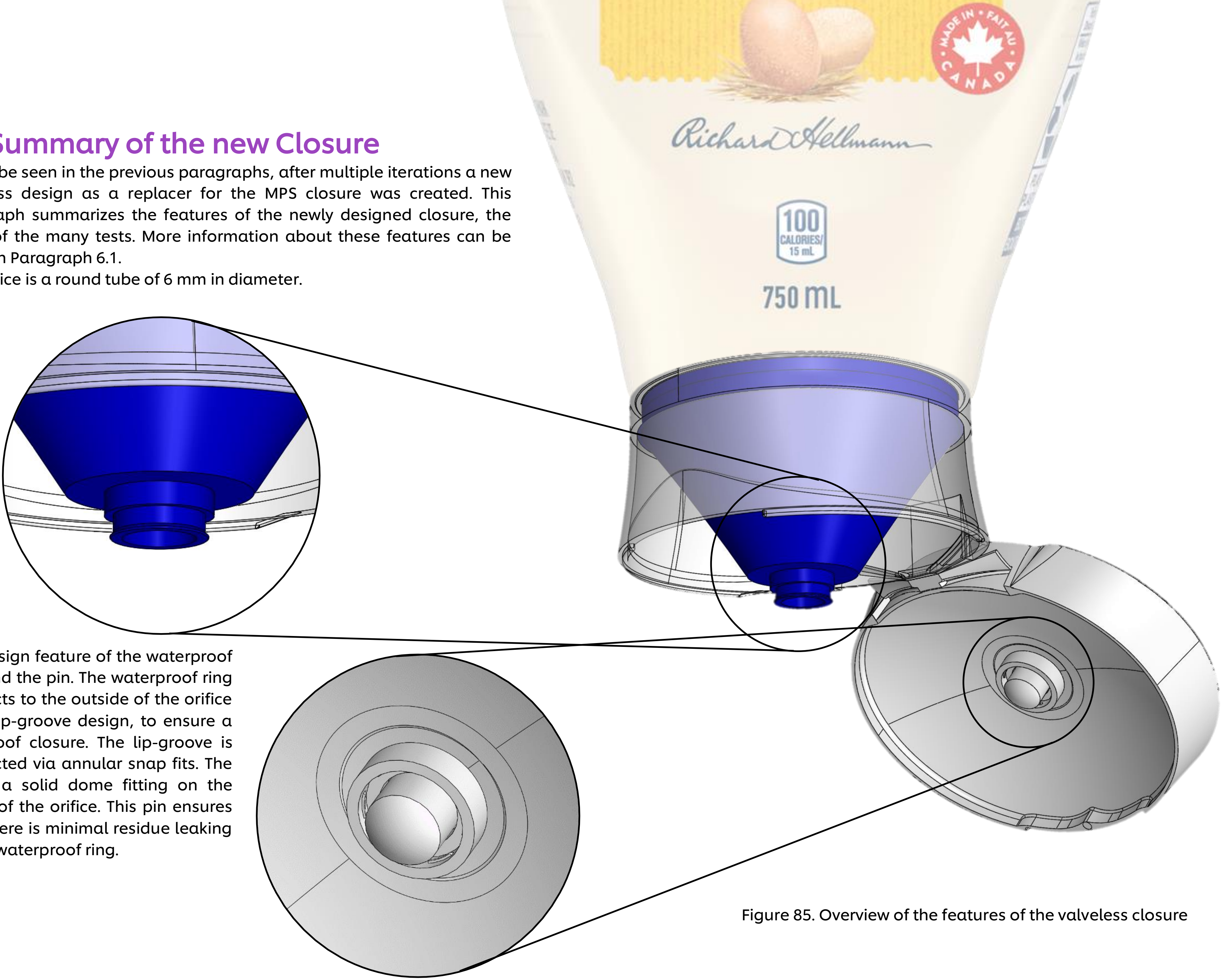
Nr.	Name	Outlet velocity (m/s)	Surface pressure max (Pa)
1	MPS	114,291	7211101
2	New closure	133,575	9443983
3	Larger 1	147,513	14300000
4	Smaller a	332,224	56000000
5	Smaller b	175,093	17600000
6	Larger 2	133,201	9616162

Table 17. Overview of flow simulation results

The new closure has a slightly higher outlet velocity and surface pressure. When the dimensions and thus the ratio are changed, the velocity and pressure also change. They become higher, and this is unwanted because, it will increase the risk of leaking and decrease the squeeze experience. The test results of test Nr.6 (Table 17), are comparable to the new closure, however, a longer inside tube is unwanted.
The longer the inside tube, the higher the required squeeze force will be, but more importantly, the more residue will be left inside the bottle. Considering that only squeeze bottles with less than 10% product left inside will be recycled, leaving the ratio as 0.7 is ideal.

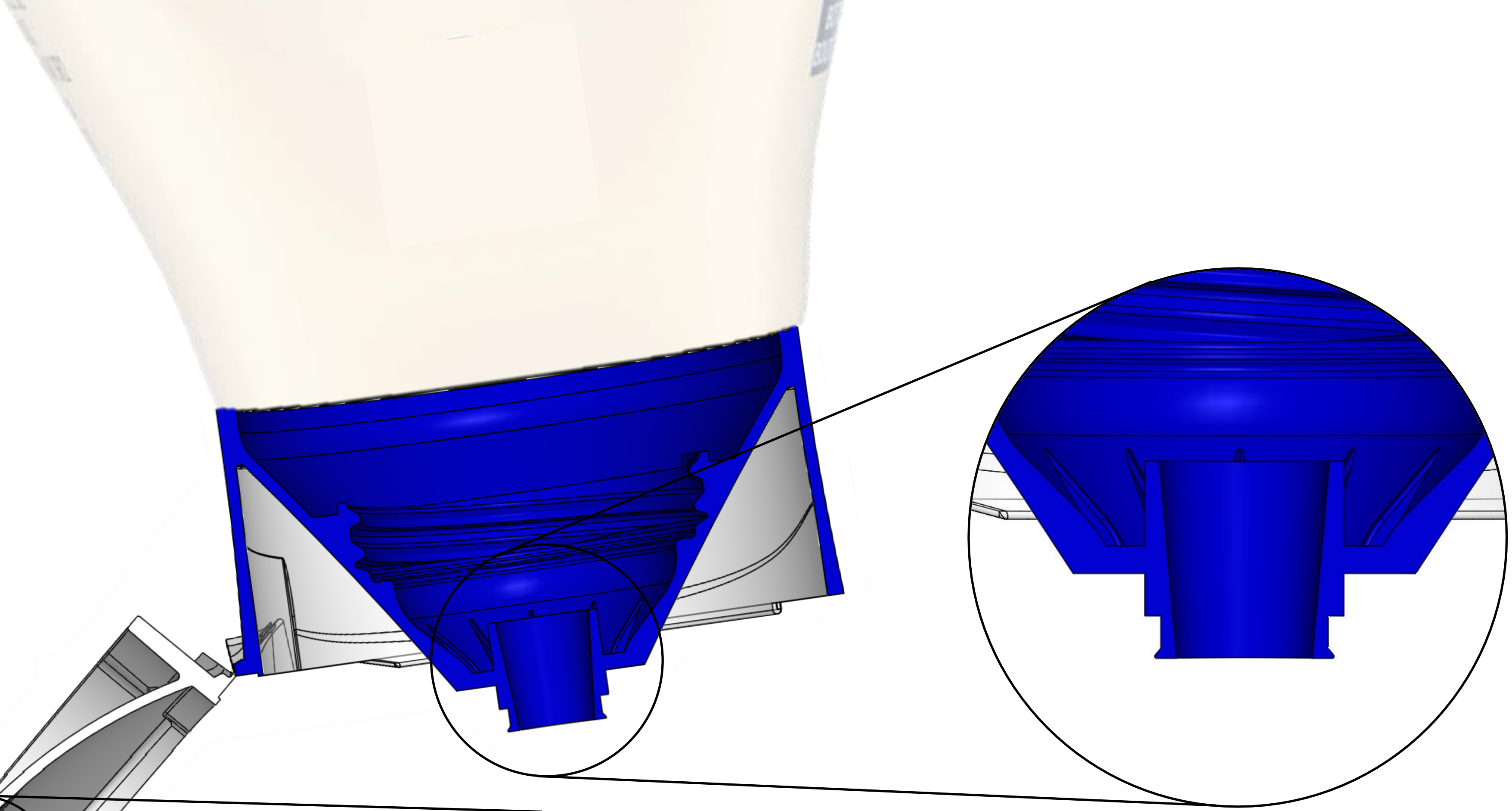
5.9 Summary of the new Closure

As can be seen in the previous paragraphs, after multiple iterations a new valveless design as a replacer for the MPS closure was created. This Paragraph summarizes the features of the newly designed closure, the result of the many tests. More information about these features can be found in Paragraph 6.1.
The orifice is a round tube of 6 mm in diameter.

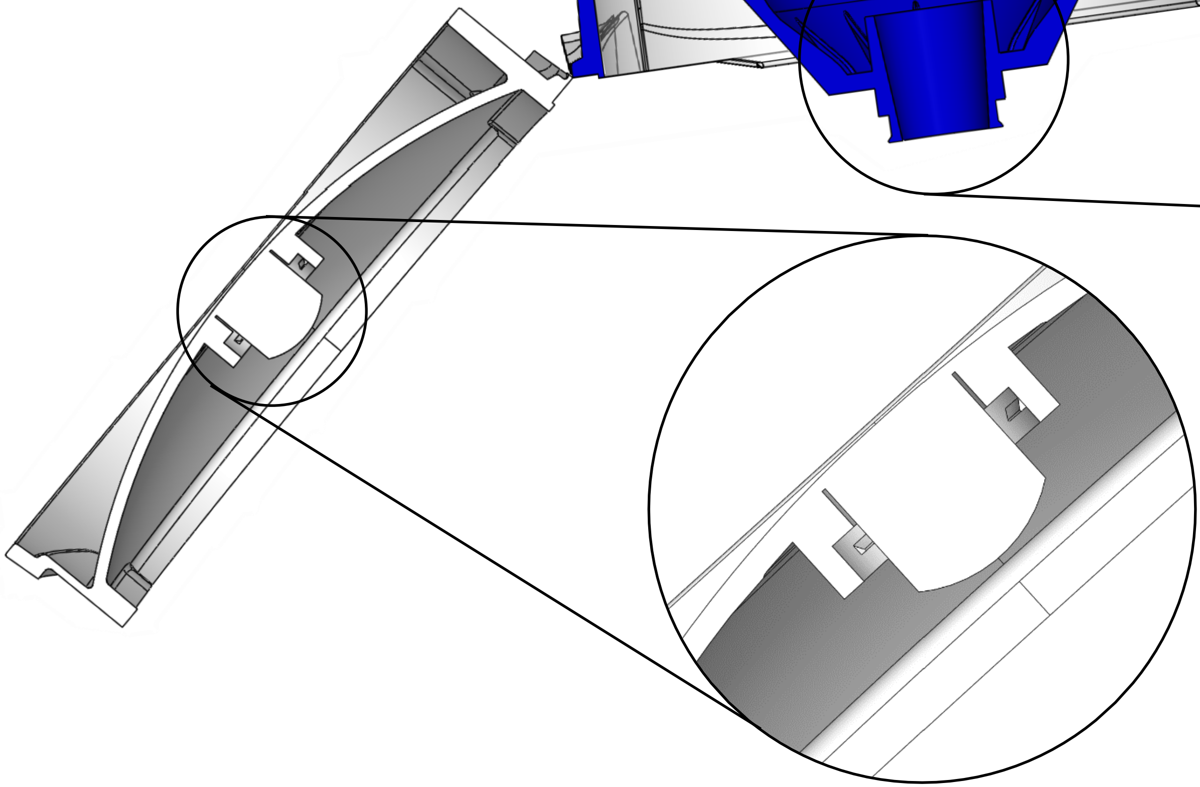


The design feature of the waterproof ring and the pin. The waterproof ring connects to the outside of the orifice via a lip-groove design, to ensure a leakproof closure. The lip-groove is connected via annular snap fits. The pin is a solid dome fitting on the inside of the orifice. This pin ensures that there is minimal residue leaking to the waterproof ring.

Figure 85. Overview of the features of the valveless closure



The tube of the orifice protrudes from the outside to the inside of the closure. The tube is not a straight tube, but a tapered one towards to outside. The diameter outside is smaller than on the inside.



On the inside of the waterproof ring around the pin, the annular snap fits are visible.

5.10 Testing the new closure

In Chapter 2, the first-wave recipes are tested with the current MPS closure and three other closures: the Interkap, Latam, and 4mm round orifice closure. To see how the newly designed closure scores in comparison to these closures, the new closure is tested with the first-wave recipes.

Testing the recipes

Recipe: Hellmann's Real mayo

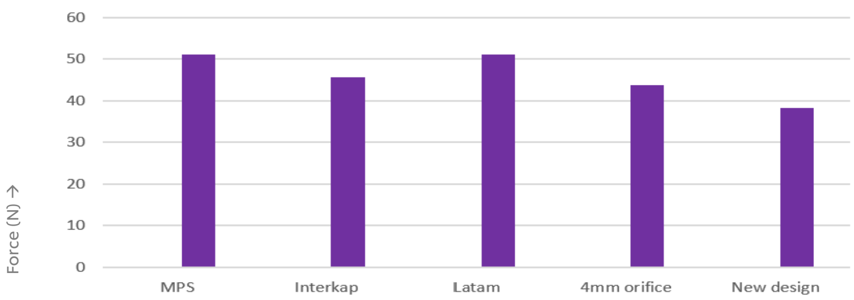


Table 18. Average required dosing force (Hellmann's Real mayo)

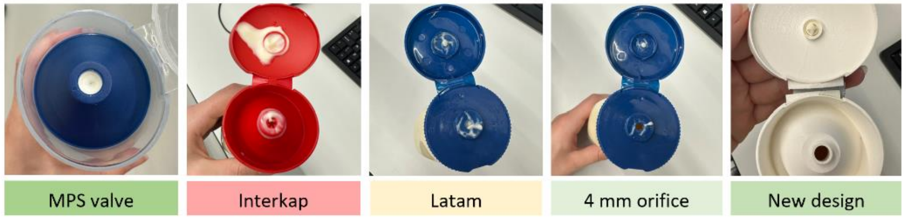


Figure 86. Cleanness after dosing (Hellmann's Real mayo)

In Table 18, can be seen that the new valveless design requires the least amount of dosing force to dose a dosing of 13 grams of Hellmann's Real mayonnaise, a desired result. Figure 86 shows that the cleanness on the inside of the closure after dosing is acceptable, not as clean as the original closure but clean enough according to the set-up cleanness scale.

The key information

Goal: Validating that the new design is compatible with the set requirements

Method: Squeeze test UMA-6341.02

Recipes: first-wave recipes

Prototype: 3d-printed designed closure

Conclusions:

- The cleanness is less than the MPS closure but still acceptable.
- The dosing force is lower
- The squeeze graph looks more like the Heinz graph -> similar squeeze experience.

Individual squeeze data in Appendix VIII

Next steps: Validating the design with stakeholders and making it production-ready.

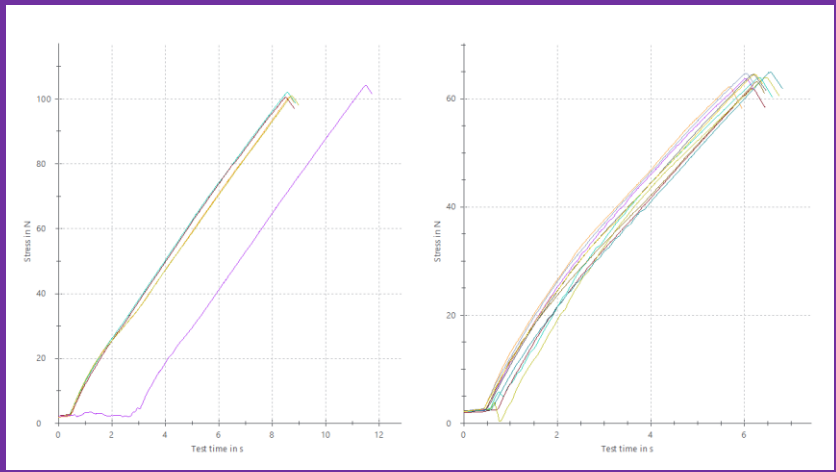


Figure 87. Graph Heinz (L) and new design (R)

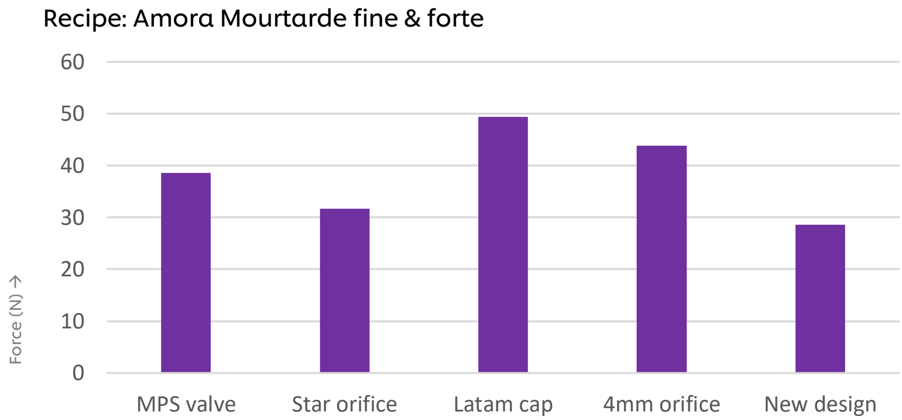


Table 19. Average required dosing force (Amora Mourtarde fine & forte)

Figure 88. Cleanness after dosing (Amora Mourtarde fine & forte)

Table 19, shows again that the new design requires the least amount of dosing force with the Amora Mourtarde fine & forte recipe. The cleanness inside the closure after dosing for the closures with this recipe can be seen in Figure 88. The new valveless design is still not as clean as the MPS closure with valve, but way cleaner than the other valveless closures.

Overview of results

All the first-wave recipes are tested with this newly designed closure and compared to the test results of the four closures (MPS, Interkap, Latam closure and 4mm orifice closure) tested closures in Chapter 2. The new test results of the new closure are visualized in the same overview used as in Chapter 2. As earlier explained, the desired spot is the left bottom corner. With a maximum cleanness score of 3, desirably 2, and a dosing force below 60 Newton, Figure 89.

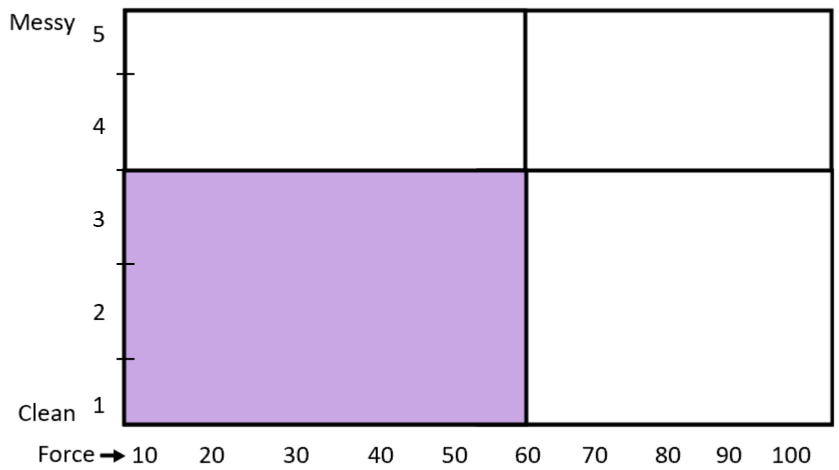
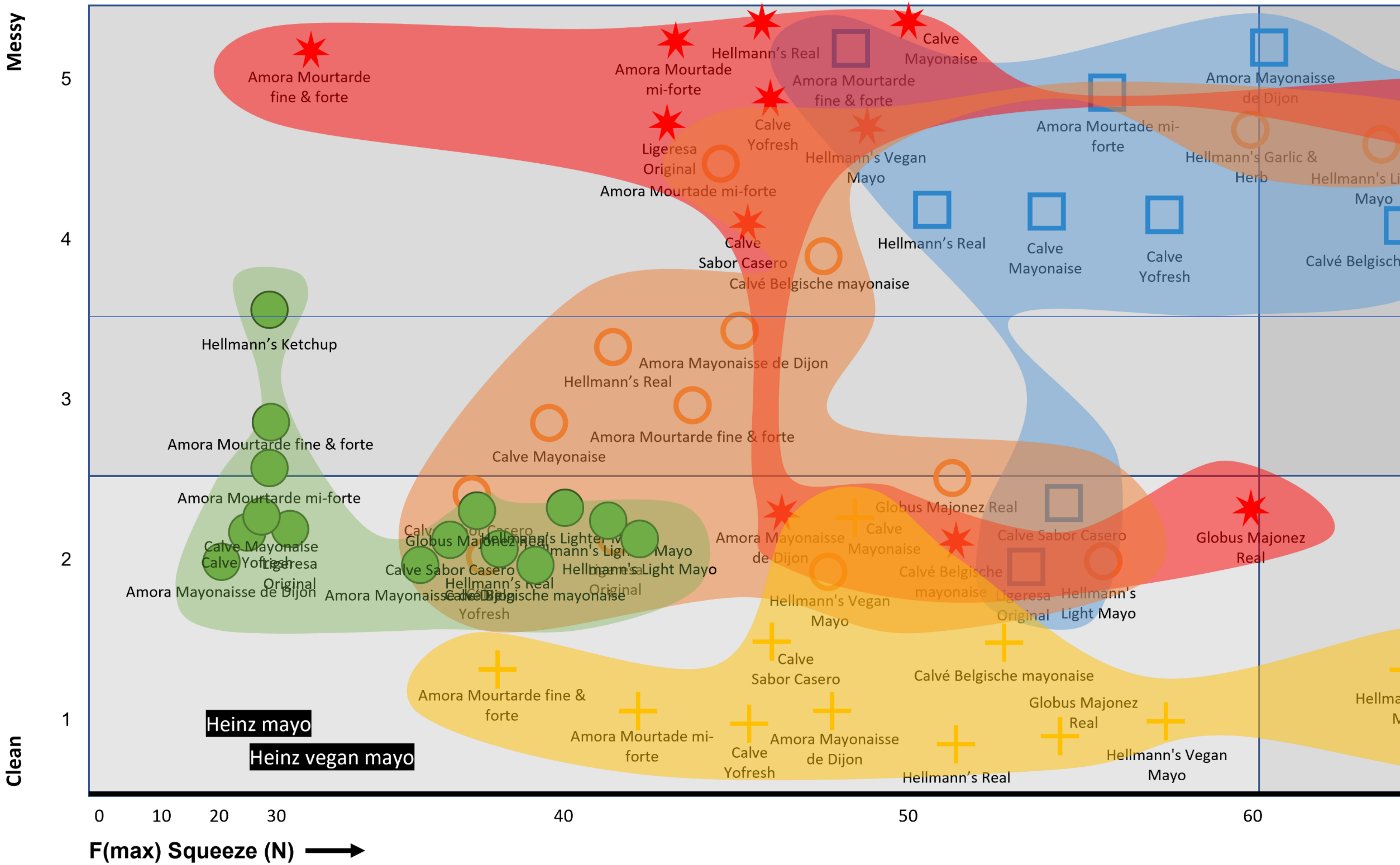
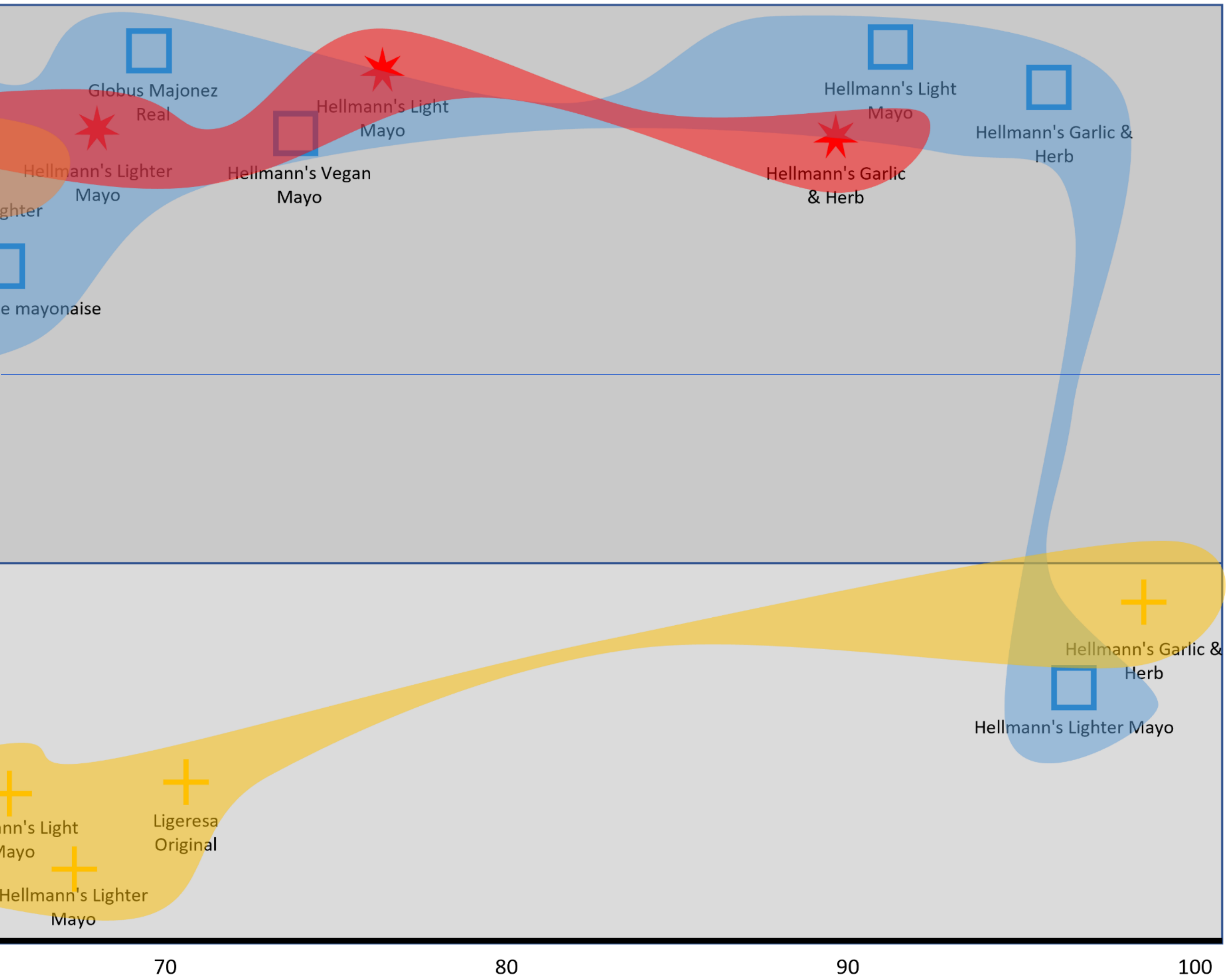


Figure 89. Desired spot for the test results

This overview can be found in Figure 90, the newly designed valveless closure scores as mentioned before good in the case of average dosing force, clearly lower than 60 N. The cleanness of the inside of the closure after dosing, is for the most part in the desired spot. A maximum cleanness of 2, except for the Amoura Mourtarde fin & forte, Amoura Mourtarde mi-forte and Hellmann's ketchup. The Mourtardes have a cleanness of 3, which is still acceptable. The Hellmann's ketchup is just outside of this spot with a cleanness of 3.5. The Hellmann's ketchup is not part of the first-wave recipes scope, it was added to the recipes to test as suggestion of the Unilever Investors Board, more about this in Paragraph 5.11.



Messy
Clean
5
4
3
2
1
0
10
20
30
40
50
60
F(max) Squeeze (N)
Amora Mourtarde fine & forte
Amora Mourtarde mi-forte
Hellmann's Real
Calve Mayonaise
Amora Mourtarde fine & forte
Calve Yofresh
Ligeresa Original
Hellmann's Vegan Mayo
Amora Mourtade mi-forte
Amora Mayonaisse de Dijon
Hellmann's Garlic & Herb
Calve Sabor Casero
Calvé Belgische mayonaise
Hellmann's Real
Calve Mayonaise
Calve Yofresh
Hellmann's Ketchup
Amora Mayonaisse de Dijon
Hellmann's Real
Amora Mourtarde fine & forte
Calve Mayonaise
Amora Mourtarde fine & forte
Amora Mourtarde mi-forte
Globus Majonez Real
Calve Mayonaise
Calve Sabor Casero
Amora Mayonaisse de Dijon
Calvé Belgische mayonaise
Hellmann's Vegan Mayo
Ligeresa Original
Hellmann's Light Mayo
Globus Majonez Real
Amora Mayonaisse de Dijon
Calve Sabor Casero
Calve Sabor Casero
Calvé Belgische mayonaise
Amora Mourtarde fine & forte
Globus Majonez Real
Amora Mourtarde mi-forte
Calve Yofresh
Amora Mayonaisse de Dijon
Hellmann's Real
Hellmann's Vegan Mayo
Heinz mayo
Heinz vegan mayo



Legend

The MPS orifice

The Star orifice (Interkap)

The bridge orifice (Latam)

The 4 mm orifice

The new design

Figure 90.
Overview of squeeze tests with the first wave recipes, the 4 different closures and the new closures.

Figure 91. 3D-printed closures

5.11 Validating the closure

An important meeting in Unilever projects is with the investor board of Unilever. This board consists of people from the different departments, from marketing, supply chain, procurement to R&D. At one of those investor board meetings, the new valveless closure was presented.

The different features of the Mono Poly closure were explained, as well as the comparison to the original MPS closure with valve and to the Interkap closure with star orifice. In comparison to these closures, the Mono Poly closure requires the least amount of dosing force and is cleaner than the Interkap closure, but less clean than the original MPS closure.

The investor board meeting went well. At first, most attendees were hesitant about the new closure, since the orifice is much larger in diameter. However, after experiencing the new closure with multiple recipes, everyone was very positive about the new design. A template was made to receive some feedback, but mainly to keep the conversations going and help the attendees to speak out about their squeeze experience.

The question however arose, will the new closure also be suitable for ketchup? This was immediately tested, the required dosing force is low, but maybe too low since it leaks when shaken. The cleanness is ok, but not great. Ketchup was not in the initial scope of the project, this resulted in needing to do some further research and testing to see what would be acceptable for ketchup.

Desirable the same closure would be suitable for ketchup. The closure thus needs to be tested with ketchup. The investor board is also interested in the results of a closure that has a smaller diameter orifice for ketchup specifically. What will this do with the dosing force, but more importantly, what will this do with the cleanness? Will this improve, or stay the same as the new Mono Poly closure?

Testing Ketchup

Since the viscosity of ketchup is much lower than that of mayonnaise, the required dosing force is also lower. The average required dosing force of ketchup is only 22.52 Newton with the new valveless closure. This is definitely an acceptable dosing force.

The challenge is thus the cleanness inside the closure after squeezing. As can be seen in Figure 73, this is quite messy with a cleanness of 3.5. This score is coming from the fact that the residue is not outside of the waterproof ring but there is some residue on the orifice. This is also enhanced by the colour of the ketchup against the white of the closure. But surprisingly, less messy than expected.

Figure 92. Cleanness of 3.5

Figure 93. Inside of the closure

The question is, will reducing the diameter of the orifice from 6 mm to 4mm improve the cleanness for ketchup? A follow-up question is, what is the ideal ratio? Is this also 0.7, or is this for instance 1 like the paper suggested, because ketchup is a more watery product, with a low viscosity.

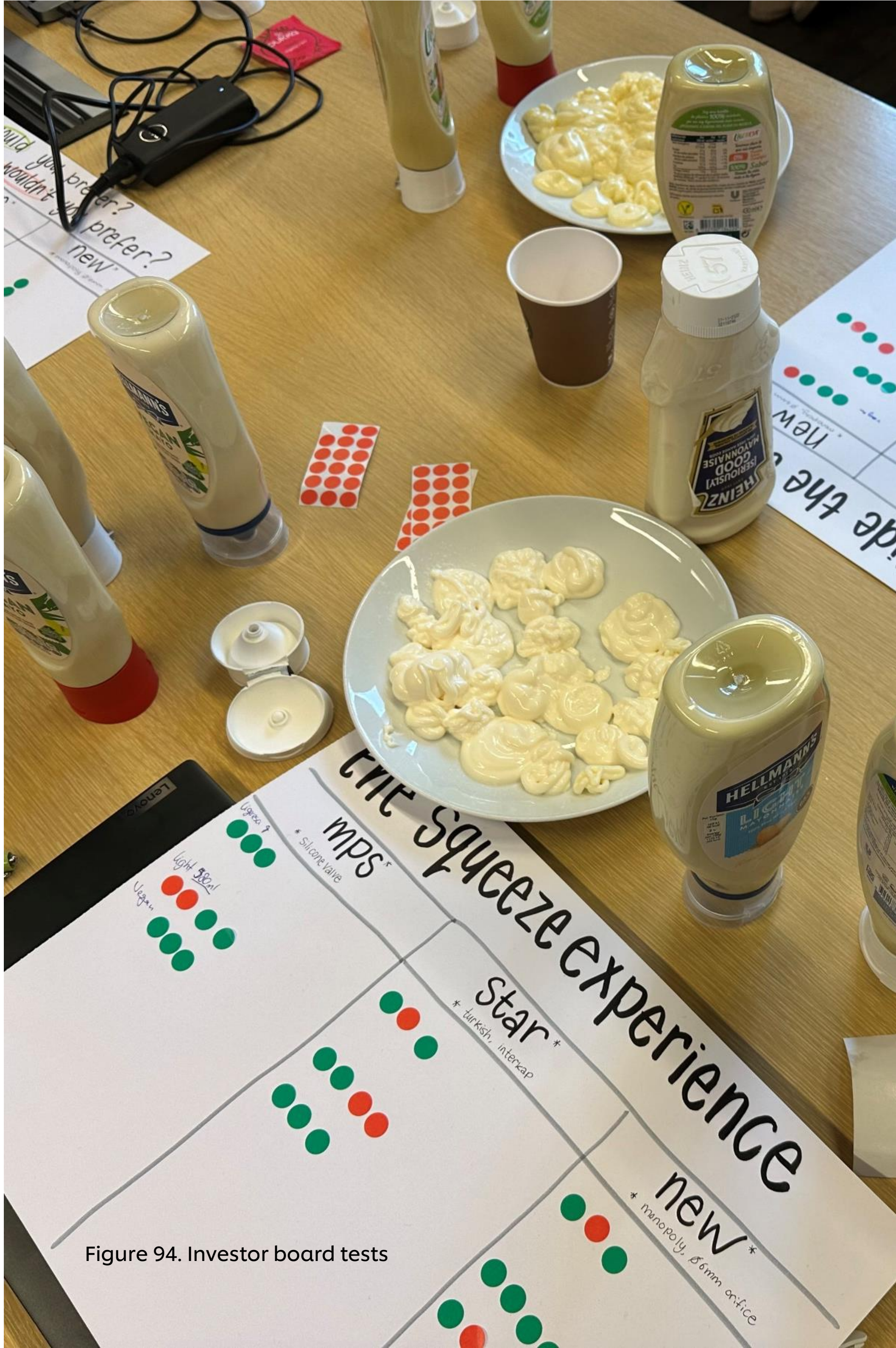


Figure 94. Investor board tests

The dimensions of the ketchup closures to test:

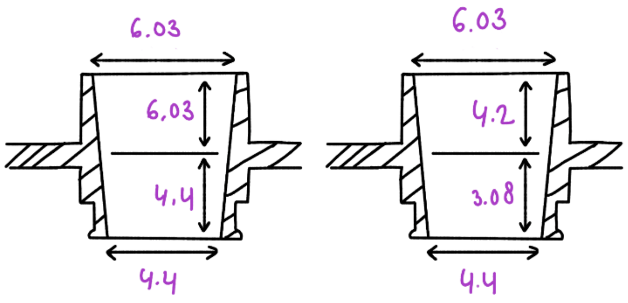


Figure 95. Dimensions of the ketchup closure to test (Ratio 1.0 L and 0.7 R)

Testing the ketchup closures

The 4 mm orifice closures are compared to the designed 6 mm orifice closure. The three closures will be compared on three aspects: Dosing leaking while shaking and cleanness inside the closure after dosing.

Testing these different options concludes that reducing the diameter will not solve the leaking problem of the closure, with ketchup and will also not improve the cleanness inside the closure after dosing. However, it does leak less than with the originally designed 6 mm orifice. Although this is then improving, it is not wanted by the stakeholders of Unilever to have multiple iterations of the closure.

	Closure 6 mm	Closure 4 mm (A)	Closure 4 mm (B)
Ratio	0.7	1.0	0.7
Dosing	 Dosing is good, stream is con-sistent	 Dosing is good, stream is con-sistent	 Dosing is good, stream is con-sistent
Leaking	 There is leaking	 There is leaking	 There is leaking
Cleanness	 Cleanness 3	 Cleanness 3	 Cleanness 3

Table 20. Experience of dosing ketchup with the 6mm closure the 4 mm closure and the 4 mm closure.

5.12 Production-ready

The closures will eventually be produced of Polypropylene with injection moulding, the same material and production technique as used for the original MPS closure. The final design is tested with 3D-printed prototypes of PLA, and the design is thus far been optimized for PLA and 3D-printing. Since these are not the final material and production technique, the design should be adjusted to these design rules and tolerances.

Tolerances of Polypropylene after injection moulding

DIN 16 901 is a standard for tolerances and acceptance conditions for linear dimensions for plastic mouldings (Deutsche norm, 1982). There are two types of dimensions, mould-related dimensions and non-mould-related dimensions. The mould-related dimensions are important to adjust with the polypropylene tolerances since these dimensions are the parts that need to be connected with each other.

There are two types of connection: a) a clamping connection or b) a movable connection, Figure 96. The designed closure contains both.

a) Is the clamping connection, this connection should have a minimal tolerance of 0.1 mm. So it will always connect.
b) Is the movable connection, this connection should have a tolerance of 0.0 mm. So it will always be movable.

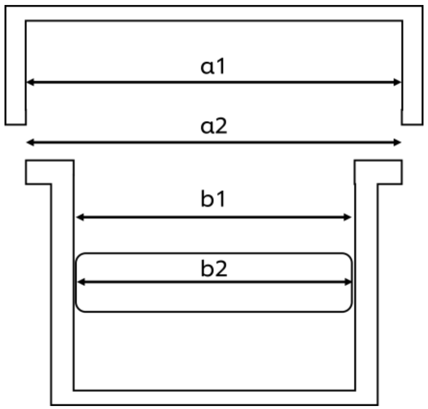


Figure 96. Example of the two different types of connections.

Below, in Figure 97, the two connections in the closure are highlighted. DIN 16 901 is used to find the right tolerances, Appendix IX. Since the material is general PP, the tolerance group is 150-B since the dimensions are also mould-related. The dimensions all fit in group 6-10, this means that the tolerance is ± 0.2 mm.

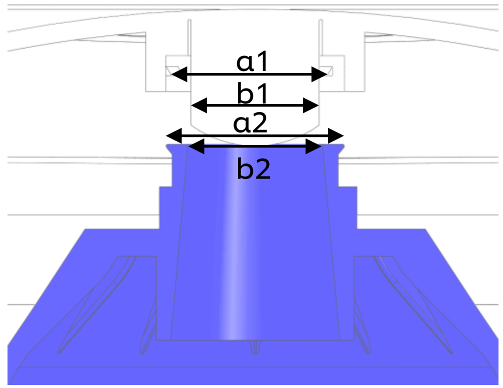
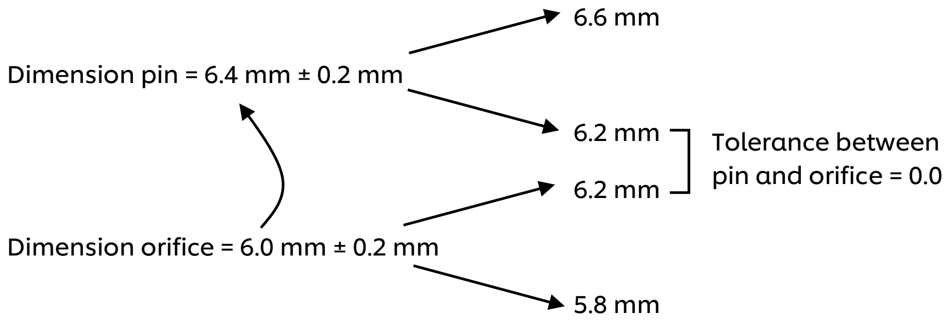
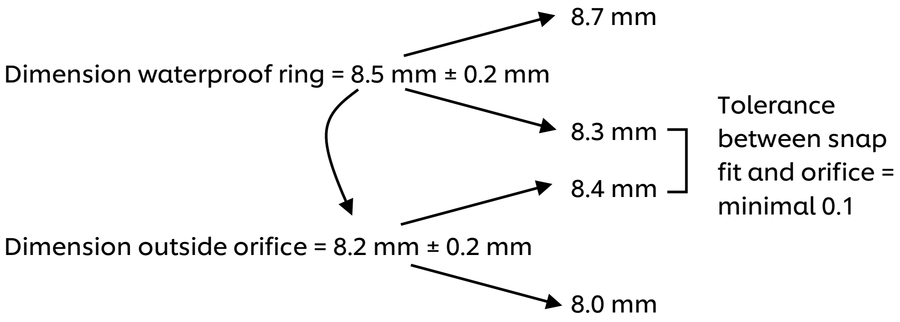


Figure 97. The two connections in the designed closure

The connection between the pin and the inside of the orifice is a movable connection. This connection should have a tolerance of 0.0 mm. The dimension that is fixed is the diameter of the orifice, this is 6.0 mm. The question is, what should be the diameter of the pin, so the pin can always move inside the orifice? The right dimensions of the diameter of the pin is thus 6.4 mm.



A similar calculation is needed for the annular snap-fits inside the lip-groove and the outside diameter of the orifice. This connection should clamp together, so the minimal tolerance is 0.1mm. The dimension of the annular snap-fits is only 0.25 mm, so this is fixed. Otherwise, the joints will become too small. With the fixed dimension of the snap-fits in the waterproof ring, what is the dimension of the outside of the orifice? This will be 8.2 mm, as shown below.



Adjusting the design for injection moulding

After adjusting the dimensions of the new orifice and pin design to fit the material and production technique, it is also important to optimize the part so it can be produced. One of the most important things with injection moulding is adding the right draft angles, so the product can be released out of the moulds after injection moulding. The closure itself is already been optimized, only the new design needs to be adjusted. Most Polypropylene products have a draft angle of 1.0 degrees when the height of the part is below 5 cm (Schwartz, 2022). The design is easily adjusted and is fully release-ready, Figure 98. The green colour means that the design is correctly drafted.

Except for the annular snap fits, those are undercuts. They are not in line with the draft angle and prevent its injection from the mould, Figure 99.

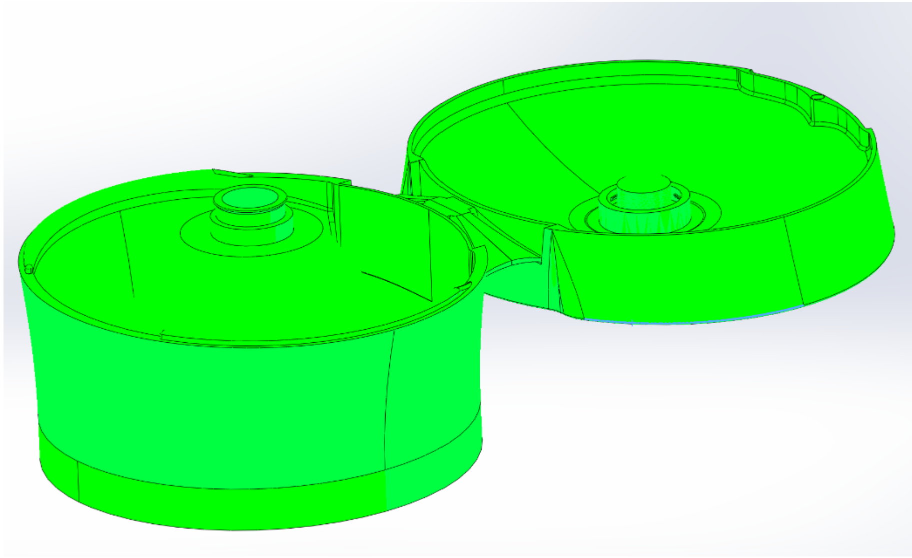


Figure 98. Draft analysis Solidworks of the new closure

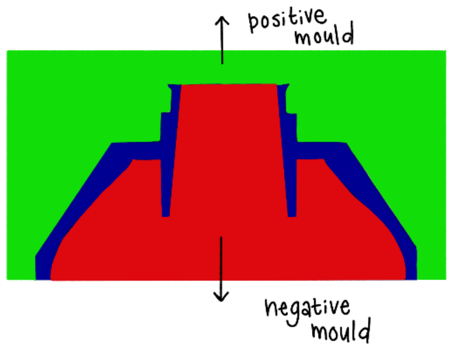


Figure 99. The two moulds for the new closure – body (positive mould = green, negative mould= red.)

Validating the production-readiness of the closure

It is possible to have undercuts with small dimensions in the design, these will not interfere with the release of the mould. However, the maximum undercut dimension is 0.14 mm (Ross, 2023) and the parts in the valveless closure are 0.25 mm and 0.27 mm on each side, Figure 100.

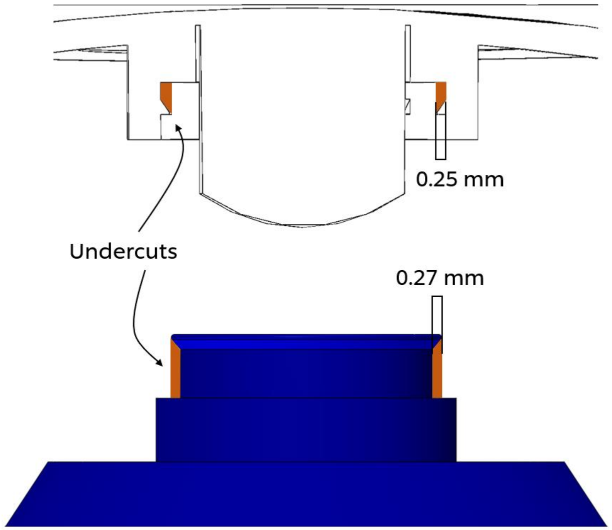


Figure 100. Undercuts of the annular snap-fit joints

This means that the undercuts should be altered to 0.07 mm on each side. It is possible to adjust these and still have working snap fits (Ross, 2023). The undercuts are the snap-fit beads in the design. The second change the beads need is a more rounded design, Figure 101 (Ross, 2023).

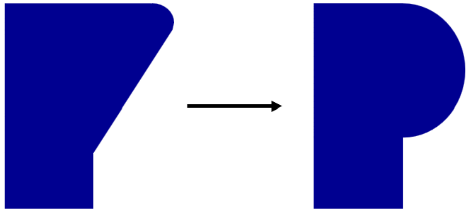


Figure 101. Changing the snap-fit bead to a more rounded design

The third snap-fit adjustment regards the place of the beads. When the beads are placed on the top of the orifice, the mould will deform the beads when the mould is extracted, Figure 102.

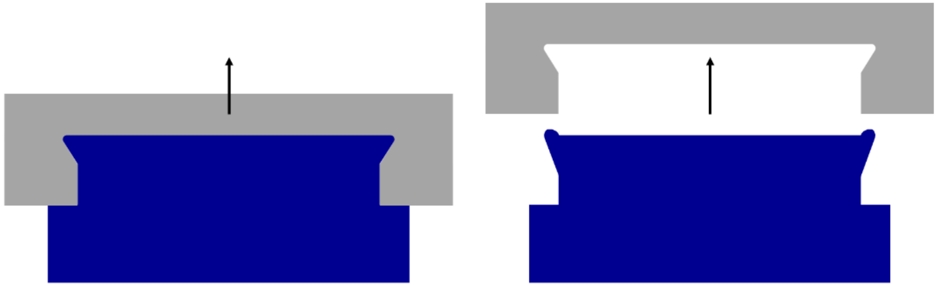


Figure 102. Snap-fit beads will deform when the mould is extracted.

This can be repaired by lowering the beads on the tube of the orifice, Figure 103 (Ross, 2023).

Figure 103. Lowering the snap-fit beads on the tube of the orifice

Besides altering the snap-fit beads, the designed closure should also be optimized for injecting the plastic during the injection moulding process.

This is done by the nozzle, which is the part that will inject the plastic into the mould but is not yet connected to the part, Figure 104.

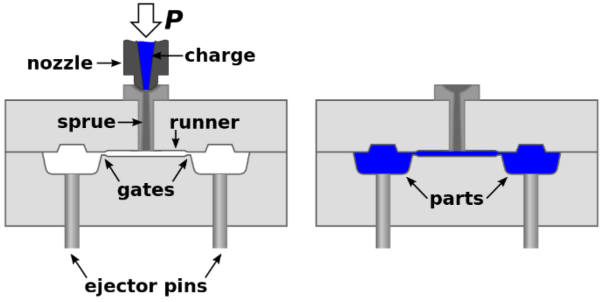


Figure 104. The parts of injection moulding (Wikipedia contributors, 2023).
The nozzle injects plastic into the sprue, which moves through the runner to the gates. These gates are connected to the products, Figure 105.

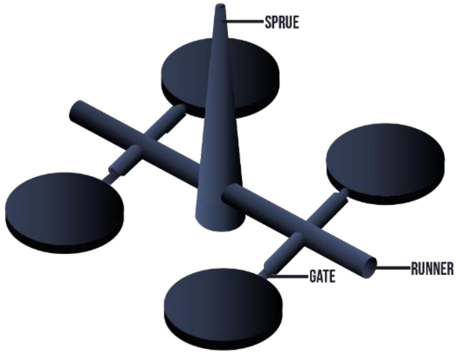


Figure 105. The sprue, runner and gate of an injection moulded product (Lechner, 2022).
These gates have a specific diameter and location. This is something that is desired and needs to stay the same as compared to the old closure. Not only because Unilever could possibly use their pilot mould, but also because the closure is still able to be filled completely. Since the current closure is a bi-injection mould (two coloured, transparent and blue), the closure has two injection points. The current closure has an injection point on the lid of the closure and on the top of the orifice. The two points are marked red in Figure 106.

Figure 106. Overview of the two injection points on the original MPS closure.
Since the part of the lid where the injection point is located, is not changed in the new design, there is no need for changing this part. But the orifice part is changed in the new valveless closure. The diameter of the injection point is 1.2 mm. Because of the wall thickness of the tube of the orifice is smaller than 1.2 mm, the injection point does not fit, Figure 107.

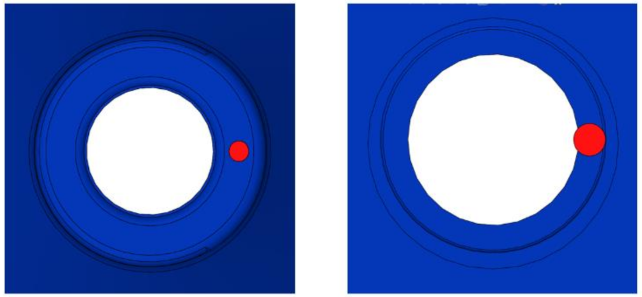


Figure 107. Injection point of 1.2 mm on the original closure (L) and the new closure (R).

Increasing the wall thickness to 1.4 mm will ensure that the same injection method can be used, Figure 108 (Ross, 2023).

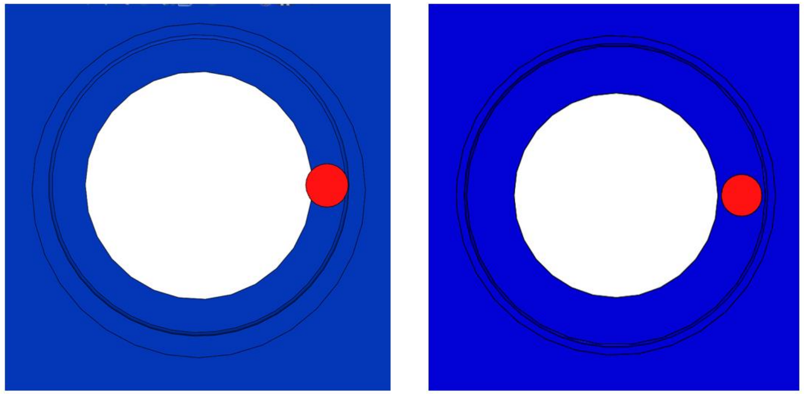
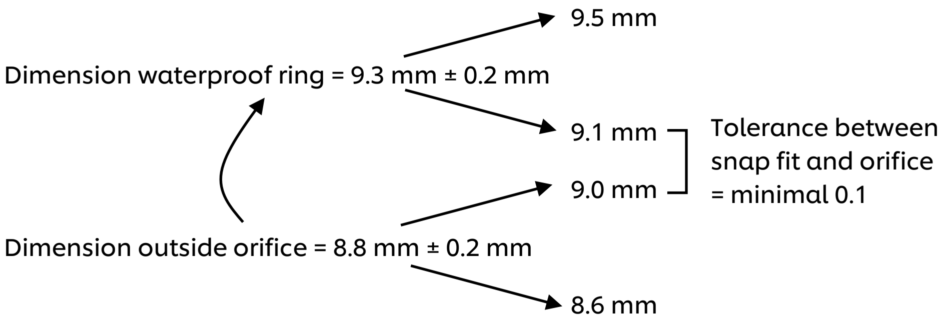


Figure 108. Increasing the wall thickness to 1.4 mm for the injection point, the earlier design (L), and the new design (R).

Because of all these changes, the earlier calculated tolerances for injection moulding PP are changing. Nevertheless, only for the outside of the orifice part and inside of the waterproof ring, parts a1 and a2 in Figure X. Since the wall thickness of the orifice tube was increased, the dimension of the orifice is fixed of 8.8 mm. This means the new dimension of the inside of the waterproof ring is 9.3 mm.



In Figure 109, the difference between the previous design of the pin and the waterproof ring can be seen. The shape and dimensions of the annular snap-fit beads, the dimensions of the pin and the dimensions of the waterproof ring are changed.

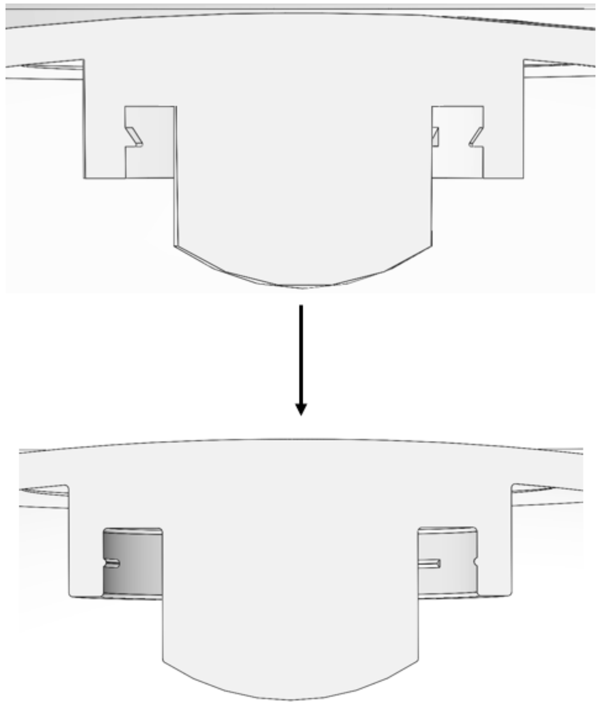


Figure 109. The previous design of the waterproof ring and pin (top) and the new design of the waterproof ring and pin (bottom).

These changes result in a production-ready lid of the newly designed closure. The same is done for the body of the new valveless closure. The wall thickness is changed for the injection point and the snap-fit bead is adapted to the injection mould requirements. These changes can be seen in Figure 110.

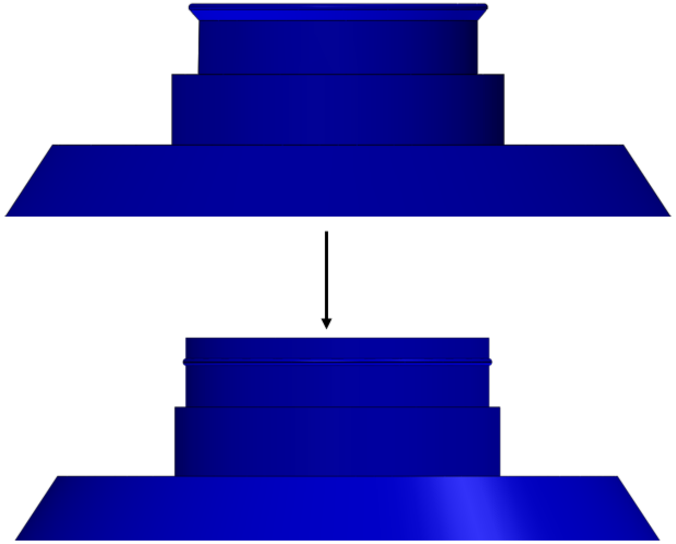


Figure 110. Previous orifice design (top), updated orifice design (bottom).
Injection moulded products should not have sharp corners but should all have a radius of a minimal 0.1 mm, Figure 111 (Ross, 2023). This is applied to the lid and body parts of the closure.

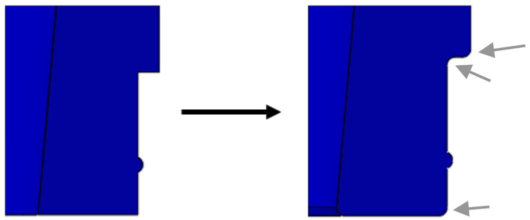
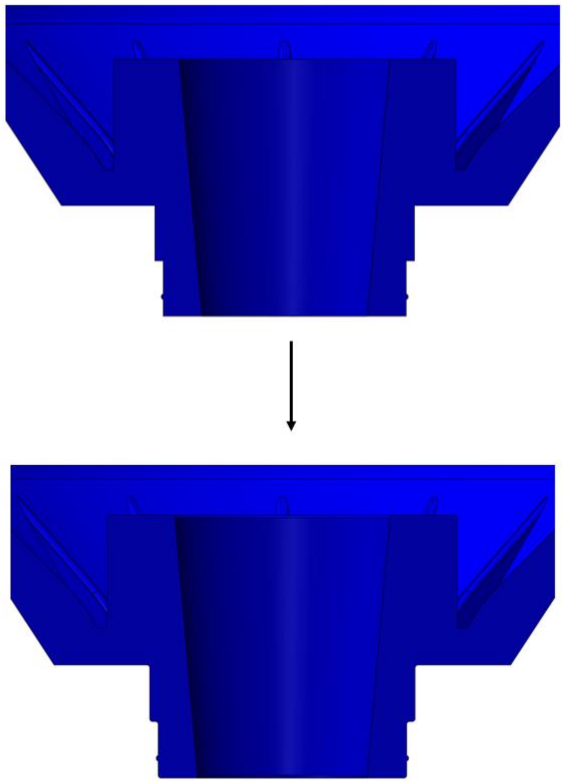


Figure 111. Improving the design by changing the sharp corners with a radius of 0.1 mm.



This results in the final end result for the orifice of the new valveless closure, Figure 112.

After updating the closure with these injection moulding-specific rules, “the design is optimized for the material Polypropylene and product technique injection moulding (Ross, 2023)”.

The future of closure regarding the production

After adjusting and validating the closure for the Polypropylene material and injection moulding production technique. The closure is made production-ready. The next steps are to let an injection moulding producer take a look at the closure, and validate what could still be optimized. However, before these final production steps are taken, the closure is inspected to see how well it would fit the already existing pilot mould. This is done by the producer of Unilever, and they are already looking into this, Figure 113.

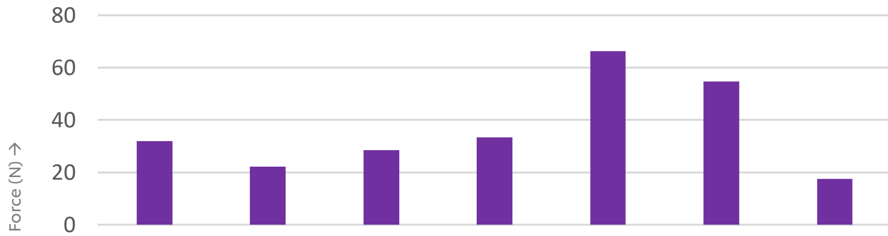
Figure 113. Schematic overview of the new design in the pilot mould (Reinderman, 2023).

5.13 Competitor Heinz

As mentioned in Paragraph 2.9, Heinz developed a new valveless closure, which only appeared on the market at the end of this project. Therefore it could not been taken into account during the development of the new valveless closure for the MPS, but the developed closure can be compared the two closures are, the physical differences are visible in Table 21. Multiple closure, bottle, and recipe configurations are squeeze-tested, Table 22. This is done to see the differences between the different closures and to see how the new valveless closure of Heinz works with different Unilever Hellmann's mayonnaise recipes.

	New Heinz closure	New MPS closure
Valve	Valveless	Valveless
Insert	PP insert	No insert
Orifice diameter	4mm	6mm
Recipe	Only Heinz ketchup	First-wave recipes
Colour	White	Two coloured closure (colour and transparent)

Table 21. Comparison between the new valveless Heinz closure and the newly developed valveless closure for the MPS bottles of Unilever brands.



Dosing (N)	31,91	22,27	28,38	33,43	66,22	54,61	17,52
Cleanness	4	4	2	2	1	1	4
Closure	Valve Heinz	100% recyclable/ valveless cap Heinz	Silicon Valve MPS	100% recyclable/ valveless cap Heinz	100% recyclable/ valveless cap Heinz	100% recyclable/ valveless cap Heinz	Monopoly (valveless)
Bottle	Heinz	Heinz	MPS	Heinz	Heinz	Heinz	MPS
Recipe	Heinz ketchup	Heinz ketchup	Heinz ketchup	Hellmann's real	Hellmann's Light	Hellmann's vegan	Heinz ketchup

Figure 22. Overview of dosing and cleanness results of the Heinz ketchup variations.

All test data results can be found in Appendix XV. After these tests it can be concluded that the new valveless closure of Heinz is not feasible for the mayonnaise recipes of Unilever, because the dosing force is high, especially for the Hellmann's light mayonnaise. Confirming that having an insert or bridge design as part of the orifice closure is unwanted. Something that was unexpected was the fact that the valveless Heinz closure leaks ketchup when shaking the bottle, something that the newly designed valveless closure for the MPS also does, but this one was not targeted towards ketchup.

06
Deliver

The final chapter of this thesis report contains the final design, the validation and experience tests, the recommendations, the discussion, and conclusion of the project.

6.1 The developed solution

Introducing the Mono Poly closure as the ultimate solution, Figure 81. This closure incorporates eight "unique" design features that improve recyclability while maintaining an ideal squeezing experience. In the following pages, each feature will be discussed in detail and its purpose in the design.

Two of these design features, feature 5 (the ratio of the length and the diameter of the orifice) and 8 (having a tapered tube), are new to the market. These are currently being researched and are about to be patent pending.

MONO

Mono[1] [mon-oh] - a combining form meaning "alone," "single," "one" (monogamy) https://www.dictionary.com/browse/mono;
One closure with a single holed orifice

POLY

Poly[1] [Pol-ee] - a combining form with the meanings "much, many" (polymeric) https://www.dictionary.com/browse/poly;
Fitting for the many Unilever recipes.

Figure 114. The new Mono Poly closure

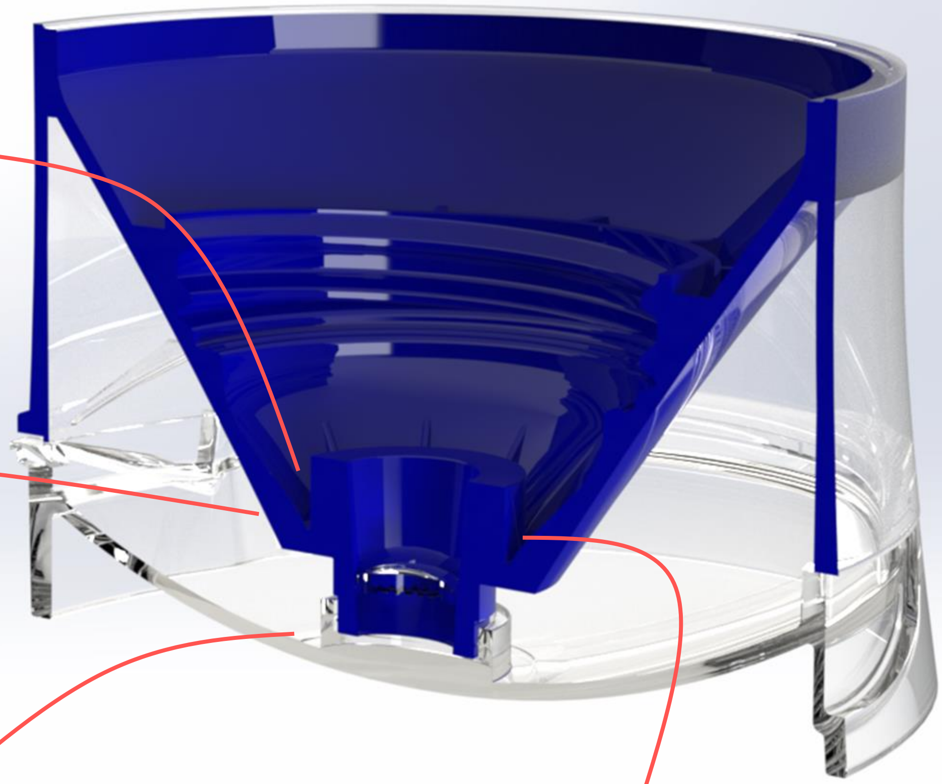


Figure 115. The new Mono Poly closure - intersection

Tapered design

The final design has a tapered tube, from 6 mm orifice outside to 8 mm orifice inside, this is around 5 degrees. This will enhance the already present features. The diameter of the tube closest to the bottle is larger than the other diameter, this will result in more resistance for the product to flow out of the tube, than inwards. Since the squeeze pressure is the same as the created negative pressure. The product will require more force to go from a larger diameter to a smaller diameter, than from a smaller diameter to a larger diameter. This decreases the chance of leaking because the product will be sucked further into the bottle than with a straight tube design.

Ratio

The final designed closure has a tube. This tube creates a ratio of 0.7, which fits the set requirements. Having a tube increases the dosing force since there is more resistance, but this will decrease the chance of leaking.

Waterproof ring design (lip-groove and annular snap-fits)

The final design has a lip groove that makes sure that the two parts can precisely join along the parting lines. With design feature 2, it is a non-permanent attachment. Used in this design to fit the pin and orifice, this also helps with creating a seal to the lid of the cap. When this stays clean, the orifice will stay clean. This lip-groove design will ensure that the inside of the part will get dirty, but since this will go inside the orifice (the part where the product will already be), no extra parts get dirty.
The final design consists of annular snap fit joints inside the lip-groove, around the pin. This will make sure that the lip groove snaps together, but is still separatable. These snap fits will prevent leaking since the lip groove will stay in place when shaking.

Inside tube

The final closure also has a tube on the inside, this reduces the change of leaking because there is more resistance. It also creates a place for liquid that is separated from products that experience syneresis. By having a place the liquid can leak to, there is less leaking inside the lid of the closure.

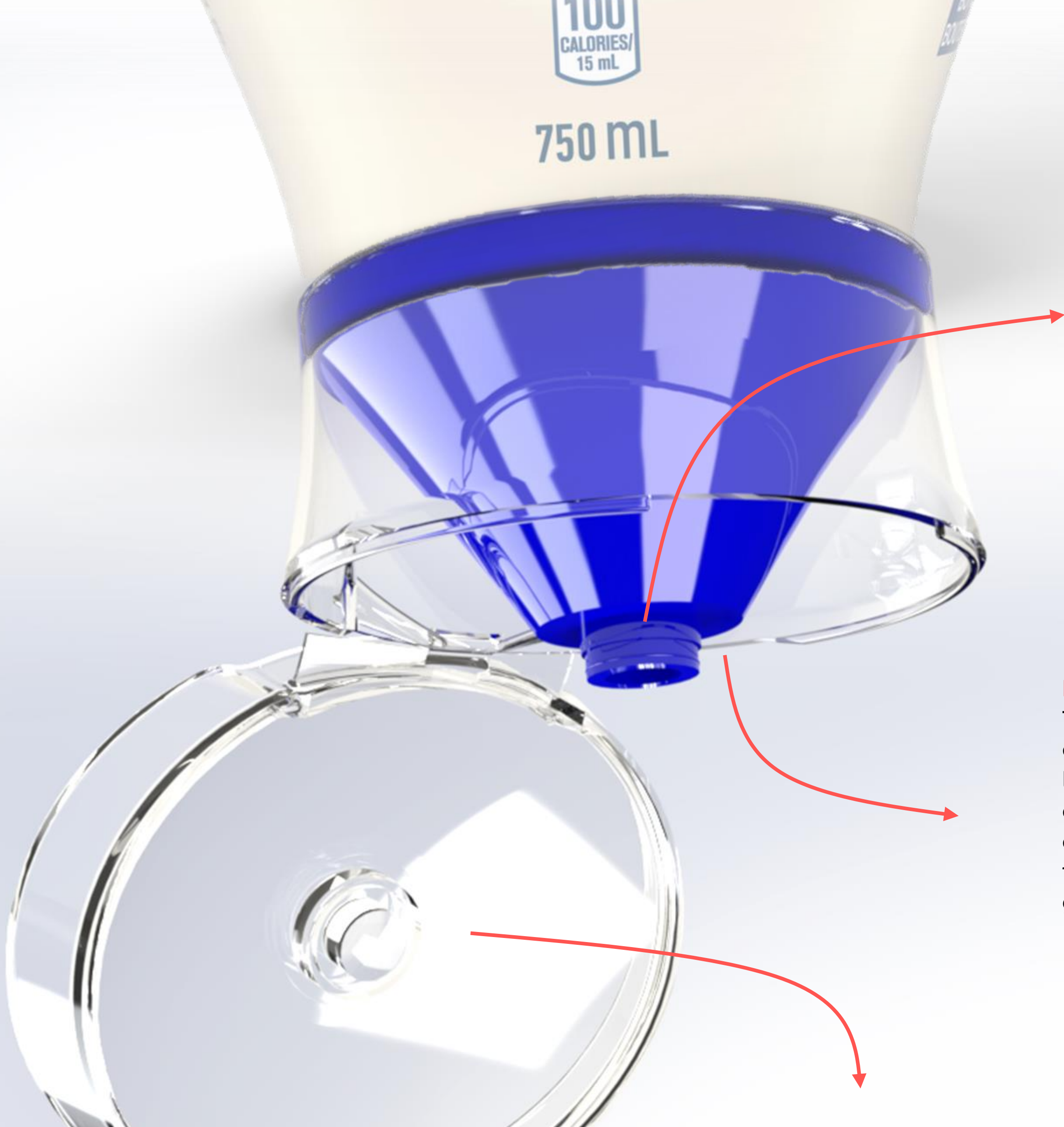


Figure 116. The new Mono Poly closure

Design of the orifice

The final design of the orifice is a circle. This has relatively the least wall area to reduce the chance of leaking. The diameter of the orifice is 6mm, this is compared to other orifices large. Having a larger orifice will reduce the required dosing force, improve the clean cut after squeezing and reduce the change of leaking with non-Newtonian fluids.

Flat top design

The final design has compared to the original MPS closure, a flat top part. This reduces the chance of leaking since a flat surface is created inside the closure. By just changing the top part of the closure, the original nozzle design stays. This fits the aesthetics requirement, but also helps guiding the liquid to the orifice.

Design of the pin

The final design is a solid dome, this helps with pushing the residue back into the orifice and less residue will stick to the pin. The pin fits exactly into the orifice.

6.2 The difference between the Monopoly closure and the MPS closure

Figure 117, shows the difference between the original MPS closure and the newly designed valveless Mono Poly closure.

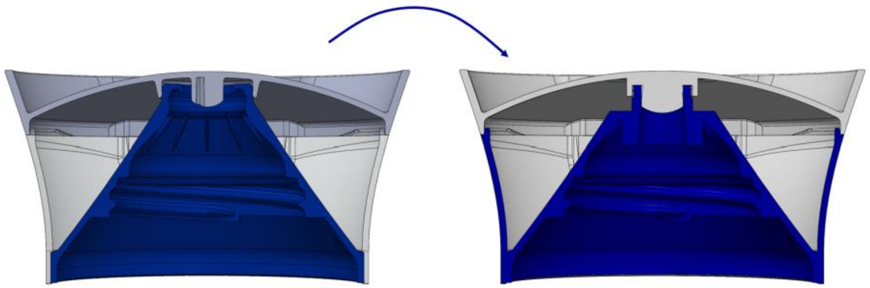


Figure 117. Original MPS (L), valveless Mono Poly closure (R)

It can be seen in Figure 118, that the outside orifice diameter becomes smaller. This could be a problem for using the same pilot mould as with the original MPS closure, since the injection point is on the top of the orifice. The hole orifice is also reduced. The original MPS closure has a hole of 8 mm for the PP insert, while the new closure has a hole of 6 mm.

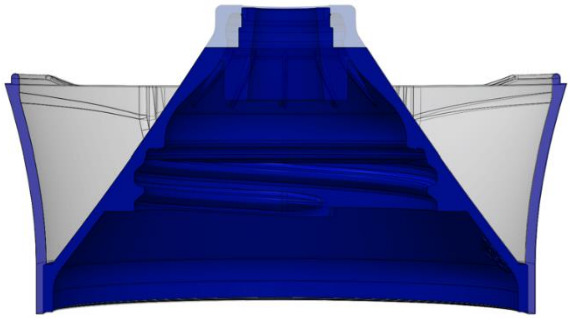


Figure 118. Overlay of the original and new body of the closures

The pin and waterproof ring are also changed, as can be seen in Figure 119. The pin diameter is enlarged, while the waterproof ring is smaller.

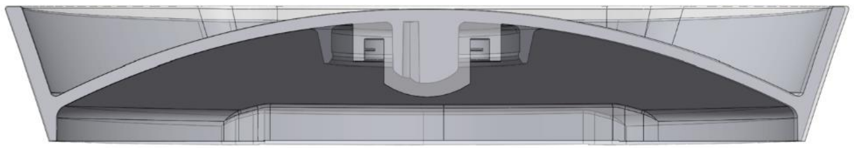


Figure 119. Overlay of the original and new lid of the closures

The weight

The weight of the original MPS closure is calculated by Solidworks with a density of polypropylene of 0.000933 g/mm^3 and is 11,39 grams. The original MPS closure also has the valve (0,07 grams) and a PP insert (0,15 grams), this results in a total weight of 11,61 for the original MPS closure.

Calculated by Solidworks, the newly designed Mono Poly closure is 11,77 grams. Since this closure is valveless no extra weight is added besides this. This means that this valveless closure is slightly heavier than the original closure. This is not unexpected, since the original closure had less amount of plastic needed to ensure the dosing experience. Only a thin layer of silicone is needed for the valve. With the new design, there is more plastic needed to create a design to ensure the desired dosing experience.

It is expected that this difference of 0,16 grams is an acceptable difference.

6.3 Structured Team Assessment

To validate the closure, the closure should be tested by consumers with multiple recipes. However, this is not possible in this project timeframe, due to the fact that the closure is confidential since two features are still patent pending. This means that the closure cannot be tested by a self-setup test. Unilever's protocol needs to be followed for testing. The CTI (Consumer Technical Insights) department of Unilever handles these tests, which are called STA's (Structures Team Assessments).

Method

The goal of these tests is to validate which recipes are compatible with the new valveless closure(s). This is done by comparing the new valveless closure to the Marco Polo Squeeze closure. Additionally also by comparing the Interkap valveless closure to the Marco Polo Squeeze closure. The Interkap closure is also included in these tests since Unilever sees this as a feasible valveless solution with a short implementation time. It is thus interesting to know how the newly designed valveless Mono poly performs in comparison to the original closure but also to the Interkap closure.

Recipe	Amora Barbecue	Hellmann's chunky burger sauce	Hellmann's real mayo	Amora mayo de Dijon	Calvé maionese
Picture					
Quantity	250 ml	250 ml	430 ml	430 ml	750 ml
Peculiarity	Low viscosity	Chunks	Higher viscosity	Normal viscosity	Large quantity

Table 23. Overview of STA recipes

For these tests, 5 recipes are used, Table 23. These recipes differ in composition, from low viscosity to high viscosity to a recipe with chunks. And also with different quantities, from 250 ml, 430 ml, to 750 ml. These recipes are tested twice by the participants, one time with ambient temperatures and one time after a day in the fridge, chilled.

To test these 5 recipes with the 3 closures and 10 participants, 50 new valveless Mono Poly closures needed to be 3D-printed. The participants are asked to compare the valveless design to the MPS closure on seven features: Product cut-off, flow consistency, precise dispensing, amount of product coming out in one squeeze, effort to squeeze, presence of product syneresis and return to original shape/panelling. The participants are able to answer with six possible answers: Equal to reference, slightly different, moderately different, distinctly different, very much different, and extremely different. Besides these quantitative questions, certain qualitative questions are asked:

After ambient and chilled test :

1) What are the main differences in squeezing experience?
2) What are the main visual differences of the squeezed product (e.g. air bubbles visible, oiliness)?
3) General remarks.

Only after the chilled test:

4) Are the differences acceptable? Please explain why or why not.
5) Will the differences change your purchase intent in future occasions? Yes/no

More information about the method can be found in Appendix XI, and all test results are in Appendix XII.

Discussion

Important to know before looking at the results is the way the results are gathered. Since the questions are formulated to know the difference in performance compared to the original closure, a difference could still be positive. Meaning that the answer equal to the reference is in all cases a positive answer. But if the answer is slightly different, moderately different, distinctly different, very much different, or extremely different, the difference could be positive or negative. This is not immediately clear. This is because the STA is not set up to gather this information, which makes it unclear to conclude a result.

To make the results useful, the quantitative data is processed in a different way. As earlier mentioned, equal to reference is a positive result. So for each closure/recipe/temperature configuration, the equal to reference percentages are added up to calculate the percentage that is equal to reference. Added up percentage / total percentage = percentage equal to reference.

It is good to know that a lower score in the equal to reference percentage does not mean that the closure performs less, but can also mean that the closure performs better. Since a difference can be negative or positive.

Results

In Table 24, is the overview of equal to reference percentages per closure, per recipe, and per temperature.

It is clear that overall the chilled tests were more equal to the reference than the ambient tests (except for the chunky burger sauce). This is probably due to the fact that the viscosity of a product increases in the fridge, and this has a positive effect on valveless designs. Except for the Hellmann's chunky burger sauce, the Interkap closure is overall more similar to the reference than the Mono Poly closure. As mentioned before, this does not mean the Interkap closure performs better than the Mono Poly closure, this just means that the Interkap closure is more similar to the Marco Polo closure. This will be researched in a different way.

Legend:

Mono Poly closure Ambient
Mono Poly closure Chilled
Interkap closure Ambient
Interkap closure Chilled

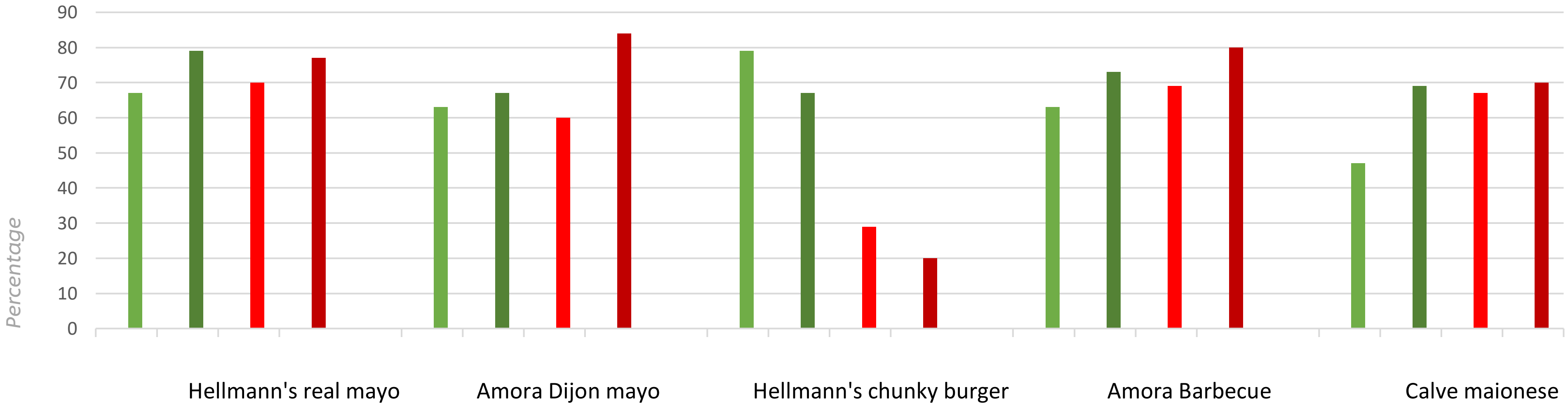


Table 24. Overview of STA results, percentage equal to reference

Questions 1,2 and 3 are open questions and will result in qualitative data. These answers will help in understanding whether the differences outside of equal to reference, are positive or negative. This is done by noting down if a comment was negative, positive, neutral or no difference. Examples of comments whether they are negative, positive, neutral or no difference. *Negative*: Requires more dosing force, dirty cap or inconsistent flow; *Positive*: less effort to squeeze or better dosing; *Neutral*: more or less product coming out of star-shaped product; *No difference*: equal to reference or no difference.

		Positive	Negative	Neutral
Mono Poly	Ambient	47	13	21
	Chilled	30	15	24
	Total	77	28	45
Interkap	Ambient	18	36	13
	Chilled	15	32	11
	Total	33	68	24

Table 25. Overview of type of comments

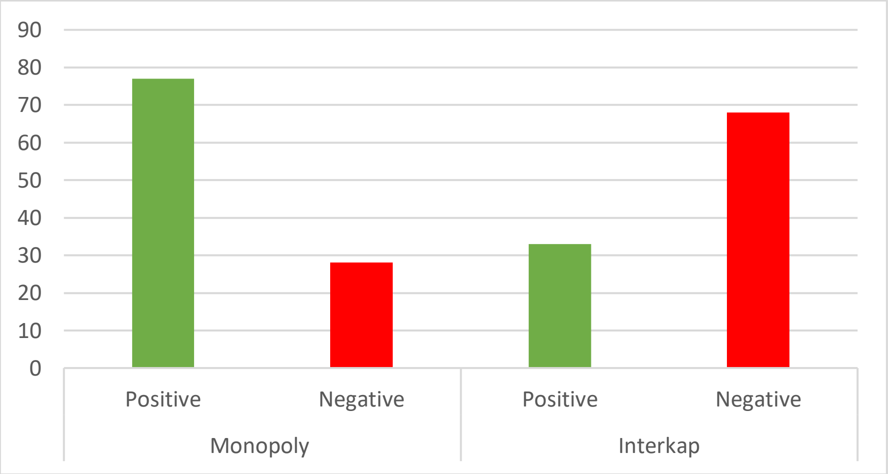


Table 26. Overview of the amount of positive or negative comments.

Earlier was stated that the Interkap closure is more equal to the reference closure. However, when looking at the type of comments in Table 25, it can be concluded that the Mono Poly closures perform better, since the amount of positive comments is higher than that from the Interkap closure, Table 26. Something that you would not expect if just the original data was used.

Questions 4 and 5 ask if the differences are acceptable and if they will change your purchase intent. The way that question 5 is formulated is a bit unnatural, since the answer yes is negative, and the answer no is positive.

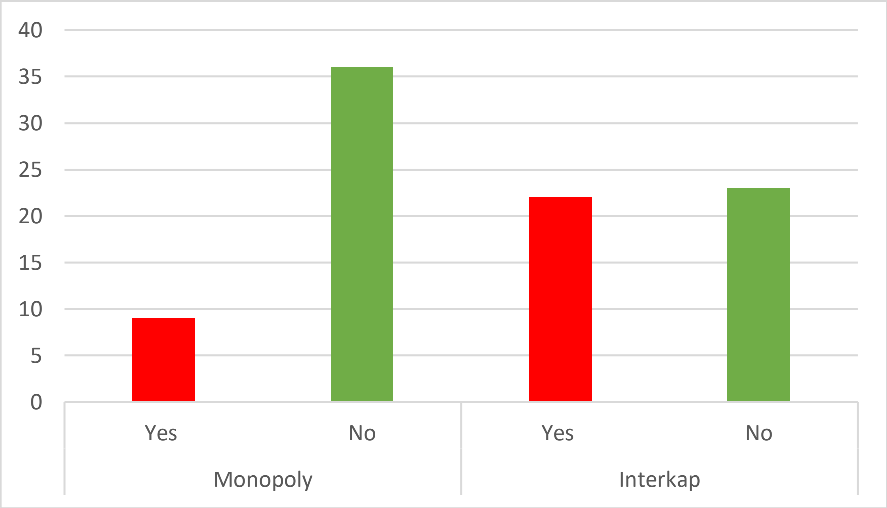


Table 27. Overview of changes in purchase intent

Conclusion

This overview (Table 27) shows a clear preference for the Mono Poly closure. Which is a positive end result for this project. However, it is important to take into account that this data is only from 9 participants and the questions could be formulated better to get more specific insights. More recommendations in Paragraph 6.8.

6.4 Technical drawings

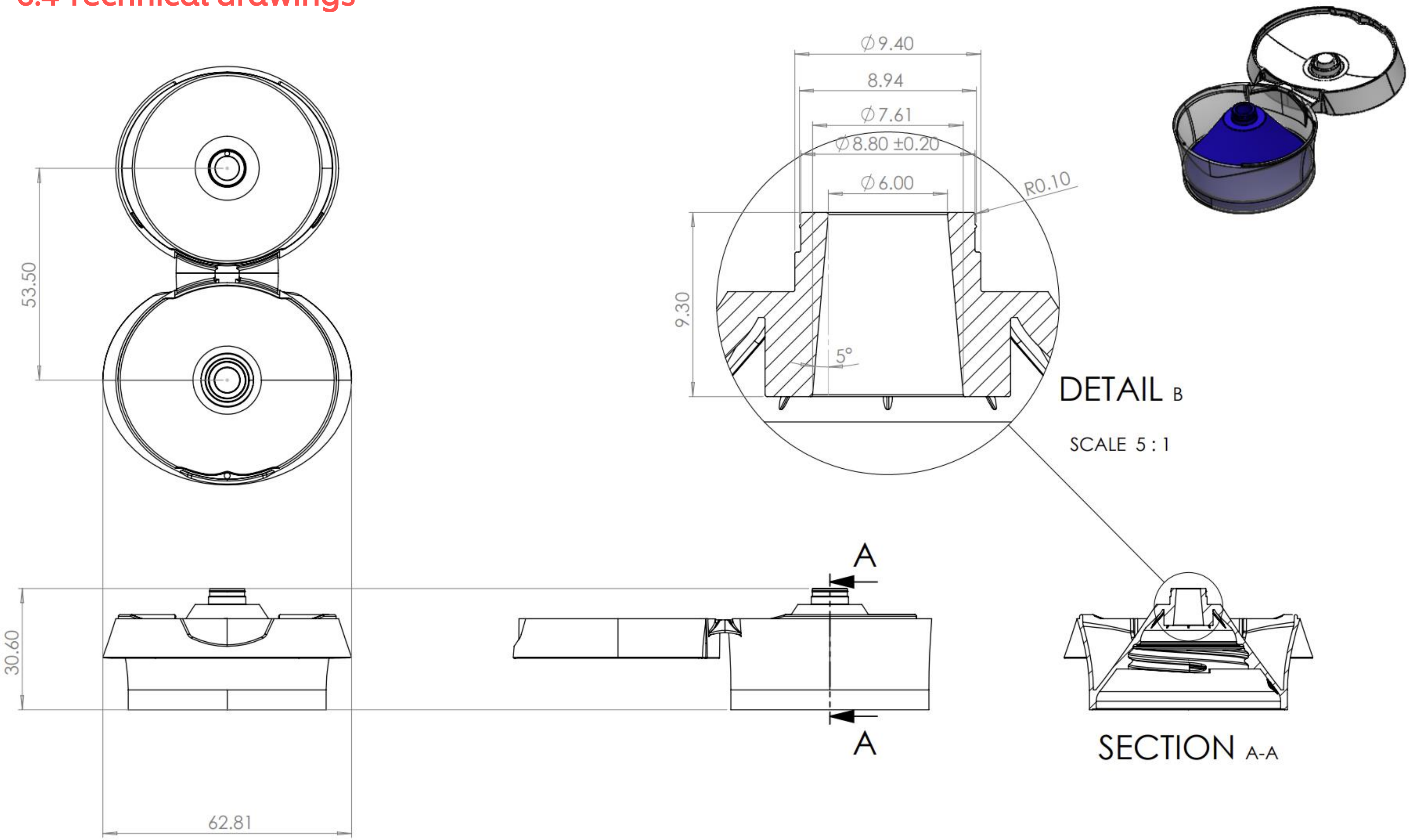


Figure 120. Technical drawing 1

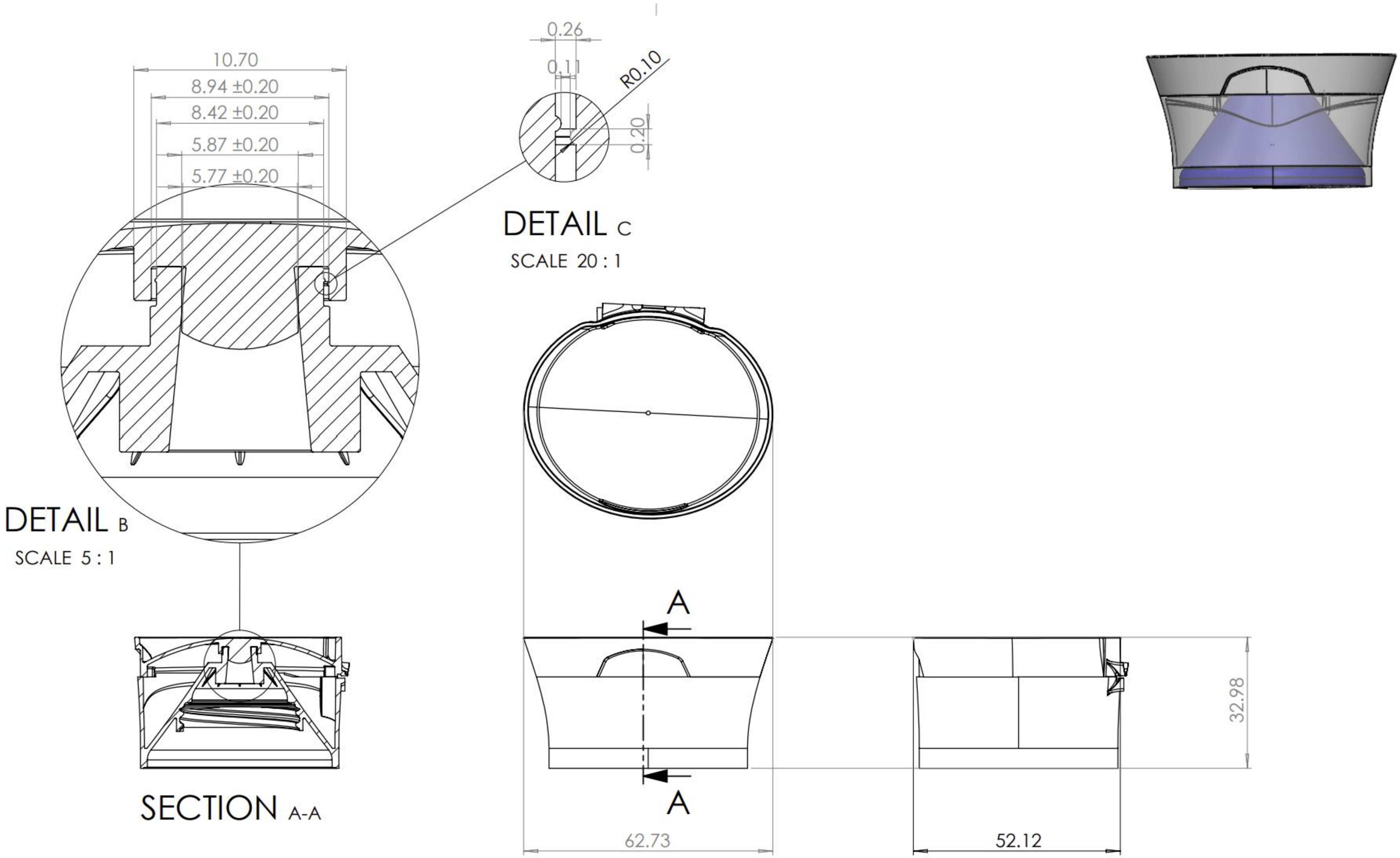


Figure 121. Technical drawing 2

6.5 Validation of the design

Although the new Mono Poly closure is designed with the requirements as goals, it is important to check those requirements and validate whether or not the set design assignment is been solved.

Requirement check

The requirements list of Appendix IV is checked. This requirement check can be seen in Appendix XIII. Most requirements are met, some still need to be tested, but it is promising that they will also check out. The most important requirements mentioned in Chapter 2, Paragraph 8 are checked below.

- *The cleanness inside the closure after dosing*
  The cleanness requirement explains that the cleanness inside the closure after dosing 10 times 13 grams of products scores no more than a 3 on the drafted cleanness scale. This is validated with the tests in Chapter 5, Paragraph 5.10. This requirement is checked.

- *A dosing force lower than 60N*
  This requirement is met, the first-wave recipes are tested with the new closure and all of them score much lower than the maximum required dosing force of 60 Newtons.

- *Outside dimensions stay unchanged*
  The fitting solution is designed in the 0.65 cm^3 set design space. Nothing outside of this area has been changed.

- *Aesthetics of the closure stay unchanged*
  As mentioned above, the design is only developed in the 0.65 cm3 design space, this leaves the aesthetics of the closure the same. The iconic cone design of the closure remains untouched.

- *Mono material design*
  The developed valveless Mono Poly closure is developed and optimized for injection moulding out of polypropylene. The closure can be moulded in one go, no inserts are needed.

- *Optimized for injection moulding*
  As mentioned in the above requirement, the closure is optimized for injection moulding. All the rules of the production technique are incorporated into the closure (Ross, 2023).

- *In line with upcoming legislation changes*
  The already mentioned requirements incorporate this requirement. The closure is a valveless mono-material closure that can be produced with polypropylene, making it 100% recyclable. This requirement is checked.

Investor b

As explained at the beginning of this thesis, the Investor board is the most important stakeholder in this project. The investor board should agree with the developments regarding the Mono Poly closure. However, this is not something that is asked in such a direct way. The Monopoly team calculates, tests and advises the investor board. Each Wednesday the Monopoly project is discussed with the Monopoly team. This team stands behind the developments of the Mono Poly closure.

Production-ready validation

As described in Paragraph 5.122, the design is optimized for the Polypropylene material and injection moulding technique. This is validated with M. Ross, an expert in developing injection moulding products within Unilever.

Patent-validation

As mentioned in Paragraph 6.1, two features of the new Mono Poly design are being patented. It is important to know if are there patents that interfere with the two patents to file.

The two patents to file are about the next two features, Figure 122:

1) The tapered design towards the outside of the closure, with a larger diameter outside than inside the closure.

   Dispensing cap (1) comprising:
   A body (2) and a lid (3), hingeably connected to each other via a hinge (9),
   wherein the body (2) comprises a spout surface (4) and a conduit (6),
   wherein the conduit has an exit orifice (7), and an entrance orifice (18), and
   wherein the inside of the conduit is tapered, with the exit orifice (7) having a smaller diameter than the entrance orifice (18).

2) The ratio of the length of the orifice compared to the diameter of the orifice.

   Dispensing cap (1) comprising:
   A body (2) and a lid (3), hingeably connected to each other via a hinge (9),
   wherein the body (2) comprises a spout surface (4) and a conduit (6), with an inner length L,
   wherein the conduit has an exit orifice (7), with a diameter D, and an entrance orifice (18), and
   wherein the ratio L:D is from 0.5 to 0.9, preferably from 0.6 to 0.8.

The legal department of Unilever researched the to-be-filed patents against the existing patents. They put a list together of existing patents to research if they interfered with the two new patents. At first sight, they are not similar enough to the to-be-filed patents. The tapered design is new since the tube is perforating the wall of the closure, meaning that a part is sticking out on the outside and inside of the closure. Having such a tapered tube is new. In the to-be-filed ratio patent, the length is smaller than the diameter of the orifice. Meaning that in a L:D ratio, the ratio is smaller than 1. Existing patents, claiming a ratio have ratio's larger than 1. However, this is not the final search, they are researched even further. This is explained in Paragraph 6.8. But at the first sight, it looks promising.

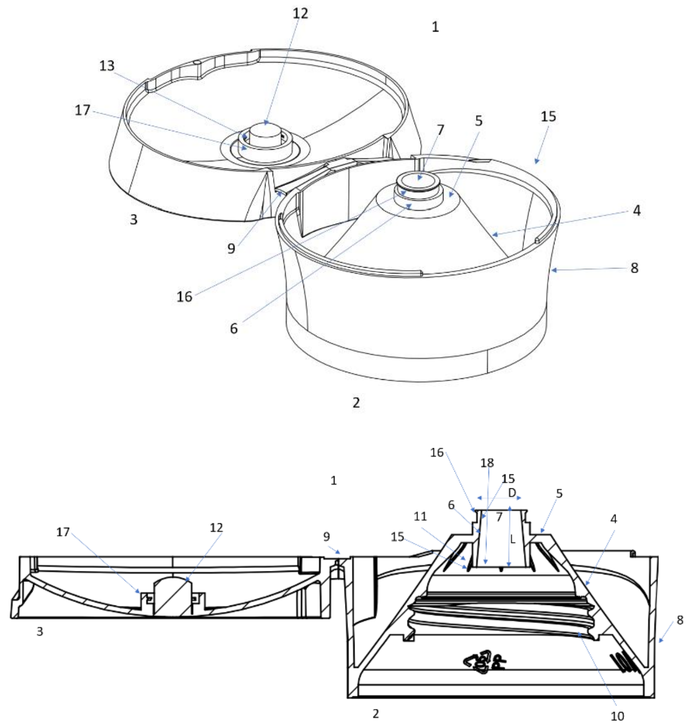


Figure 122. Overview of parts of the new Mono Poly closure.

6.6 Discussion

The tests during this project are all conducted with 3D-printed prototypes. These prototypes are as mentioned before, made with a FDM printer out of PLA. This results in a rough surface of the product, rougher than an injection moulded product would be. This roughness will probably decrease the cleanness of the closure since these edges will cling more to the mayonnaise than a smooth surface. It can be expected that having prototypes of the closure with a smooth surface, the cleanness of the inside of the closure will be improved. By choosing FDM as the prototype technique with PLA, to quickly develop the prototypes, it was not able to print a working hinge. Since this was not a feature to test, it was not considered a problem. The hinge was forged by using a piece of duct tape. This allowed the closure to open and close. But it was not ideal. Although it was explained to the STA participants, it was considered an inconvenience and affected the results in a negative way. By prototyping the closures with a different technique and material, as mentioned above, this will be solved.

The UMA-6341.02 squeeze test method is as described in Chapter 2, not a real comparison to a consumer squeezing the packaging. Since a consumer is squeezing with more than 1 point, for instance, with 1 or 2 hands, it is likely that a higher dosing force is achieved earlier. This is something to take into account when tests with consumers are conducted. It could be possible that the required dosing force is too low and it is unwanted that the products leave the closure with too low an effort.

As mentioned before, the way the questions were formulated for the STA results, gave not the wanted results. The questions should be formulated more independently, to know how the feature performs, instead of immediately asking for the difference between closures.

6.7 Conclusion

During this project a successful solution for the given assignment was developed: to design a new sustainable closure for the Marco Polo Squeeze bottles of Unilever, that is compatible with the first-wave recipes, and ensures the same dosing experience without changing the outside dimensions and aesthetics of the current closure. As will be explained, there are still a lot of steps needed to get this closure on the market. Starting with some more testing, producer alternations, setting up the production lines etc. However, this project has come to a successful end, the closure has been developed as far as the initial assignment desired. There was a desire of Unilever that the developed closure could be patented. This was not taken into account as a requirement for the project. Nevertheless, it is a desirable development that this is the case. Making the end result much more valuable for Unilever.

6.8 The future

Although this project has come to an end, the Monopoly project has not. The Monopoly team will continue the project to improve the closure further to get it market-ready. After being part of this project team and developing the Mono Poly closure, there are of course recommendations for the future steps:

- Further developing the cleanness scale. Validating this with more pictures and more stakeholders and/or consumers to create a larger database. This way the cleanness scale is even more dependable and can be used in the next projects.
- The closure should be tested with a different prototype. One where the surface is smooth and the hinge is working properly. This will result in more reliable test results. It could be solved by using a different 3D printing technique or using a pilot mould. This new prototype should be tested with the UMA-6341.02 squeeze test method but also with another STA and consumers.

- As previously mentioned, the STA tests should be run again in a different form, where the questions are formulated differently. To know if the closure performs up to standards and is acceptable. Not focusing on the comparison to the original closure, but mainly on the performance of the new closure.
- The closure should be tested with consumers (outside of Unilever), and be compared to competitor closures. This is a test that Unilever has performed before with consumers. It would be interesting to test the new Mono Poly closure with other valveless closures on the market, for instance, the 4 mm orifice closure of Heinz, the newly developed valveless closure of Heinz, the AH valveless closure or the valveless closure of Remia.
- The closure should undergo final adjustments from the producer, to finalize the optimization for the material and production technique. This needs to be done for the pilot mould by the producer. Therefore it is important to know what features and dimensions are vital to the working of the closure, and what is allowed to change:

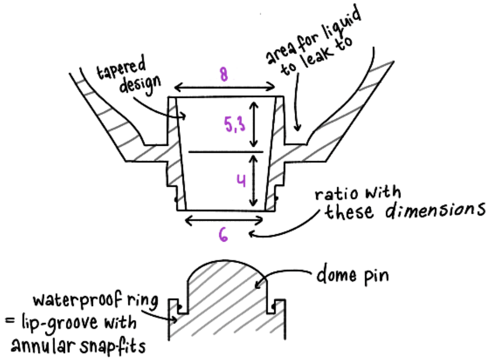


Figure 123. The restrictions of the design

The ratio of the orifice should remain 0.7, with an outside diameter orifice of 6 mm and a tapered designed tube, that protrudes outside and inside. Resulting in a space for the liquid to leak. The waterproof ring should clamp around the outside of the orifice, while the pin fits inside the orifice hole. The waterproof ring is fixed to the orifice with a lip-groove design and annular snap-fits.

- The excisiting patent search should be finalized, before finalizing the patents and filing them. For this, it is important to know what makes the two features different from other patents. What is the uniqueness of the features?

  Ratio patent: The ratio is different from other patents (found so far) since the diameter of the orifice is larger than the length of the orifice. Resulting in a ratio smaller than 1 -> 0.7.

  Tapered tube patent: The tapered design is towards the orifice opening and the tube is partly inside and partly outside. That the tube is protruding the top wall of the closure is a unique feature.

- With the squeeze tests, investor board tests and STA, is researched what recipes are fitting for the new closure, and which recipes will be less suitable. Although not in the initial scope (the first-wave recipes), the ketchup recipe did not fully meet the set requirements, and the cleanness inside the closure was too messy (scored a 3.5 instead of the maximum of 3 on the set cleanness scale). As mentioned earlier, the colour of the closure can reduce the cleanness appearance of the inside of the closure. Since the ketchup recipe is red, a red closure could help perceive the closure as less messy. This is something that is worth looking into.

- A final recommendation would be to validate the Mono Poly closure with two more standard Unilever tests, when the improved prototype is developed. The leakproof tests, where the packaging is placed top-down or on the side to tests how much leakage there is to the lid of the closure. And the empty test, is the bottle easy to empty where less than 10% product remains inside.

Appendices

This last chapter contains all the appendices, from the references used, list of requirements to the test data. The appendices are visible in the separate Appendix file.

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The other appendices

Other appendices can be found in the Appendices pdf file consisting of the following appendices: