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SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Project work in a company : Development of a closure system for a pressurized insulated food container at BlueThink S.p.A

Tesi di Laurea Magistrale in
Mechanical Engineering - Ingegneria Meccanica

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Abstract

Numerous food packaging companies have to face pressure related challenges in the development of their product, with more or less success. This thesis dives into the impact of pressure generation inside simple food containers on their mechanical performance, aiming to provide innovative solutions for the user to open the lid effortlessly.

The primary objectives of this research are to understand the cause for the blockage of the lid, identifying the potential variables that have a role in this, and propose ways to cope with the problem at hand. The study seeks to add yet another solution to the ones existing on the market.

An extensive research design was employed, including benchmarking analysis, international food contact standards breakdown, various solutions comparison with selected KPIs, CAD model simulations, and prototype testing. The designs generated were based on 3 main categories: block the problem's source, slow down its effect, or modify the mechanical behavior of the container.

The main findings revolved around creating straightforward yet efficient systems, whose material recyclability could be optimized while still being easy to use. The principal design followed the idea of activating a structure that liberates some of the pressure build-up; by separating the lid concentrically and keeping partial connections, the user unknowingly opens an air channel whose shape blends into the structure all the while opening the lid.

This master's thesis underscores the critical importance of addressing pressure problems in food containers. By presenting an analysis of the impact of food spoilage and ways to tackle it, we contribute to the development of an innovative design solution that could be used by manufacturers. The study also recommends pivoting towards using smart technologies to monitor pressure conditions more precisely.

Keywords: food container, pressure relief system, microbial activity, pressure valve, container lid system

Abstract in lingua italiana

Numerose aziende produttrici di imballaggi alimentari hanno dovuto affrontare sfide legate alla pressione nello sviluppo dei loro prodotti, con più o meno successo. Questa tesi approfondisce l'impatto della generazione di pressione all'interno di semplici contenitori per alimenti sulle loro prestazioni meccaniche, con l'obiettivo di fornire soluzioni innovative per consentire all'utente di aprire il coperchio senza sforzo.

Gli obiettivi principali di questa ricerca sono la comprensione della causa del blocco del coperchio, l'identificazione delle potenziali variabili che hanno un ruolo in questo, e la proposta di modi per affrontare il problema. Lo studio cerca di aggiungere un'ulteriore soluzione a quelle esistenti sul mercato.

È stata impiegata una ricerca approfondita, che ha incluso l'analisi di benchmarking, l'analisi degli standard internazionali di contatto con gli alimenti, il confronto di varie soluzioni con KPI selezionati, la simulazione di modelli CAD e il test di prototipi. I progetti generati si basavano su 3 categorie principali: bloccare la fonte del problema, rallentarne l'effetto o modificare il comportamento meccanico del contenitore.

I risultati principali si sono concentrati sulla creazione di sistemi semplici ed efficienti, la cui riciclabilità dei materiali potesse essere ottimizzata pur restando facile da usare. Il progetto principale ha seguito l'idea di attivare una struttura che libera parte della pressione accumulata; separando il coperchio in modo concentrico e mantenendo connessioni parziali, l'utente apre inconsapevolmente un canale d'aria la cui forma si fonde con la struttura, mentre apre il coperchio.

Questa tesi di laurea magistrale sottolinea l'importanza critica di affrontare i problemi di pressione nei contenitori per alimenti. Presentando un'analisi dell'impatto del deterioramento degli alimenti e dei modi per affrontarlo, contribuiamo allo sviluppo di una soluzione progettuale innovativa che potrebbe essere utilizzata dai produttori. Lo studio raccomanda inoltre di orientarsi verso l'utilizzo di tecnologie intelligenti per monitorare con maggiore precisione le condizioni di pressione.

Parole chiave: contenitore per alimenti, sistema di scarico della pressione, attività mi-

crobica, valvola di pressione, sistema di coperchio del contenitore

Contents

Introduction

This thesis work is based on the closure system for a pressurized food container.

Firstly, the container in itself is evaluated and analyzed, which is usually double walled with vacuum as insulation to keep food warm longer. All existing systems used to close food containers and their ability to counter temperature loss and even pressure if applicable will be assessed.

Then, a phase is dedicated to generate innovative solutions, basing ourselves on the state of the art and coming up with new systems for closure of the food container.

A phase concerning Concept Design comes after, where the solutions are "brought to life" by generating some calculations and CAD models, but also simulating them. This phase is of course followed by a comparison and thus an evaluation of the designs we have so far.

Finally, a phase of prototyping and a testing campaign is carried out on the best designs, in order to further understand if they can fulfill the wanted requirements.

All through the concept phase, the solution design will undergo some iterations of modification regarding Design for Manufacturing, such that the product could be processed more easily and could be ready to be sent to industries to be produced.

1 | Problem analysis

1.1. Project scope

A commercial model of food pot has the problem that the user cannot open it when he/she stores food which is prone to fermentation. The chemical fermentation releases carbon dioxide which increases the pressure inside the pot. Pressure increase prevents the user from unlocking the lid and eventually may lead to the pot explosion.

It is necessary to develop a technical solution which can avoid pot explosion and allow the user to open the lid in a safe manner even when pressure increases inside the pot.

1.2. Project decomposition

First of all, it is necessary to understand what we are dealing with. In the food and container industry, a food pot (or food jar) is a closed cylinder object, large enough to fit food inside that is in solid or liquid form. Volumes can vary but we can concentrate on this project on a $500mL$ container.

Moreover, the food jar characteristics are usually to keep hot food warm for a long time, and cold food fresh for a long period of time, longer than if the food was stored outside and longer than if it was placed in a simple container. Therefore the so-called "food pot" is almost always built with the same necessary parts:

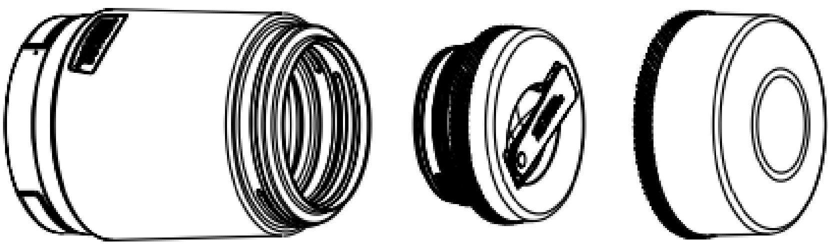


Figure 1.1: Generic food pot parts decomposition

- The jar body is often in stainless steel, and is double walled: the inner and outer walls are thin sheets of steel, manufactured with threads on the top, and in between vacuum if done to increase thermal keeping efficiency. Indeed vacuum is a very poor thermal conductor as there are no particles to execute convection or conduction between the inside and outside, which is perfect to keep inner temperature as constant as possible for long times.

- A lid or cover that fits and screws onto the jar body, which can have exterior or inner threads depending on its shape. Its function is to let users access the food inside, but also close the container when needed to store the food away, with as little temperature loss as possible. Indeed, as the rest of the container is well insulated, the main air loss is through the thread at very low speeds, thus making the container have a recommended thermal time limit. The lid can be of steel or plastic, or any material that doesn't absorb liquids and is accepted for contact with food.
  To ensure sealage, the lid often comes with a silicone rubber gasket; a deformable ring that is placed between the lid and the jar body (usually inside) and that is squeezed onto the inner wall when the lid is screwed on. As the material is very elastic, it is because it wants to return to its original undeformed state that we are sure no liquid will pass through.
- Other non-primary pieces may be added for aesthetic purposes, such as a top cover that can be doubled as a bowl, or a foldable spoon...

Note that these pieces require a careful selection of their materials as they come in direct or indirect contact with food, and so some chemical substances contained in their composition might be transferred into food. These are called Food Contact Materials or FCM [14]. Usually laws and regulations exist to ensure that such migration does not raise health concerns for the users.

Now in our problem, we are also talking about food fermentation [22]. This is a phenomenon that happens when food is in contact with renewed air for a long period of time, that brings new bacteria every time (e.g. botulism, health risk). A chemical reaction happens that modifies the surface aspect of the food, and bacteria also transform the material into gas. Therefore, food spoils less if placed in a container that has efficient insulation, as it will not have as much contact with the outside air, and even more if placed in a refrigerator, as cold temperatures slow down bacteria.

This is why some foods are considered to be more prone to spoiling than others, namely homemade soups and dairy products which are humid environments, and tomatoes which are high in acid. Also meat, eggs, seafood and fruit juices are considered high-risk where bacteria grow more easily. Each ingredient has a spoilage time, that depends on the temperature at which it is and the type of environment it is in [31].

Moreover, food spoiling releases gasses like carbon dioxide and methane, which we know take more volume than the solid or liquid form. Different types of food have what is called BMP Biochemical Methane Potential [27] , which is closely related to its molecular composition. In general values range from $[216 - 1476]\ mL\ CH_4/g$, which is that much quantity of gas prone to be released when 1g of food is spoiled.

Finally, why is the food pot impossible to open? As a result of food fermentation, the pressure inside the jar will increase. Indeed, the whole container is closed and has a finite volume but we are generating more and more gas (following $pV = nRT$). The only movement that is feasible is the relative one between the jar body and the lid, due to thread tolerances.

As the pressure pushes the lid up, then the contact force is increased between the thread flanks. As a result, friction is increased which also increases the torque needed by the user to open the lid compared to normal conditions. One might even have to push the lid down to counterbalance the pressure and relieve the force on the thread. But when food was left for too long or was very prone to spoiling, the pressure can become very high for which the force values can be larger than those delivered by users, especially elderly people. The tangential force on the thread can even be as high as to deform them, which effectively blocks the mechanism and makes it impossible to open the food pot.

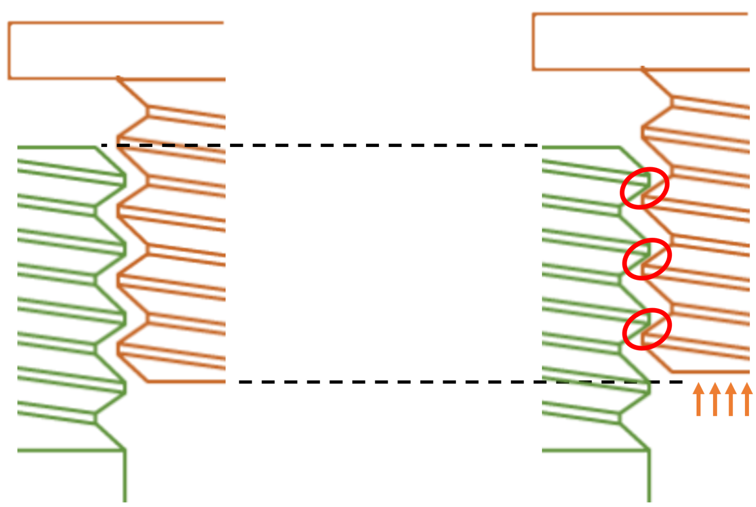


Figure 1.2: Schematization of the lid problem

Moreover, when everything is sealed and no action is taken to relieve some of the pressure, then the buildup can be so high that when unscrewing the lid without any physical obstacle, the lid can pop off quickly pushed by that over-pressure. This situation is prone to creating accidents. We can also note that if pressure continues increasing while everything is closed, then stress values in the container body can reach stress limits which will increase the risk for the body to break open, and have an unsafe container.

1.3. Problem description

Summarizing from all of the above, the problem can be described in the most synthetic way as follows:

Figure 1.3: Problem description

1.4. Other causes

Of course the main reason of the problem has been identified, but in a concern of reviewing all possible situations, we can list other possible causes that makes opening the food jar difficult and may be necessary to control:

- Food stuck in the thread increasing friction of adding radial pressure on the lid, if we have threading on the inside of the pot.
- Wear of the thread due to multiple opening and closing cycles increasing the friction, if the material selected wears easily.
- Rubber gasket deforming into the thread and blocking the mechanism deformation of the jar body due to a collision, and blocking the lid movement (e.g. sharp angles).
- Dent or leak in either one of the inner or outer walls, which reduces the insulation efficiency and so promotes food spoiling faster, thus increasing the pressure risk.
- If there is a leak in both walls at the same time, then the food will be in direct contact with the exterior air, and so no pressure difference will exist, relieving the problem but removing the vacuum insulation property.

- Food temperature reducing a lot, or cold elements in the container, which according to the ideal gas law will reduce the pressure, and so the lid will be pulled down.

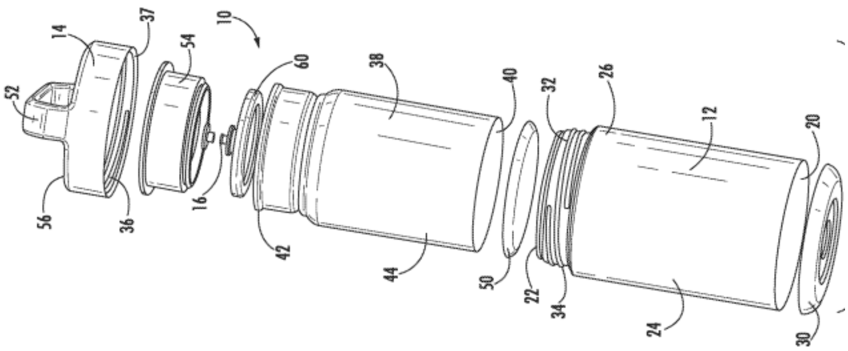


Figure 1.4: Identification of other possible causes

1.5. Requirements

For the problem, the main requirement is of course safety. As said before, we want the user to be able to open the container in a safe manner, without the jar exploding due to over-pressure. But there are also a couple other requirements as listed below:

1. Liquid and gas tightness has to be guaranteed in all conditions
2. The user should be able to clean all components of the pot in contact with food
3. The solution should be manufactured with typical manufacturing processes
4. Environmental impact of the solution should be minimized, e.g. recyclable materials, limit the number of different materials
5. The total cost of the solution should be minimized as much as possible
6. The solution should be suitable for all people disregarding gender and age
7. Thermal exchange with the external environment must be minimized such that the internal temperature can be kept for 6 hours
8. The same internal volume of the pot (500 mL) should be assured while minimizing the increase of external dimensions

Let's see how each of these requirements pan out and can be taken car of:

1.5.1. Liquid and Gas tightness

The first item is generally guaranteed by the use of the silicone gasket. Silicone [19] is a polymer that is highly elastic. There exists various categories of it, but usually the softer they are, the more sealing they provide with less closure force needed, but may need larger deformation. Now it is because the gasket deforms onto an inner surface, and elastically wants to return to its original shape, that it tightens the jar's top opening and prevents leakage. In order to deform in the right direction without preventing closing the pot, notches and holes can be implemented into the material (indeed a hole = path of least resistance to which silicone will first deform).

Finally silicone rubber is usually chosen as a FCM [29] because it is:

- Temperature resistant: maintains integrity at boiling temps and remains flexible at low temps
- Flexible: durable yet low compression set (returns to original shape)
- Chemical resistant: to strong chemicals like acetic acid, fish oil, vinegar, sodium sulfate, ammonia gas
- Food safe: no petroleum or BPA (Bisphenol-A) so no health risk with toxic elements on food
- Water repellent
- Resistant to environmental elements: ozoning, ageing and weathering resistant

1.5.2. Components cleaning

The second item must be anticipated in the design process. Namely, for simple cleaning, the lid opening should be large enough to fit a hand or a brush, which will also be beneficial for eating. For more thorough cleaning, all pieces should be possible to be taken apart. Moreover, stains can be cleaned using club soda, so material should resist that acid substance.

1.5.3. Manufacturing

For the third requirement, to help with manufacturing, the food jar solution must be simplified as much as possible, with the least amount of different pieces. This will be anticipated in the design process.

As reference, the actual state of the lid cover system we wish to improve looks like below:

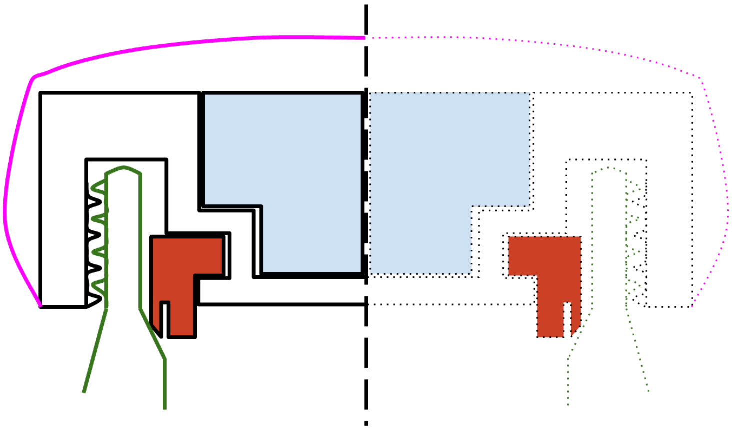


Figure 1.5: Schema of the actual lid

We can note that the threading is done on the outside of the jar body (green), but on the inside of the lid structure (black), and the silicone ring (red) is being squeezed onto the inner wall. Moreover the lid is filled with Styrofoam (blue) to increase insulation towards the top of the entire pot, enclosed into the outer cover (pink) for aesthetics.

1.5.4. Environmental impact

For the fourth requirement, as said above the solution should be designed as simple as possible. Food grade materials are not usually ecologically friendly, but some recyclable materials can be used within standards (e.g. Regulation (EC) No 282/2008 [6]). The right selection of materials should help not to use unnecessary pieces.

1.5.5. Solution cost

The fifth item goes in accordance with the paragraph above 1.5.3. Namely, the simpler the design the less it should cost. Moreover, the right selection of the FCMs will also play a role, as some materials are more expensive than others while having some specific performance advantages.

1.5.6. User suitability

For what concerns the sixth requirement, it is necessary to know what are typical forces generated by people of different gender and age when opening containers, in order to compare it with the ones needed in the solutions, and see if it is feasible to open it without discomfort.

According to some research papers, numerous tests were carried out in order to measure the normal torque a person can apply to a lid. It is useful to note that this value varies a lot depending on the diameter of the cover compared to the hand size and thus the position of the finger along the lid to maximize friction, but also the grip force delivered by the person.

Here is a first example of test results, referenced in article [24]:

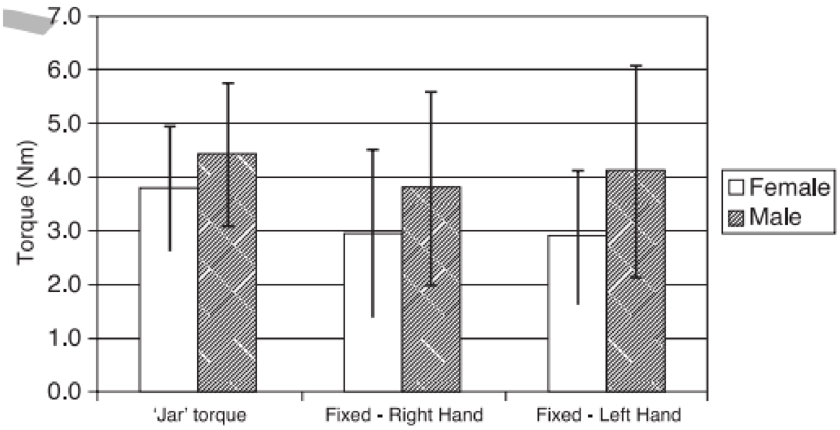


Figure 1.6: Torque measurement for different configurations

Therefore torque values range at max from 3.0 Nm to 6.0 Nm, here for a glass jar with diameter 60 mm and users of 20 to 90 years old. Overall the higher the age of the person, the less force it can deliver, but also women deliver around 20% less torque than men, due to the large size of the container.

Another example has measured slightly different values, but still in the same order of magnitude, referenced in article [28]:

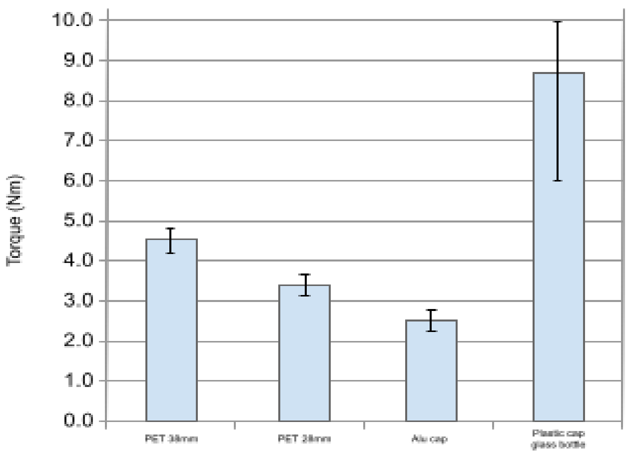


Figure 1.7: Torque measurement for different bottles

Here the users are 65 to 80 years old, and the container are plastic bottles with caps of 28 mm and 38 mm of diameter. As the size is smaller than above, the necessary torque should be smaller and this is what the test found, with an average of 4.4 Nm and 3.4 Nm respectively of torque applied to open the cap. Differences are noted due to the material and size of the bottle.

It can be interesting to note that to ensure sealing, industries usually screw bottle caps for instance with torques that are dependent on the diameter [20], and their values are in the same order of magnitude as found by the measurements but slightly lower, therefore meaning that users are supposed to be able to open those containers with ease.

1.5.7. Thermal retention

Regarding the seventh requirement, for the jar body temperature loss will be minimized by the vacuum formed between the inner and outer walls. Indeed as we said before in 1.2 vacuum is a very good thermal insulator for convection and conduction.

The other loss to consider is through the lid and cover, for which adequate insulator material can be chosen. Concerning the air leaving through the thread, the silicone gasket will help a lot in order to minimize the loss there, on top of choosing the right tolerances between inner and outer threads to reduce convection.

1.5.8. External dimensions

The last requirement will be anticipated in the design process, where solutions must not be too bulky and if possible incorporated into the existing container.

1.6. Benchmarking

In order to further analyze our product and its problem, an evaluation of the state of the art has been done, looking at products such as food jars, thermal bottles for liquids, pressurized containers such as pressure cookers, but also any generic food containers insulated or not.

Concerning the food pots on the market, as described above in 1.2, they all have more or less the same structure [1]. The one main difference though is having or not a system called "pressure valve" or "pressure relief", which is most generically speaking a channel connecting the inside to the outside, covered by a silicone piece which can be opened automatically or by the user, and thus letting the pressure equalize between the container and the atmosphere.

Thermal bottle products are very close to the food jars as they are also vacuum insulated to keep liquids inside hot or cold for long periods of time, but they are usually smaller in volume, have a smaller opening diameter, and usually don't need pressure reliefs.

More broadly, the food containers evaluated were made of plastic like tupperwares, but also glass, silicone rubber or stainless steel, having many different features.

In the end the goal was to analyze the closure systems used, and we managed to group them around similar characteristics that are detailed below:

A. A simple lid that screws onto the container body, mainly used by the insulated jars and bottles. Their main feature is a silicone rubber gasket that deforms onto the container body when screwing, to ensure sealing. The gasket can be removed or not.

Figure 1.8: Example of system A

B. A simple lid or top part, round or rectangular, used by any container. It also comes with a silicone gasket that deforms when closing, which is ensured by either plastic clamps that clip onto the container, or a hook system.

Figure 1.9: Example of system B

C. A lid that screws onto the container body just like A, but here adding a silicone valve in the center. The valve covers a short channel through which the over-pressured air escapes to the outside. The channel connects the container body to an opening in the lid, often accessible by removing the top part of the lid. The valve can be activated by a button or by pushing the valve from the top with a toothpick.
The main property is that the valve is easily accessible, and the channel easily cleaned.

Figure 1.10: Example of system C

D. A lid that screws onto the container body, with a silicone valve just like C. But here the channel can start at the center or on the side, and can finish on the side between two threads, or in top center. The silicone valve can be manual, and thus activated by a button that deforms it, or automatic, and thus deforms when the right pressure is attained in such a way to open the way to the channel.
The main property is that the channel is usually longer than C and difficult to access.

Figure 1.11: Example of system D

E. Here the lid can be whatever but must be tightly sealed. The main feature is that there is a vertical channel on it connecting directly the inside with the outside, topped with a small cover that moves vertically. That channel is the only way for gases to escape, and so the over-pressure works against the weight of that cover, until it pushes it out of the way or opens up the airway.

Figure 1.12: Example of system E

F. An improvement of the system in E, where here the channel is topped by a cover and a spring keeping it shut closed. Then the over-pressure works against the spring force until it opens the channel.

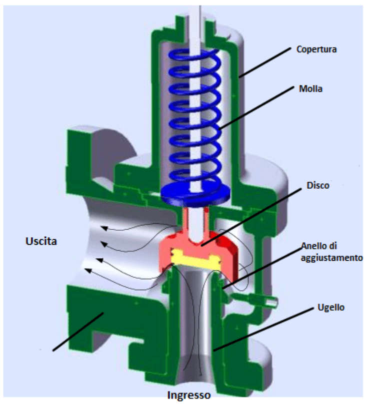


Figure 1.13: Example of system F

G. A classic simple container, also called tupperware, where the lid or top piece is in plastic or silicone. It deforms slightly onto the top of the container until it snaps in place, and thanks to its elasticity it will ensure closing. The advantage of this system is that it is the simplest, but it does not have the same insulating properties as A or C.

Figure 1.14: Example of system G

H. An improvement of G, where the container comes with a system (often silicone) on the lid that is able to accommodate a vacuum pump. This system's feature is that it does not really need any clamp or screw for the top piece, as the vacuum generated in the container will be the one keeping the container closed.

Figure 1.15: Example of system H

Classifying the different closing systems helps us compare them more easily. We can even confront them against the requirements listed above 1.5:

	A	B	C	D	E	F	G	H
	(screw on lid with rubber gasket)	(lid with gasket deforming when closed/clamped)	(screw on lid with valve and short channel to lid container)	(screw on lid with valve and long channel to outside)	(weight-adjusted cover of a channel)	(spring-adjusted cover of a channel)	(tupperware cover that snaps into place)	(thin lid has system for vacuum pump)
Liquid and gas tightness guaranteed in all conditions	very good	good but maybe less sealing force	very good	very good	NO because works in one side (reverse pressure cooker and all falls)	very good if spring>>weight	medium cuz no thread/clamp and pressure temp can deform easily container	medium as there is no thread/clamp and pressure compressing all can fan out
Ability to clean all components in contact with food	very good	very good	medium if easy assembly but still multiple pieces	very difficult to clean channel, worse if central	very difficult due to small size	depends on size of system / spring in direct contact	very good	good but system may be difficult to access fully
Solution manufactured with typical manufacturing processes	good, still needs threading	very good, simple	medium as needs threading and holes on cover	hard to have long channel, which can be excentric	depends on complexity of the container, weight lid in itself very simple	good depending on channel /system size	very very good, simple	good, may be difficult for pump system
Environmental impact of the solution should be minimized,	good, only steel and bit rubber	good, only 2 or 3 materials	medium, has a bit more pieces	medium, has a bit mnore pieces	very good, small and almost one material	bad, has multiple pieces of diff materials	very good, one material	good, only 2 materials
Total cost should be minimized as much as possible	good, not too many pieces	good, not too many pieces	medium, can be hard to manufacture	medium, can be hard to manufacture	good, not too many pieces	medium, can be bulky and complex	very good, simple	good, not too many pieces
Suitable for all people disregarding gender and age	medium, can close up with pressure	good, just needs to be stronger than clamp	very good, valve removes pressure problem	very good, valve removes pressure problem	very good, automatic system	very good, automatic system	very good, plastic is deformable	very good, can have clamps or not (even easier)
Minimization of thermal exchange with the external environment	very good, double wall vacuum + gasket	medium, usually no vaccum	very good due to double wall vacuum. more pieces can mean more loss though	very good. also if button activated good; if automatic, then medium cuz temp loss everytime valve deforms	medium, usually big tolerances and no gasket, temp loss everytime cover moves	good in itself. slight loss everytime it moves	bad, usually no vacuum and gasket, only plastic wall	medium, vacuum ensures less heat transfer but still no double wall
Same internal volume of the pot (500 ml) while minimizing external dimensions	good, cover can be a bit large and outer wall adds thickness	very good, closure system takes a bit more place	good, cover can be a bit large and outer wall adds thickness	good, cover can be a bit large and outer wall adds thickness	very good, usually small item	medium, spring system can take place	very good, simple	very good, simple

Figure 1.16: Comparison of the systems presented

Overall, these closure systems have very good compliance with the requirements, but there is always one point that can be improved.

For instance the system G, or tupperware, is the most simple system, easiest to produce, but has no temperature insulation feature whatsoever. On the other hand the vacuum-insulated containers like C or D that have pressure valves are very good in terms of thermal losses, but then cleaning and disassembly can be complicated with the channels.

This comparison also tells us where the actual state of the lid system stands compared to others: it responds pretty well to many of the requirements, but the main problem is still the pressure that prevents opening the lid.

Lower compliant systems are not to be put aside either. For example the system F with the spring-loaded cover is a bit complex in terms of number of pieces and can be bulky, but it has one of the best liquid and gas tightness due to the spring force and works automatically.

1.7. Food contact standards

Any food container and its different materials and articles which are intended to come into contact with food are more generally called Food Contact Materials or FCM [14], as already said in the paragraph 1.2. The denomination also includes indirect-contact materials such as the multiple layers in packaging, or even the ones used in processing equipment. Indeed the safety of FCMs must be evaluated as chemical substances contained in their composition might be transferred into food. Therefore these materials answer to some regulations and standards, listed below:

1.7.1. Stainless steel

Stainless steel is one the most commonly used material for what is defined as “food-grade material” [18]. There exists multiple types of stainless steel, often classified by a serial number that characterizes its composition, but the most common one is the 304 (also called $18 - 8$). This version of steel is often used in food-contact applications because it is a naturally safe and stable material. This alloy is composed of iron to which we add 18% of chromium and 8% of nickel, hence the name. These elements confer it great corrosion resistance, good malleability and durability, and make it one of the strongest of mild steels while being budget friendly and low in maintenance.

In comparison, the alloy 316, which includes 3% of molybdenum as an extra element, has better resistance to corrosion but is less malleable. The 316 is often referred to when dealing with salty environments or food, but is also a bit more expensive.

The 400 series are similar to the above, but with much less nickel in its composition, making it more affordable. In consequence, they also have less resistance to corrosion and a bit of magnetization.

Finally the 200 series are sometimes used as FCM. They contain manganese instead of nickel, and thus are considered less safe due to their much lower corrosion resistance.

Overall stainless steels are the reference material in food-related industries because they are structurally strong, but also their surface is very smooth making it easy to clean and not predisposed to bacteria development in grooves. Moreover, compared to iron or aluminum, the material is non reactive even with acidic food and thus will not release any of its components into food.

1.7.2. Food contacts safety

One of the main European legislation regarding Food Contact Materials is written by the EU Framework Regulation [10] and set out in the Regulation (EC) No 1935/2004 [4]. As we said above, FCMs must be analyzed so that their substances don't migrate into food, and thus this Regulation sets out requirements such that any potential transfer does not raise safety concerns.

Note that we call "migration" any chemical contaminant transferring from material to food, directly in contact or indirectly through multiple layers.

In Article 3, the Regulation states that materials must be inert enough and not react with the constituents, in order not to:

- Release their substances into food at levels that are harmful to human health
- Change food composition, taste and odor in an unacceptable way. For instance FCMs should not change the amount of aldehydes and amines or the color of food such that the spoilage of the food would not be recognizable anymore.

The Regulation also dictates that the labeling, advertising and presentation of a material or article shall not mislead the consumers.

It is important to note that this legislation then depicts procedures to perform safety assessments of the substances in FCMs, rules on labeling and the symbols to use in packaging, but also guidelines for compliance documentation.

1.7.3. Plastics

The above regulation sets out general principles of safety and inertness for FCMs, but in the same Framework there are also specific EU measures to cover for certain FCMs such as ceramic materials, regenerated cellulose film, plastics and recycled plastics, and active materials.

For what concerns plastic materials and articles, they answer to the Commission Regulation (EU) No 10/2011 [7]. This Regulation is divided into two parts; the first one consists of what is called the Union List, which details all the acceptable substances that FCM can have in their composition without high safety risks. On the second part migration limits are set out, which are values of the maximum amount of substances that are allowed to migrate to food, and considered safe.

When talking about the overall material safety, the Regulation defines an Overall Migration Limit, or OML, which is a value of total migration. The Regulation states that for a FCM to be considered safe, then its OML value must be lower than 60 mg for 1 kg of food. This value is general and often used as reference for many materials. The OML can also be expressed in another dimension as 10 mg for 1 dm^2 of food contact surface.

As the Union List suggests, some substances and elements are more toxic and thus need stricter margins. Therefore, many limits were set out by the Regulation for every risky element for it to be considered safe, called Specific Migration Limit or SML. Here are some example of values defined for generic elements:

Element	SML $mg/kgfood$
Barium	1.0
Cobalt	0.05
Copper	5.0
Iron	48.0

Table 1.1: Specific Migration Limits for some generic elements

Regarding recycled plastic, the material must follow the directives defined in the Regulation (EU) No 10/2011 of above, but should also answer to a specific legislation: The Commission Regulation (EC) No 282/2008 [6].

This Regulation requires that the recycling process endured by used plastics must follow specific standards, and a thorough cleaning of possible contaminants, all supervised by the European Food Safety Authority or EFSA, which is the entity that ensures that all processes are compliant with the Framework dictated in (EC) No 1935/2004.

More generally, The Framework of (EC) No 1935/2004 and (EU) No 10/2011 then set out very standardized test procedures to evaluate the migration levels or different substances in their Appendix, but also guidelines [3] for labeling packaging that are FCMs, namely requiring to apply the following logo:

Figure 1.17: Food Contact Material symbol

Moreover it also imposes that a document called the Declaration of Compliance [30], or DoC, has to be provided by any FCM producer, on which it must be expressly listed that the migration limits of each substance are below the acceptable values.

1.7.4. Silicone rubber

As said before, silicone pieces are often used for sealing, therefore they are considered FCMs and thus must answer to regulations.

The Regulation ResAP (2004) 4 [2], which is an extension to the above Regulation (EU) No 10/2011, adds specifications for silicone rubber among other new materials. It states that silicone can fall into particular categories depending on the temperature, relative food-contact area, contact time and number of repeated uses, for the application it is used in. Therefore, silicone being an inert material, some categories are promptly considered safe, while others must be subjected to migration level tests. Overall, it is required for the material's OML to respect the above defined limit of 60 mg/kg food, but silicone can be processed with certain additives and substances, for which specific SML were drawn and listed in this Regulation.

More generally, for silicone rubber but also plastic materials and even resins, one main concern for health is the presence of Bisphenol-A or BPA [16]. This is a chemical compound widely used in manufacturing these materials that may have some health concerns with the nervous system.

As a consequence the EFSA has defined a very low value of TDI at 4 $\mu g/kgbw$ which may be lowered in the latest re-evaluations [13]. TDI or tolerable daily intake is an estimate of the amount of a substance that can be ingested daily without representing risk, expressed for a kilogram of body weight.

In accordance with the Regulation (EU) No 10/2011, BPA has then been assigned a specific SML as itself but also when present in coatings and varnishes in the latest re-evaluations, with a value of 0.05 mg/kg.

1.7.5. Aluminum

When it comes to Food Contact Materials, aluminum can be found either as itself, or as an additive to some compounds. Aluminum is also an element naturally present in food, food additives, colors, ... even though its amount is usually very low.

Moreover, too much aluminum might be unhealthy, and this is why the European Food Safety Authority EFSA has set out a safe threshold at 1 $mg/kg\ bw/week$ [12]. Note that the value is so small that it is defined over a week instead of the usual daily base, thus introducing a Tolerable Weekly Intake or TWI. It is also likely to be exceeded due to the amount of exposure, but is still considered a good base.

Regarding regulations as an FCM, aluminum follows Resolution (2020) 9 [9], where it is identified as being an additive in plastic materials or sweeteners, or as an element in metal alloys.

For the first case, requirements like in the Directive 2002/72/EC, but also the (EU) No 10/2011 as they are linked, have lists of the substances considered safe and a value for SML for them, depending on the use. For the second case, aluminum is often required to be coated with resins or epoxy so as to prevent corrosion from oxidation or from reaction with acidic food, which could release aluminum into the food at too high quantities. Resolutions like the (2020) 9 or the (EU) No 380/2012 give recommendations when using the material such as:

- Limiting the use of uncoated aluminum when storing acidic, alkaline and salty food
- Proper labeling that alerts the end consumer that uncoated aluminum is used

1.7.6. Compliance testing

Concerning the products more broadly instead of their materials, in order to ensure that they are made with FCMs but also respect the above Framework (EC) No 1935/2004, there exist standardized requirements for articles in contact with foodstuffs called DIN EN 12546, written by the European Committee for Standardization CEN.

This particular standard is divided in two parts, where the first section [11] concerns vacuum ware, insulated flasks and jugs for domestic use with food or drinks. Different tests are also written, including verifying stability, heat loss performance, thermal shock and leakage sealing efficiency for these containers.

The second section [25] specifies requirements for portable domestic insulated containers such as boxes, chests and bags to use with food or drinks. The tests for this part consist of measuring insulation performance, impact resistance, and leakage blocking.

1.7.7. American Regulations

The requirements listed above take effect in Europe but there doesn't exist any international Framework. Nevertheless, regulations are very similar in different parts of the world, while still having some specificities. It is for this reason that we can look into the American regulations in place so as to compare.

A first adjustment put in place in the USA is the existence of the California Proposition 65 [21], which aims to protect water sources from being contaminated with chemicals that are known to cause harm to human health. This Proposition therefore keeps and regularly updates a list of all dangerous chemicals and substances that should not be used when producing for instance FCMs. It also states that if one of the elements in a composition is reported on that list, then proper measures must be taken to ensure that the exposure level does not pose safety issues, or clear warnings are to be provided.

Such substances are of course linked to legislations about "food-safe" materials, such as the Code of Federal Regulations Title 21 [15], delivered by the Food and Drug Administration or FDA. This entity regulates all requirements regarding food and pharmaceutical products according to the Health Department. More specifically, the Chapter 1 Sub-chapter B of the Regulation concerns food for human consumption, and states that a material is considered to be safe with food if it:

- Is durable, corrosion resistant and non-absorbent.
- Possesses sufficient weight and thickness to withstand repeated ware-washing.
- Is finished to have a smooth and easily cleanable surface.
- Resists pitting, chipping, grazing, scratching, distortion and decomposition.
- Prevents the migration of deleterious substances, and prohibits the modification of colors, odors, or taste to food.

In general, a food container must not be composed of any poisonous or harmful substance which may render the food or drink contents injurious to health.

An example of requirement that Title 21 specifies can be read for rubber articles intended to serve as food contact materials. The text states for instance migration values equal to 310 mg/dm^2 after 7 hours, and 15.5 mg/dm^2 after 9 hours of contact.

1.7.8. Other legislations

For a more complete and thorough understanding of the framework around the European legislations, we can note some other important regulations concerning Food Contact Materials.

For instance there exists Regulation (EU) No 2018/13 [8] that sets out rules for coatings and resins with the use of BPA, including the compounds with aluminum elements, and lists out the SML for different substances. Along with this one is the (EC) No 1895/2005 which concentrates more on epoxy that can be found on the surface of FCMs in packaging.

Further along, we have the Commission Regulation (EC) No 2023/2006 [5] which dictates what are called Good Manufacturing Practices or GMP, which are requirements and guidelines that ensure all materials and articles intended to come into contact with food are produced in a way that, when finished, will respect regulations and standards without endangering human health.

2 | Solutions generation

2.1. Introduction

Knowing what our problem is and also knowing what kind of solutions exist in the state of the art of the food pots, we can now turn ourselves towards a phase of solutions generation. This is a creative step, a divergent phase where we will explore different ways to try and tackle our problem.

I have followed 3 main steps in order to start generating ideas:

1. The first one was to look at our previous comparison of existing closure systems, and from there get some features that could help or must be avoided.
2. The second one was to create what is called an "interaction diagram", for which different pieces of the food pot are distinguished by their function, and I seek to find the actions and consequences each piece and environment have with each other. At the same time, some of those ties are explained and searched upon to get ideas.
3. The third one was to actually separate the solution framework into 3 main categories depending on where they will affect the product. Namely, the solutions found should either:
    (a) Block the problem source
    (b) Slow down the problem source
    (c) Modify the mechanical behavior

2.2. Systems comparison

This analysis which was done before in Figure 1.16 has let us generate a synthetic table that compares the different existing closure systems against the requirements that we had listed. We can think of reading the table differently, in a way to understand which are some great features, and which features are to be improved or even avoided.

Moreover, we can even attempt to combine some systems together in order to spruce up some new ideas. Indeed it is not because a certain system or feature has a bad score in a certain requirement that it has to be put aside. It can also mean that it can be improved by using it in a different scenario.

Here is a first analysis of the Systems Comparison table. Some good features to note are as follows:

- The sealing is often guaranteed by a silicone gasket as it is simple. It offers higher performance when it is pressed by a threaded system than just by clamps.
- A large opening and simple design are preferred in terms of cleaning and manufacturing.
- The system using a silicone valve piece coupled with and air-channel is the most common technique to solve the problem of over-pressure (mostly coming from hot elements and not fermentation) in the state of the art.
- As a note to this valve system, we can deduce that it is better if the opening of the airway is activated by a button pushed by the user, than moving whenever a pressure difference is achieved, such as to reduce the heat losses we could have every time.
- Any opening system that includes deformable pieces are usually preferred by users as they are easier to open (e.g. tupperware).
- The system solution should be inside the lid as much as possible to reduce the overall size.

Some disadvantaging features to avoid or improve can be noted:

- Small pieces that cannot disassemble are hard to clean.
- Long channels that can come in contact with food are difficult to clean and manufacture.
- Thermal retention is still best with vacuum or different layers of insulation.
- Using springs can take up large space.
- Weight-adjusted pieces are bad, but they can be used to follow gravity even when turning the container.

Thanks to this list we can have some ideas on functions and design choices to make later on when searching for solutions. They may be incorporated into an idea or used as the basis for another idea.

2.3. Interaction diagram

The interaction diagram is a tool to distinguish the different relevant parts composing the food pot and their functions in the overall functioning of the product. The diagram is very important in order to understand the links and relationships between the different parts, and thus see what actions can be taken with what consequences.

Therefore, to separate the food container into its functional parts, we have to remind ourselves of the product's purpose: it keeps food hot inside the container against the outside environment, thanks to its double-walled structure, and should reduce overall the time for food to spoil. Thus we can understand that the actors that play a role into the food container are the following:

- Container Walls keeping the inside air and sets the pot shape.
- Container Lid which can be considered individually as it has different functions.
- Air inside the container which needs to be regulated.
- Air outside the container which follows ambient temperatures and external changes.
- Food inside the pot can be considered by itself.
- Bacteria which are connected to the food as they try to spoil it, and are important to notice as they generate the pressure problems.

Moreover, by expressively writing what the relations are between these actors, we can create the following diagram:

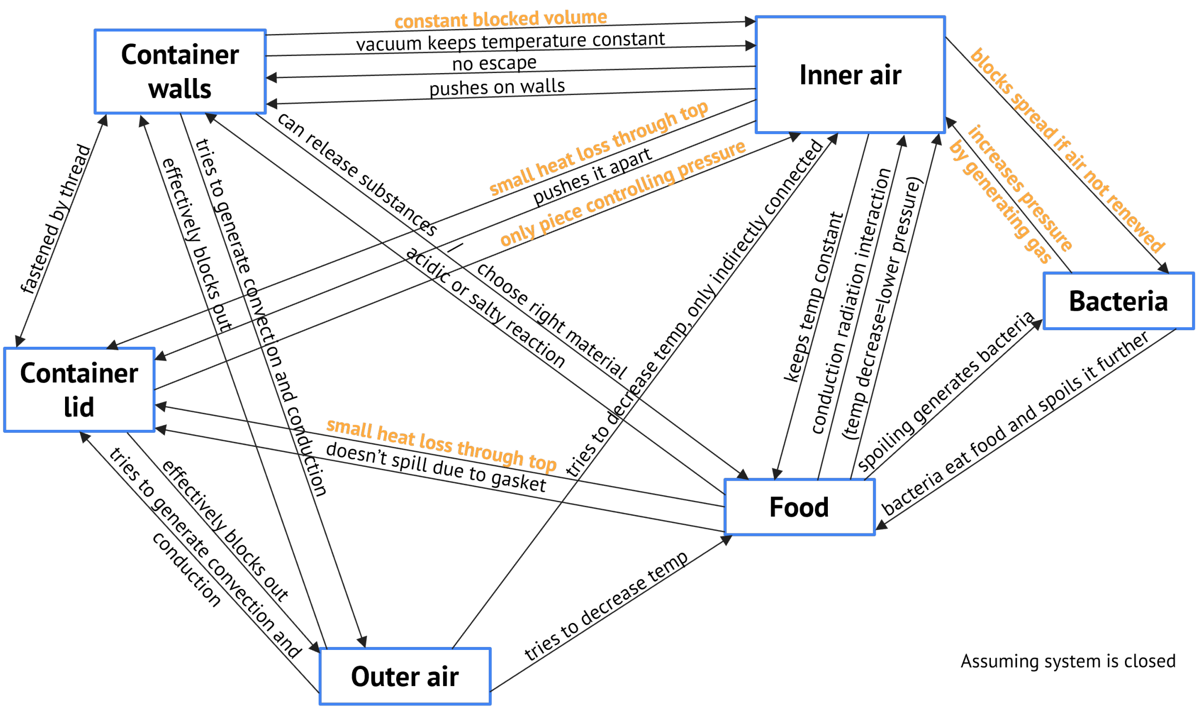


Figure 2.1: Interaction diagram

For instance as said above, if bacteria are present they will eat the food in order to spoil it, and in return will generate gases which will increase the pressure of the inner air. Or the walls of the food pot are rigid and contain vacuum, which are there to keep the temperature of the inner air constant while blocking it from escaping to outside, and in the same time stop the outside air's impact on inner temperatures.

Among all connections, some are highlighted as they have been considered to be points of improvement or actions on which we can surely work on when generating the ideas. Modifying the base design, already seen in Figure 1.5, along these points may result in an upgrade.

Let's go through them:

- "Constant blocked volume" shows that the container in itself has a given geometry with a finite volume, and as the pressure increases due to bacteria, then air pushes onto the inner walls.
  - From this an idea can be to use flexible walls such that when pressure increases, the inner volume can increase and thus the overall pressure will be decreased. We do have to note that this feature will only mitigate the problem, as of course the volume cannot increase indefinitely (one of the requirements was indeed

overall size). If pressure keeps increasing then we would still have blockage, but we are still able to delay this for a couple hours.

  - On the same theme we could also think about using flexible connections in our food pot, e.g. between the inner container and the lid, such that those can extend when pressure increases, which will in turn relieve the force on the thread.
    Again, we should be aware that this will only momentarily reduce the problem.

- "Increases pressure by generating gas" means that when fermentation occurs, it transforms food into gas which occupies more space than its solid counterpart. With the volume and temperature blocked, we will have an increase in pressure.

  - We also know that one of the main gases released by bacteria is CO2, therefore an idea could be to use a substance or element that can absorb the CO2 molecules produced and in consequence we could preventively stop the increase in pressure.
    This type of material could be placed inside the structure of the container, or on top of an air channel such as to work as a filter. Removing those CO2 molecules would bring back the inner air back to normal conditions.

  - An example of existing material that is used in industrial plants is Zeolite, which is a solid that can absorb certain amounts of CO2 gases.

- "Blocks spread if air is not renewed" shows that we know bacteria grows and spreads by consuming oxygen but also whenever 'new' air brings along 'new' bacteria organisms.

  - Therefore, if we manage to block any new air from coming from the outside and ensure that the inner air of the container is sealed, then we can control the growth of bacteria.
    This is actually an idea which is at the basis of many food containers, because of course enclosing food inside a container is better for its conservation than leaving it in the ambient air. It is by adding the silicone rubber gasket, which also exists outside food pots, that we are ensuring inner sealing.

  - Basing ourselves on this knowledge, we can understand that by controlling the amount of oxygen and so O2 molecules inside the container, we may be able to control the amount of fermentation onto the food.
    As a step further, we may think of removing completely the air inside the pot. This idea will certainly stop bacteria from growing, as it totally removes

oxygen and other molecules. We can note that multiple food containers use this solution to extend the storage life of products as we had seen in Figure 1.15.

- "Spoiling generates bacteria" shows that if we want to block the problem at the source, then we should act on the very first step of bacteria growing from food.
  - A usual technique performed by industries that ensures containers are bacteria-free and ready to be shipped anywhere is to pass that container under special treatments. Those include either extreme heat or chemicals that kill all bacteria present, or very high pressure which inactivates the bacteria.
- "Small heat loss through top" means that we can identify where the heat usually leaves the food pot, namely around the lid cover as it is much easier than through the walls that have vacuum. Indeed we know that the food inside the jar decreases slightly over time, meaning that inner air and heat escape very slowly over time. The usual paths are either directly through the lid by conduction, or along the walls to the top by diffusion.
  - Knowing where heat often dissipates, we now can efficiently understand where to place insulating materials and systems in order to increase performance in heat retention, which can be beneficial in the designing phase.
- "Only piece controlling pressure" shows that as the whole container body is pretty simple in design, it's its assembly to the lid that unveils multiple features.
  - Therefore it is by increasing the complexity of that connection, but also of the lid in itself that we may be able to generate new ideas, which may count as purely mechanical.

This list of connections between the components of the food pot is a strong basis for solution ideas presented below.

2.4. Ideas generation

As a result of both analyses above which generated points on which to focus and paths that could be improved, we can dive into the actual creation of ideas.

When tackling our problem, we manage to distinguish different approaches that look at different facets of the problem. In consequence the solution ideas can be regrouped into 3 categories:

1. Block the problem source
   Thus act on the reagents and chemical kinetics present in the reaction of fermentation

2. Slow down the problem source
   Thus act on the products of the chemical reaction of fermentation

3. Modify the mechanical behavior
   Thus act on the pot design itself and the opening system

On top of this distinction, we can ask ourselves a question: should the system idea be activated every time there is an over-pressure, or only when the user wants to open the cover? As a result, a couple of ideas here but also further down in the design phase can be declined into being either 'automatic' or 'button-activated'.

Here is a list of ideas below generated from the 3 categories. It is important to note that these are generic ideas meant to illustrate a feature, and thus can change when designing them.

2.4.1. Block problem source

Here the solution ideas try to act on the reagents of the fermentation and on the pressure creation such as to preemptively stop the problem.

1) Restrict the food type depending on its BMP level (ref §1.2), therefore simply choose to only contain food that is certain not to generate too much gas when spoiling. We can clearly anticipate that this idea is contrary to the purpose of the food pot and does not rejoin the user's expectation, thus can be put aside in further steps.

2) Put the food and the inner air under vacuum, which as we know is effective in greatly reducing bacteria growth. It will also be beneficial in increasing heat insulation.

3) Place the food container under extreme heat of even HPP treatment, such as to inactivate the bacteria that can be present.

4) Use a chemical inside the food pot in order to eliminate bacteria. Those can be substances that inactivate bacteria growth, or high energy radiation that wipes out fungi that can be present.

5) Use a dehydrator system in order to make the environment less humid, and so less favorable to bacteria growth. To an extreme, we can even dehydrate the food such that no humidity is present.

6) Control the pressure level with a pump, which can be tuned to specific food types. As said before some food may release more gases and thus we would need tighter tolerances than others.

7) In the same way we could control the oxygen level, which is the other parameter that is favorable to bacteria growth. Its level can be raised or more importantly reduced such that bacteria don't consume it.

2.4.2. Slow down problem source

Here the solution ideas intend to act on the products of the fermentation, and more generally to mitigate the consequences of pressure increasing such as to relieve force acting on the thread connection.

8) Place the food into a cold environment in order to slow down the propagation of bacteria and so delay the time it spoils.
   We can again anticipate that this idea is contrary to the purpose of the food pot which is to keep food warm, and thus can be put aside in further steps.

9) Use a substance or element that could filter out CO2 molecules generated by bacteria, while keeping heat inside the container. We could think of a filter on top of an air channel that could only let CO2 molecules get out, or a paste that could attract those molecules inside the pot.

10) In the same idea we could use a block of Zeolite placed in the lid, which can absorb the CO2 gases coming from fermentation, while providing good insulation.

11) Use a pump that simply reacts to pressure changes, such as to keep it as constant as possible even if spoiling happens. It would then only respond to the pressure increase.

12) Use flexible parts such as to absorb the increase in pressure by an increase in volume.
    (a) A first idea would be to replace the inner wall of the container with a flexible membrane, which could inflate when pressure increases and thus present a larger adjustable volume.
        It is noticeable that this idea really only mitigates the problem, as the inner wall cannot expand infinitely since we need to have finite standard external volumes, as said in §1.5.8.
    (b) A second version could be to have a flexible membrane inside the lid, which would inflate and give an extra chamber for the inner air. The system could

either be let free, so as to grow progressively, or be retained by pins and released when chosen by the user

13) Place the food in an extra chamber inside the container of the pot, which could be a bag or a silicone film enclosing the aliments, in order to have yet another barrier to outside air and bacteria and ensure a safer environment.

14) Have moving pieces inside the lid so as to move under the pressure force. These parts are unconnected to the threading element, and thus will respond to the over-pressure instead of the thread, in order to relieve the latter.

2.4.3. Modify mechanical behavior

Here the ideas tend to modify some pieces and features of the original model mechanically in order to respond to the over-pressure and equalize it instead of working against it.

15) Create an air channel inside the lid that is covered by a valve, which has a spring blocking it. In that way, the spring ensures that the channel is closed and the inner air doesn't escape as easily until a certain pressure value is achieved, but also we can have more control into that critical value as we are selecting the right stiffness value.

16) Make the lid connection to the jar body stronger than just with the thread element, for instance by adding clamping pieces or hook systems on the exterior of the food pot, such that we reinforce the link between the two main parts. As a result the lid would be more resistant to the over-pressure and thus would move less, avoiding the thread to deform.

17) Place any type of opening on the lid, which could be useful to equalize the pressures between the inside and outside of the food pot.

    (a) The system can be simply a deformable piece on top of an air channel.

    (b) The system can also be actioned by the user, by means of a button displacing the cover of an airway or sliding pieces that open up a channel.

    (c) A more detailed idea of a cover that could save space would be to use a hatch-type opening, motioned by a slider.

18) Use sensors that measure the changes in inner air and react to it, so as to inform the user or a system to activate another solution. These sensors can vary in what type of parameter they measure:

(a) If we want to tell pressure variations, then the simplest design is to have a thin silicone sheet over a hole. When pressure goes down the rubber piece is pulled inwards and thus will deform, which can be noticed visually.

(b) Using chemical sensors can let us know about certain gases or substances present in the container. Indeed often a coloring dye will undergo chemical reaction with certain elements like CO2, which modifies their pH level. We would then observe a color change, informing us of the presence of said element.

(c) Temperature or humidity sensors could also be installed such as to indicate some moments that may be more prone to food fermentation.

19) Reinforce the lid against the vertical pressure pushing on it. This could be done by adding springs in the cover that help resist against the pressure force, or even add a cup washer at the base of the threading such as to pre-constrain this piece and reach higher force values without problems.

20) Use flexible components, such as a rubber piece, to serve as a link between the lid and the inner wall. Under pressure, it can extend and thus relieve forces as we are letting pieces move freely. In the same way that was said above, with this idea we can gain some extra volume but it will only be a mitigator to the problem, as we cannot extend infinitely in size under our requirements.

21) Activate some elements in the lid by exposing them to heat. The idea could be that whenever we have a pressure problem the user could turn on heating systems that would serve to subsequently activate other opening systems.

2.5. Analysis and comparison of the ideas

As reference, it is important to note that we consider the actual state of the food pot to be the basic design, as we have already seen in §1.5.3. The model is simply composed of the double-walled vacuum container, with a threaded lid cover that screws onto the jar body and can be considered one block as it is made out of only two materials: stainless steel for the outer shape and insulation material on the inside.

It is thus on that generic basis that all new ideas generated tried to improve some of the features, according to the points found above. Therefore if we want to qualitatively compare the performance of those solutions, we will also compare them against this base design.

In order to compare the above list of solutions, we need to define a list of indicators that can help us know how feasible and how good those solutions perform against the requirements but also general levels of satisfaction. We thus need to generate a list of KPIs (=Key Performance Indicators):

- **Simplicity**: Ability to assemble/manufacture and clean the parts and having low number of it.
- **Recyclability**: Impact of having multiple different materials that are hard to separate in the end of life.
- **Thermal insulation**: Performance on retaining heat compared to base design.
- **Cost convenience**: Increase compared to basic design relative with each other.
- **User satisfaction**: Fulfillment of its expectations (wants a container to keep food warm as simple as possible without any problem).
- **Ease of use**: User comprehension of the functionality for ease of use.
- **Pressure locking reliability**: Effectiveness of the idea on ensuring that the locking will resist to the over-pressure.

For each of these KPIs it is important to set some generic classes or levels which could then be used to easily compare the different ideas on the same basis. In order to increase the accuracy and transparency of the comparison we can even assign a number for each level, which would be beneficial for later graphs.

Here is then how each level is defined to which we rate the KPIs, where a score of 1 is the low level while 5 is the highest:

2.5.1. Simplicity

For this KPI, the levels were defined according to the complexity of the system in terms of number of components. Therefore the lower score is attributed to ideas that need to incorporate a large extra complex system (e.g. a dehumidifier) while higher scores go towards having less extra components. A score of 5 is defined for the base design as it is considered to be the most basic and simple, because it doesn't have extra features.

Classification	Score
Uses a very complex additional system	1
Uses extra components	2
Uses only a couple new elements	3
Uses only a new piece/material	4
Same as basic design, no relevant change	5

Table 2.1: Simplicity indicator levels definition

2.5.2. Recyclability

Regarding this indicator, the score reflects how much the extra components are hard to disassemble. Thus with a base design scoring 5, the lower we go, the more and more elements we have and the more complex they get. At the very bottom a score of 1 is given if the idea needs chemical materials.

Classification	Score
Uses a dangerous or toxic element	1
Uses a complex system composed of multiple materials	2
Uses only a few materials easy to disassemble	3
Uses very similar materials easy to disassemble	4
No added elements from simple basic design	5

Table 2.2: Recyclability indicator levels definition

2.5.3. Thermal insulation

On this KPI, the levels were defined whether the solution was beneficial or disadvantageous to the thermal performance. By assigning a score of 3 to the base design, then lower scores are given to ideas that worsens the heat retention, while higher scores are linked to features which increase the time food stays hot in the container.

Classification	Score
Works in counter direction to heat retention	1
Worsens the heat performance	2
No relevant change from basic retention time	3
Helps insulation and increases the heat time	4
Increases a lot the performance time	5

Table 2.3: Insulation indicator levels definition

2.5.4. Cost convenience

Now this index shows to which degree the added items and components contribute to the cost necessary to manufacture it. Therefore from the base design which has a score of 5, the more we use costly and complex elements, the more the score goes down.

Classification	Score
Uses a very complex and expensive system	1
Needs a high-priced component	2
Uses a beneficial element that can be costly	3
Uses a simple element easy to implement	4
No relevant change from basic design	5

Table 2.4: Cost indicator levels definition

2.5.5. User satisfaction

This KPI refers to the inherent function of the food pot and how much it is respected, but also by how the whole pressure problem is tackled. Therefore, low scores are given to ideas that tend not to ameliorate the overall state of the food pot, while high scores concern solutions working to reduce pressure problems. As a reference, a score of 5 is assigned to the most optimized version of the container, even if it's not simple.

Classification	Score
Idea provides features contrary to expected	1
Lowers the basic functions of a food pot	2
User has a simple working pot with reduced problems	3
Spoilage or pressure problems are effectively reduced	4
Includes optimized functions of a food pot	5

Table 2.5: Satisfaction indicator levels definition

2.5.6. Ease of use

For this indicator, levels are defined on how easy it would be for the user to grasp the inherent function of the solution and effectively perform the steps necessary. For instance low scores are appointed to solutions that require complex extra tasks (e.g. using a HPP machine §3)). Going up in the levels, the processes become less complicated and may only require the user to periodically replace a piece. Finally a score of 5 corresponds to an automatic solution where nothing is needed and all is performed by opening the lid.

Classification	Score
User needs to perform complicated extra tasks	1
Requires couple more steps to be done	2
User needs to push one or two buttons	3
User may need to execute task once in a while	4
Everything is automatically executed	5

Table 2.6: Ease of use indicator levels definition

2.5.7. Pressure locking reliability

Regarding this KPI, the idea was to put a value to the ability to take care of the pressure while opening the lid. Thus the levels are defined as low if the idea does not ensure proper care of the pressure inside the container, while they are defined as high if the solution lets the user open the pot effortlessly.

Classification	Score
Lowers or blocks the capacity to open the pot when under pressure	1
Decreases ability to take care of pressure	2
No relevant change from basic design	3
Efficiently helps the opening of the container	4
Problem removed, user can open effortlessly	5

Table 2.7: Locking reliability indicator levels definition

From the list of ideas and the different KPIs enumerated, then we can assign the proper scores and easily compute the total scores for each solution. Some interesting visual aids can be generated as follows, such as Spider plots. For instance this is what the first category of ideas score overall:

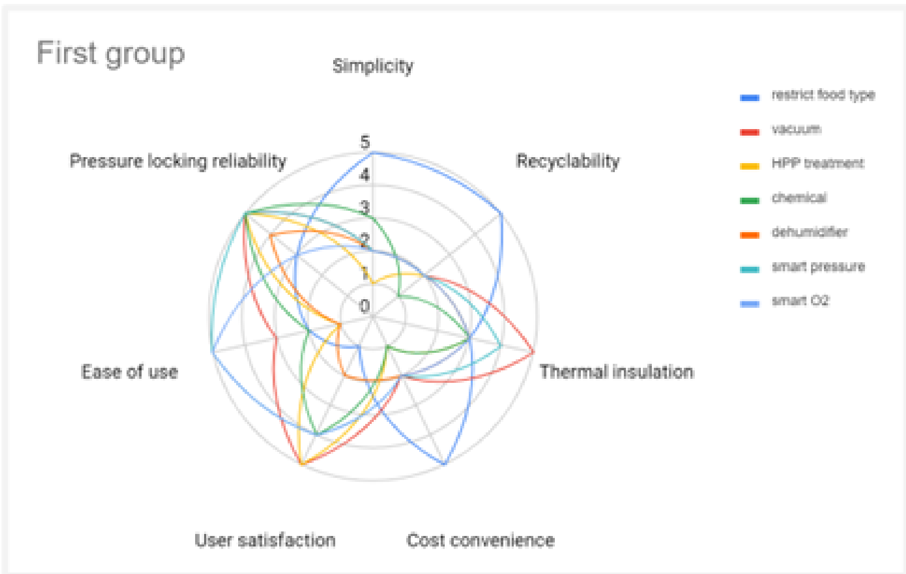


Figure 2.2: Spider plot for ideas category 2.4.1

Thanks to this type of diagram we can easily compare the different ideas but also observe for which KPIs they get a low score or high score.

Dispersion, or Bubble, diagrams also tell us at a glance how all the different solutions score when comparing a pair of KPIs. The more the idea places towards the top right quadrant, the better it is compared to the others, as it represents top scores for both x and y axes.

Figure 2.3: Bubble diagram for indicators comparison

Bubble diagrams can be generated for any pair of KPIs from which we can deduce the most recurrent ideas that are on the upper right quadrant. Among all, the most favorable solutions often were: smart pressure, spring in lid, flexible membrane, flexible connection, moving piece, zeolite, extra pouch, spring valve.

This means that at least for the Simplicity and Recyclability KPIs, having flexible pieces or using simple materials, as well as placing springs to reinforce are all considered good ways to have a simple design.

Overall, we should keep in mind that we are here judging the generic idea, and not the specific design, which could be very different. It is for each solution that we can think of multiple different ways to construct it which may then influence its feasibility and even perform better on some of the KPI afterwards.

Finally the scores can be put together and used to order the idea solutions:

		Total score
13	extra pouch	**28**
10	zeolite	**27**
14	moving piece	**26**
19	springs in the lid	**26**
12	flexible membrane	**25**
15	valve with spring	**25**
20	flexible connection	**25**
1	*restrict food type*	*24*
2	vacuum	**24**
6	smart pressure	**24**
9	filter CO2	**24**
11	*counter pump*	*24*
17	opening systems	**24**
8	*cold food*	*22*
16	*stronger lid*	*22*
18	use sensors	22
7	smart O2	21
21	use heat	21
4	chemical	19
3	HPP treatment	18
5	dehumidifier	16

Table 2.8: Decreasing order of the ideas' total score

We can conclude that the top five scores comprise ideas like placing the food in an extra chamber inside the container (#13), having movable or deformable parts to accommodate a larger volume (#14, 12, 20), reinforcing the lid by placing springs (#19), creating air channels covered by a spring-supported valve (#15), or controlling pressure of our inner environment (#2, 6). Even the zeolite solution (#10) scores greatly for our defined KPIs. What is important to notice is that even though the top idea has the highest score, it doesn't necessarily mean that it is the clear best compared to the other solutions. In the same way, the lowest scoring ideas are not to be put aside, and can also give some suggestions of designing choices.

It is important to note that thanks to the above-mentioned diagrams, especially the Spider plots, it is possible to know for each solution how it scores for each KPI, and thus know which ones need to be revised. Those improvement points are listed below and can serve as paths for further design and subdivisions of our ideas:

		Total score	**Design improvement points**
13	extra pouch	28	→ improve Reliability
10	zeolite	27	→ improve Recyclability+Cost
14	moving piece	26	→ improve Simplicity+Satisfaction
19	springs in the lid	26	→ improve Insulation+Cost+Satisfaction
12	flexible membrane	25	→ improve Recyclability+Insulation+Satisfaction
15	valve with spring	25	→ improve Simplicity+Recyclability+Insulation+Cost
20	flexible connection	25	→ improve Recyclability+Insulation+Satisfaction
1	*restrict food type*	*24*	→ *not taken*
2	vacuum	24	→ improve Simplicity+Recyclability+Cost
6	smart pressure	24	→ idem
9	filter CO2	24	→ improve Simplicity+Recyclability+Insulation
11	*counter pump*	*24*	→ *not taken*
17	opening systems	24	→ improve Simplicity+Recyclability+Ease of use

Table 2.9: Top five scores and the corresponding ideas

For instance if a solution needs improvement in Recyclability, then its design must anticipate easy disassembly or separation of some specific materials.

If it needs better Cost, then an adequate material selection or a downgrade in material may need to be done, as well as using similar materials as much as possible.

If the solution needs improvement in User satisfaction, then the design must be thought as simple as possible such that the user does not execute actions that would seem out of place (e.g. not use an extra oven or a complex dehumidifier system).

Improvement in Thermal insulation means that adequate material selection must be done and sensible placement of insulating pieces can be analyzed.

If the solution needs improvement in the Ease of Use, then the design of the lid must not be complex from the outside view. The functioning must be limited to one button, or even better, the mechanism can be hidden inside such that it is activated by the unscrewing of the lid.

2.6. Further classification and declination

As anticipated in the above list in §final score, but also while analyzing the scores along the KPIs, some of the solution ideas can already be put aside as they do not align with the main objective and purpose of the basic food container.

Indeed, idea #1 about restricting the type of food to be placed inside the jar makes no sense vis-à-vis the user that shouldn't be brought to divide the food he can or not store.

In the same sense idea #8 which considers decreasing the temperature of the food in order to decrease the chance of it spoiling works in the opposite direction to how the actual food pot functions.

Moreover, ideas like the strength of the lid (#18) or a pump (#11) may seem either too basic when tackling the pressure problem or can just be added to any other existing idea as they are similar. From a first filtering point of view, we can put them aside too.

Now among the top scorers, we can actually observe some resemblance among some of the features and use them together on improved designs. Therefore from the list we can have some groups formed, which counts already as an added step from the first list of ideas, shown below:

		Total score
13	extra pouch	**28**
10	zeolite	**27**
14	moving piece	**26**
19	springs in the lid	**26**
12	flexible membrane	**25**
15	valve with spring	**25**
20	flexible connection	**25**
1	*restrict food type*	***24***
2	vacuum	**24**
6	smart pressure	**24**
9	filter CO2	**24**
11	*counter pump*	***24***
17	opening systems	**24**

Table 2.10: Regrouping of the ideas by similarities

In the same time, subdivisions of the solutions can be generated by thinking more in detail to the assembly or the idea's base function and giving attention to the actual design of the solution:

1. Extra pouch + vacuum + smart pressure (yellow)

   1.1. According to the base idea, the function is to enclose food further from the outside environment and bacteria, such that we can effectively decrease the amount of spoilage. Some bacteria will still be present on the food, but then it will not be renewed and grow as there will be no transfer with the pot's inner and outer air.

      1.1.1. At first glance, we could think of a plastic film that is closed upon automatically when food weighs down on it. The feasibility of such a system must be analyzed to see how it would be implemented.

      → As anticipated by its KPI score, this needs improvement in Pressure locking reliability. Therefore, extra care must be placed into closing the pouch properly so that inner air and pouch air are not mixed. We want the sealing to be strong enough to resist high pressure and easy to reopen by the user; the simplest mechanical solutions that are reusable are using a sticky line on top of the pouch (as long as it doesn't deteriorate too fast), using clips or zip locks (but it would need precise alignment), or rubber bands snapping around the neck.

      1.1.2. Another subdivision can be to just sell extra plastic or silicone bags with the pot, that the user has to place food in and close before placing it inside the jar.

      1.1.3. The structure of the bag itself can also be designed such as to have flexibility on the volume needed. Indeed, if we have some sort of "accordion-like" rigid shape, then the pouch could extend if we need a larger volume for more bulky food items, or collapse if we only need less space for smaller items.

   1.2. If we couple it with a pump, then we can create vacuum inside that bag, which is even better for bacteria removal. Energy consumption values will be lower as we are with a much smaller volume, thus also easier to control.

      1.2.1. The pouch or bag can thus be either always connected to the pump, and in such case the pump would have to be accommodated inside the lid as a complex extra element.

1.2.2. Or it can have its pressure removed prior to placing it in the jar. In that case the pouch has to be more rigid around the valve for it not to deform during its life-cycle. We could also add a pressure sensor to indicate when the user should stop removing air.

1.2.3. Thinking about the actual pump system, it could either be electronic and automatic, or manual and performed by the user with a syringe-type mechanism, or even more disguised as a silicone button that needs to be pushed repetitively.

→ According to the KPI score, this needs improvement in Cost and Recyclability. We could think that for an external pump, having the company sell a version that works for multiple products, or asking the user to provide its own would clearly reduce costs and help reusing pieces.

1.3. Now one great extra feature from packaging food in an extra pouch is that we can easily store different food types in separate bags, and can still be in the same pot which will keep it hot. Food will not mix and we can gain more flexibility in the meals stored. Moreover if we employ variable-size pouches, then the variety of volumes can help the user place more or less bags into the inner container.

2. Moving piece + flexible membrane + connection (green)

2.1. The different parts composing this group could be used separately as they were defined in the list, because they have distinct functions.

2.1.1. Recall the flexible membrane (idea #12) to be used instead of the inner wall, has its sole purpose to inflate and provide a larger volume for the inner air, as well as keeping the food hot. Its material must then be chosen so as to be elastic enough to deform under high pressure values, but rigid enough to maintain shape and resist vacuum between the walls, and keep great insulation properties.

2.1.2. The flexible connection (idea #20) between the inner wall and lid is really used to relieve the force on the thread. It is originally folded on itself and as it extends it moves in counter direction to what the pressure would push.

2.1.3. Idea #14 of the moving piece's objective is to serve as the last resource to add a little bit more volume. Importance must be put into the simplicity of the sliding mechanism (not over-complexifying it).

Some concern might be put in its thermal properties; having a sliding piece means that there is an empty volume not used in the lid, therefore we could think about placing an extra insulating material that can fold on itself in that free space.

2.2. An extra step from the base design would be to put together these ideas: it will add their advantages and we gain in performance while losing a bit in simplicity.

2.2.1. Indeed we can add all extra volumes generated with the ideas above, and get a much larger volume that can be inflated to manage the over-pressure. Thus when pressure increases, we would have the inner wall of the container that will extend, as well as its connection to the lid to disperse the stress, and even an extra volume can be liberated in the lid.

→ As anticipated by its KPI score, this needs improvement in Recyclability, Insulation and User satisfaction. Concerning the first point, adequate assembly must be adopted with press-fitting being the best solution so as not to add pieces. For insulation, both steel and silicone are great non-conductive materials, therefore its selection only depends on having a sheet strong enough to be used with vacuum [17]. User satisfaction is low because this solution is only a mitigation of the problem, and so only delays the time the user won't be able to open the jar.

2.2.2. If we actually want to keep the same material as the rest of the pot for Recyclability purposes, then we could also think of using stainless steel for those ideas, but that would mean that its structure has to be modified such as to be able to inflate and fold on itself. Therefore instead of one solid piece, we could use a matrix or multiple small pieces that create some flexibility or can slide next to each other to offer a larger surface.
This subdivision is mainly based on origami's crease folding or strategic cuts, that offers new movements for sheets of materials.
One concern though is that we would have great difficulty in manufacturing these pieces compared to simply selecting flexible rubber silicone.

3. Springs in the lid (brown)

3.1. According to the base idea, the function is to offer a reaction force working in counter direction to the over-pressure, that is different than the thread and thus decrease its stress. For that we need to use springs as they are the most common to generate a force under a displacement.

3.1.1. At first sight, the main decision concerns its placement. We want the springs to act along the stress path from the bottom of the lid to the thread. Therefore we need to horizontally separate the lid's structure's central region in two parts, and place springs in between. With this configuration, both the thread and the central part that is subject to the pressure will be dissociated.

→ Since we are planning to place springs under the pot lid, which take a certain volume, then we anticipate thermal losses as the lid is the zone of main heat exchanges. This is shown by the lower score in the Insulation KPI. Using a filler material could solve this as shown below.

3.1.2. Another declination could be to select a rubber cushion material to compress instead of the metal springs, while offering the same elastic properties. The main advantage with this idea, which responds to one of the KPIs, is to offer better insulation properties and thus have less heat losses through the lid than the metal springs would provide by needing free space.

3.1.3. In order to increase the rigidity of all, we can think of mixing the two together, meaning having a spongy insulating material with vertical channels to accommodate multiple springs. But such an idea will increase the overall complexity and reduce the recyclability ease.

4. Valve with springs (pink)

4.1. An airway channel topped with a valve is the most used and common solution to over-pressure in the food pot industry. The airway passes through the lid and when the valve deforms gasses are let go. It is important to notice that if the jar is displaced then we could have food falling into that channel, which is detrimental to its function and cleaning.

4.2. Therefore, to ensure that the channel stays closed when not needed, but also to have better control on its opening and closing, we can add a spring to the channel cover. That way, the air channel opens up only if the over-pressure goes over a predetermined value.

4.2.1. The solution that takes the least space would be a vertical airway with a horizontal/perpendicular moving cover that has an inclined face. Through that inclined plane the vertical pressure is transferred into a force longitudinal with the spring. The problem is that such design would be hard to manufacture, as it requires that side space to accommodate for the spring.

4.2.2. To help with manufacturing, we could have the whole design to be vertical, meaning the channel is vertical and the spring-mounted valve will sit vertically inside the channel. But again manufacturing this is quite tricky, as well as its assembly and disassembly. Adding the steel spring finally reduces its KPI performance in recyclability.

→ As anticipated by its KPI score, those two ideas need improvement in Simplicity and Insulation. For the first point, we need to add pieces therefore the objective is to minimize their number. At best, we must have a steel spring for elasticity and a rubbery material for sealing. For the second point, if we consider that fermentation is constantly increasing then the channel's opening will be repeatedly activated, thus letting heat exchanges happen with the exterior every time. A solution is presented below.

4.2.3. A declination to the above ideas is about their opening. Left free to move, these pieces will open the airway whenever the pressure increases. But if we retain them with a pin, then we can decide when the cover moves, i.e. when the user opens the lid or pushes a button. Moreover, blocking the opening can ensure spilling safety even if the container finds itself upside down.

5. Zeolite + filter CO2 (light blue)

5.1. These to ideas have as objective to attract and stop CO2 molecules propagation. As we already know, that is one of the main products of fermentation and thus needs to be disposed of so as to reduce problems with pressure.
Unfortunately, those ideas would not be practical as they depends heavily on the chemical composition of the paste used which is not in the scope of this project. Moreover, and as anticipated with Zeolite material, those elements can only absorb so many molecules and thus would need additional steps to be executed by the user to de-saturate them, such as placing the material in an oven.

6. Opening systems (dark blue)

6.1. According to the base idea, the solution comprises any design where the function is simply to move if a pressure equalization is needed between the inside and the outside of the pot. It can be seen as an extra component to an existing food pot and thus relies on simplicity and blending with the surrounding lid cover.

6.2. Subdivisions may include button moving pieces, sliding parts, or more generally needs the user to push a small piece. We could also think of actioning the mechanism with the opening of the lid, thus necessitating extra care into manufacturing ease and simplicity.

We now have generated some ideas and solutions to our pressure problem, and even filtered some of them according to their performance thanks to KPIs. With this list, we even went further into figuring out some design and function concerns which let us decline even more our top scorers. The next step is thus to actually design the systems, draw the assemblies, and get a first sense of how the pieces will fit.

3 | Concept design

3.1. Introduction

The following chapter concerns the design approach to the previously mentioned, top scoring ideas that have performed the best against our Key Performance Indicators. By starting on some technical drawings and getting a sense of how the solution's function will come to life, we can already understand what difficulties will be generated, in terms of assembly but also manufacturing, which is already a step into Design For Manufacturing.

Thanks to that visual aid, we will be able to filter out more all the ideas presented, branch out the ones that worked, and finally select the solution that was kept.

3.2. Calculation and sizing

In order to have a correct design dimensioning, some values must be calculated so as to have an order of magnitude of the phenomena at hand, and get a sense of dimensions and thicknesses needed when developing the solutions.

3.2.1. Torque values

Recall from research papers [24] that measurements have been done on humans about the torque value needed to open a bottle container. It depends a lot on the diameter of the lid/opening, but also on the material. For instance it was found that plastic water bottles are easier to open than metal food pots, as the friction between the threaded surfaces plays a large role. The opening ease also depends on the dimension of the user's hand (or more specifically on the effective diameter that the hand can grasp). According to the paper, female users usually have smaller hands than their male counterpart, while older people or those with deficiencies have lower grabbing force to be considered.

Overall the order of magnitude for the torque needed to overcome static friction is within 10 Nm, with an average of 3.4 Nm for a $\varnothing 30$ mm plastic bottle, or an average of 4.5 Nm for a $\varnothing 70$ mm glass jar.

3.2.2. Heat performance

Some introductory calculations can be done for what concerns heat transfers through the side walls of the container, in order to understand what phenomena happen while the temperature goes down inside the food pot and heat is lost to the exterior.

For a vacuum-insulated food pot, it is well known that the side walls are constituted by two separate thin walls, enclosing vacuum in between. If we follow the idea # 2.2.1 from the list above, then this is the structure we can have:

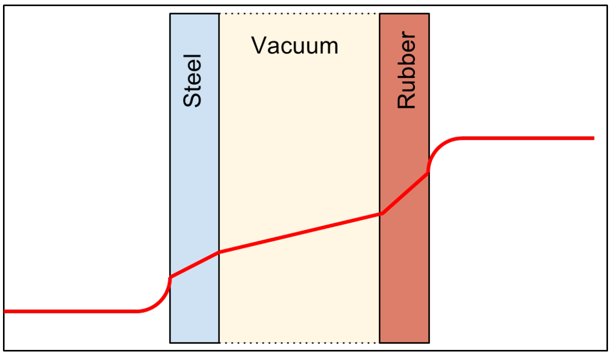


Figure 3.1: Scheme of the heat transfer phenomenon

Here the temperature level is shown by the red curve, enduring either conduction through the layers or convection in the vicinity of the inner and outer wall. The performance of the food pot is won by having very small temperature loss over the "vacuum" layer since no energy transfers easily there.

Overall the equation governing the heat transfer phenomenon is as follows:

$$\dot{Q} = \frac{T_2 - T_1}{R} \qquad R = \frac{1}{A}\left(\frac{1}{h_1} + \frac{1}{k_s} + \frac{1}{k_v} + \frac{1}{k_r} + \frac{1}{h_2}\right)$$

Such equation can be used if further analysis is needed regarding the heat performances of the whole food pot.

3.2.3. Thread fiction and torque

As the initial problem relies on the opening of the food jar, for which the region of interest is the lid thread, it is interesting to get some numbers for what accounts unscrewing torque and friction. We assumed to have a rectangular thread for worst case scenario, for which forces and interactions are well known, all based on this kind of scheme:

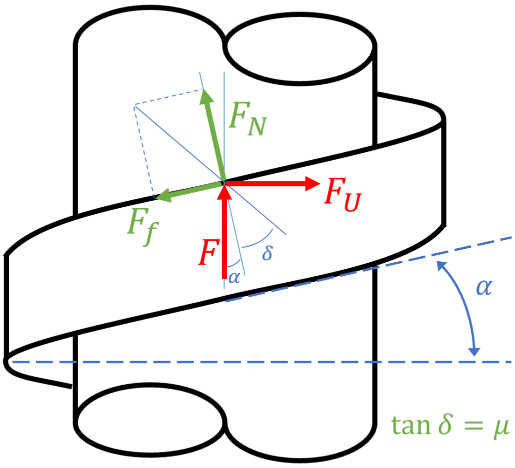


Figure 3.2: Scheme of the forces over a thread

For such thread, we can link vertical force F and screwing or unscrewing torque M by the following formula:

$$M_{S/U} = \frac{d}{2} \cdot F \cdot \tan(\alpha \pm \arctan\mu)$$

Therefore knowing the diameter and the geometry of the thread, with the friction coefficient, we can easily compute the torque needed against a vertical force.

Thanks to this formula, we may be able to get some values on the actual over-pressure phenomenon at hand, namely what is the pressure value in our problem. Multiple techniques can lead to it:

- To get the value of the typical over-pressure, then we can try to find the amount of gas and CO2 ejected by common dishes. Those values though are very difficult to quantify or measure, and they are subject to many parameters such as inner temperature and humidity, adding more variability. Also nothing is really presented on the internet about such calculations.

- Going at it from a different angle, we know that the average torque delivered by a user is 5 Nm, and thus this would be the limit to overcome when the lid is blocked under vertical force (as depicted above). Therefore we can find the pressure value that makes it so that the unscrewing torque is larger than the one performed by a human, namely:

$$M_U = \frac{d}{2} \cdot F_z \cdot \tan(\alpha - \arctan\mu) > 5\ Nm \qquad with\ F_z = \Delta p \cdot \frac{\pi d^2}{4}$$

Standard values for a 70 mm diameter thread (type SP400) is to have a pitch of 4.24 mm which entails a thread angle α of 1.105. Moreover, the friction coefficient for steel on steel interaction is known to be 0.4, thus we can find:

$$M_U = \Delta p \cdot \frac{\pi d^3}{8} \cdot \tan(\alpha - \arctan \mu) \qquad \longrightarrow \qquad \Delta p = 98\ 260\ N/m^2 = 0.983\ bar$$

We then conclude that the users cannot unscrew the pot lid because the pressure inside the container has increased of 0.983 bar from the atmospheric pressure.

3.2.4. Hydro-static pressure

For what accounts dimensioning, the over-pressure value must be compared to other values that may play a role into critical components of the food pot, in order to verify which one is the decisive one.

We then may execute a quick verification on hydro-static pressure. Then if the entire volume of the pot is filled, for instance, with soup, then we can check that the pressure it generates on the bottom is not enough to deform or disassemble pieces. That force is calculated simply with the formula $\Delta p = \rho g h$.

Assuming the pot has thick soup, whose density is known to be 1.09 g/mL, and the height is 130 mm (recall the container is fixed at 150 mL and we took a diameter of $\varnothing 70\ mm$, then the largest value of pressure is:

$$\Delta p = 1\ 389\ Pa = 0.014\ bar$$

We can thus note that this pressure is very small compared to the one generated by food spoiling, thus it can considered to be non-relevant. Dimensioning according to the over-pressure will thus be more than enough to overcome any hydro-static concern.

3.3. Preliminary drawings

We can now base ourselves on the list of solution ideas presented before (c.f. section 2.6), as well as their subdivisions and the improvements that could be thought of. We will follow the same order that was listed in that section, and generate technical drawings of the various concepts presented and analyzed. Notice that we will use the word "design" in this section to refer to the newly drawn solutions, while we will call "ideas" the solutions coming from the previous list.

Indeed, the idea behind is that by going towards a technical drawing instead of a functional one (as what was presented up to now) then we can better understand how to assemble the system and how each piece with its function will be utilized in the overall structure.

1. Extra pouch

Recall that this concept comes from the idea listed **1.1.**, for which the objective is that by enclosing food into a smaller volume, we can protect it further from the outer air and better reduce the spoilage in a smaller container.

One main concern for this idea is on the feasibility regarding the pouches, with the question being "how to place them in the container?". We could think about placing the pouches on the top of the jar's body in order to fall into the jar when full of food, but that would mean that we cannot stack multiple of them. To solve that, another solution can be to collect pouches on the side of the jar and open one when needed.

1.1. Pouches on top

1.1.1. Version 1

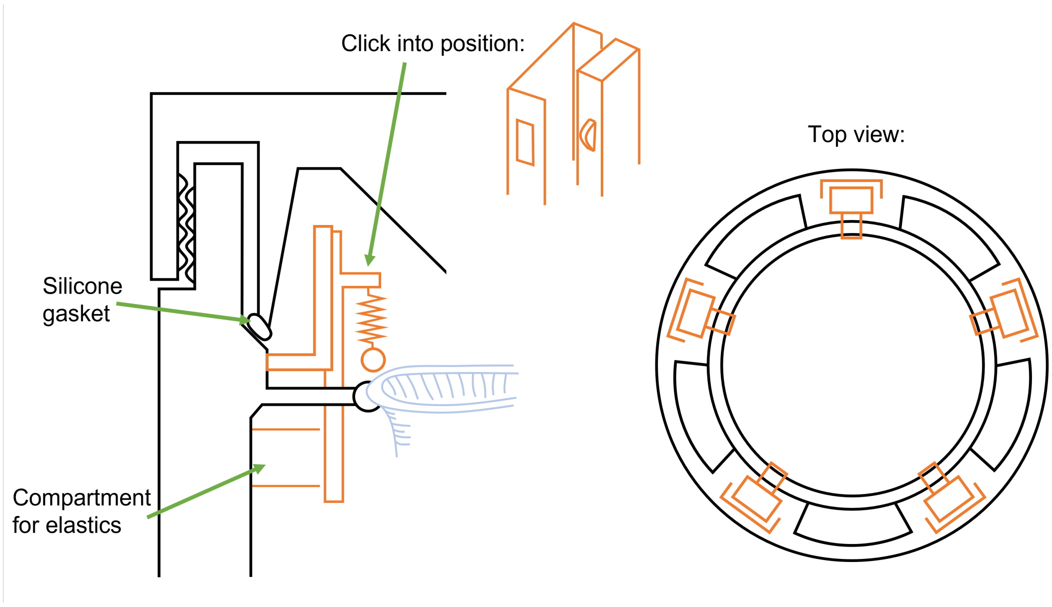


Figure 3.3: Scheme for design 1.1.1.

In this idea the system is placed onto the body of the container and not the lid, as it is supposed to be operated when the container is open and the user wants to place food inside the container. Therefore in order to have the pouch stay in place during that process, we could think of pinching the pouch between two surfaces, and here in this version the bottom surface is some sort of ledge coming directly from the inner wall, while the top surface is mounted on a spring that bases itself on a sliding column. The idea is indeed for the user to have some space to place the pouch on the bottom surface, and then slide down the column so as to press the top surface down (with some elasticity thanks to the spring).

Now as the food weight will require a large compressive force between the two surface, then friction will not be enough to position the top surface, and thus we have to think about a system to lock the top surface in position (whether it is "up" to leave space for the user, or "down" to press down on the pouch): the idea presented above is based on the sliding column having rigid pins that have to fall into holes of the guides, so as the structure not to be deformed (thus relying on a "resting" position), for which the efficiency of the locking is a consequence of the size and angle of the pins. By performing two holes at different heights for the same pin, we can thus define two height positions for the top surface.

For what regards the closing of the pouch, we can see that it is when the column slides up that we generate an opening, on the bottom, to a chamber containing rubber bands for instance for which the column is one of the walls. Therefore, when the column slides up, one rubber band is allowed to move out and will then snap around the plastic pouch.

Now some disadvantages can be observed from this solution: first of all the user can only place one plastic pouch after the other, which can be cumbersome if it wants to use multiple. Moreover, the space available to place the pouch on the bottom surface can seem pretty restricted, as it is close to the wall as we do not want to lose too much space to the mechanism. Then the coordination between placing the pouch and pressing down the top surface is complicated, which can leave time for the pouch to slip out of position. Finally, the chamber with the elastic bands is not ideal to dispense only one band at a time, because the bands themselves are in rubber which can stick more to the walls than wanted and they are deformable enough to intertwine easily. We could think about using other closing mechanisms such as tying a knot, using clips or glue, or a zip-system as described before, but those wouldn't work properly; indeed, they need either the pouch top opening to be small or the closure to be very precise, which is not feasible while the pouch is falling down into the container's body. For those reasons, this version of the solution is not further designed.

1.1.2. Version 2 and 3

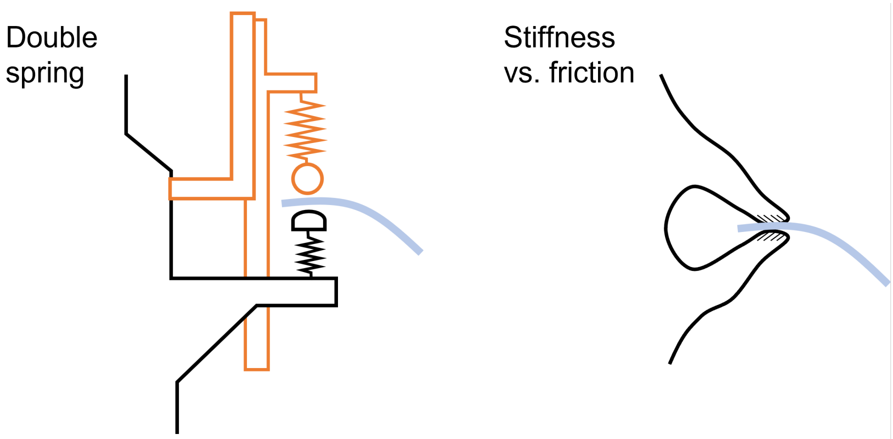


Figure 3.4: Scheme for design 1.1.2.

For this type of idea, other subdivisions can be done on the pinching mechanism. A first version is to have both top and bottom surfaces to be based on springs, where the bottom one is fixed to the inner wall, while the top one can slide vertically as defined previously. With this version we could get more flexibility while pinching the pouch, as well as an easier placement of the pouch by the user. It is indeed more pleasant to have a soft reaction to placing an object on a surface than a rigid reaction coming from a solid ledge. Then as above, the top surface could be slid down onto the pouch to complete the pinching.

But as explained, we could still have a problem of coordination due to the fact that the pouch can fall out of its position before we could pinch it. To resolve that, a third version was envisioned in which the user must slide in the pouch between two solid surfaces. Pinching is thus performed because both arms will be bent out of their resting position, due to the pouch's thickness, and thus will deliver a reaction force pressing down on the pouch. We could think about pre-constraining those arms in order to increase the pinch force, as well as coating them with rubber or another material in order to increase friction.

Nevertheless, the closing problem is not resolved with these versions, and thus this design "1.1 Pouches on top" will not be further designed.

1.2. Pouches stacked on side

1.2.1. Version 1

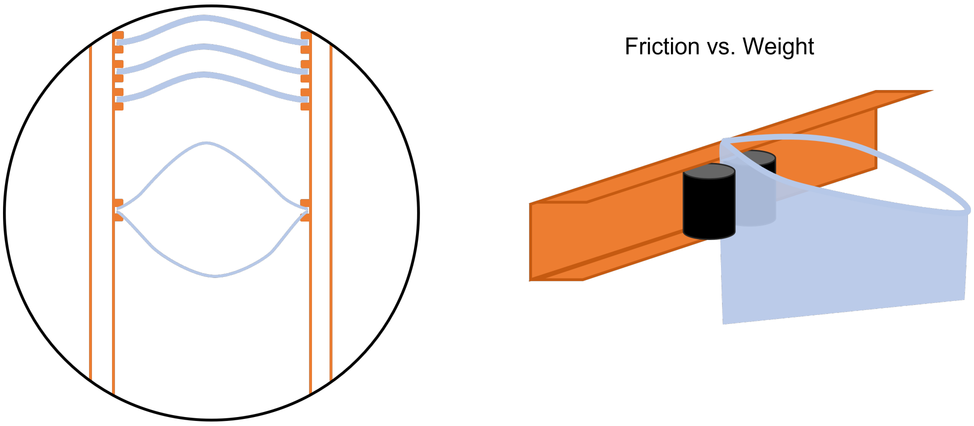


Figure 3.5: Scheme for design 1.2.1.

In this idea, we decided to include the possibility to place multiple pouches in the container. Indeed, as anticipated in the subdivision paragraph 1.3, using film pouches lets us develop an extra feature for the user for which different types of food can be placed and stored in the same container without mixing everything. Therefore, with only one food pot, the user can for instance safely keep a salad, a main course, some side vegetables, and a dessert, and have a complete meal without fearing to have everything mixed inside the pot.

Now analyzing the feasibility of this idea, the solution is to be able to stack multiple pouches on the side of the container, taking as less space as possible, and be able to have a central position where the pouch can be opened and filled with food before falling into the container body like defined with the previous idea. To perform this function, the solution relies on beams that serve as guides, on which small carts slide along while pinching pouches. The guides must be linked to the inner wall because the system should be operated when the pot is opened. Then from their resting position on the side of the container, the user can grab one pouch and push it into the center of the pot by bringing along the carts sliding on their guides. As soon as the pouch is filled with food, it can be closed and fall into the pot, leaving the central region free to slide in another pouch.

The important design point for this idea is to properly size the carts so as to provide enough pinching force, just like idea 1.1.2. Version 3 (Fig 3.4), in order to grab the pouches before needing to put them inside the pot. Moreover, enough care must be given on the positioning of the guides and their assembly with the rest of the container.

1.2.2. Small calculations

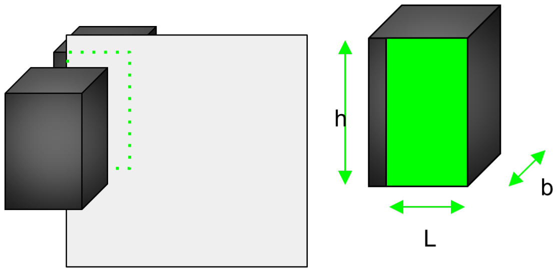
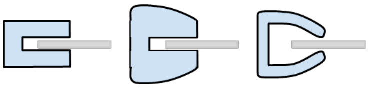


Figure 3.6: Scheme of the carts

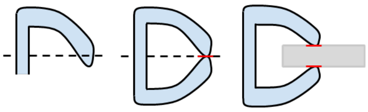
For the carts in question, the objective is to provide a pinching force on the pouch against its weight, which is the main tangential force in play. Assuming that the friction surface is a simple rectangle, the situation could be brought down for each arm of the cart to a cantilever beam problem:

$$\frac{mg}{A_i} = \mu \cdot \sigma_{flex} \qquad \delta = \sigma_{flex} \cdot bh \cdot \frac{L^3}{3EI}$$

for which the pouch thickness is noted $\delta \approx 45\mu m$ and the bending inertia depends on what shape are used for the arms:



Some of these formats may also be designed such as to have pre-constraint on their pinching/bending, which means that their displacement under the same stress must be lower than a pouch's thickness, or even have the arm in its resting position lie over the middle plane and thus meaning it is bent when assembling both arms of the cart:



1.2.3. Version 2

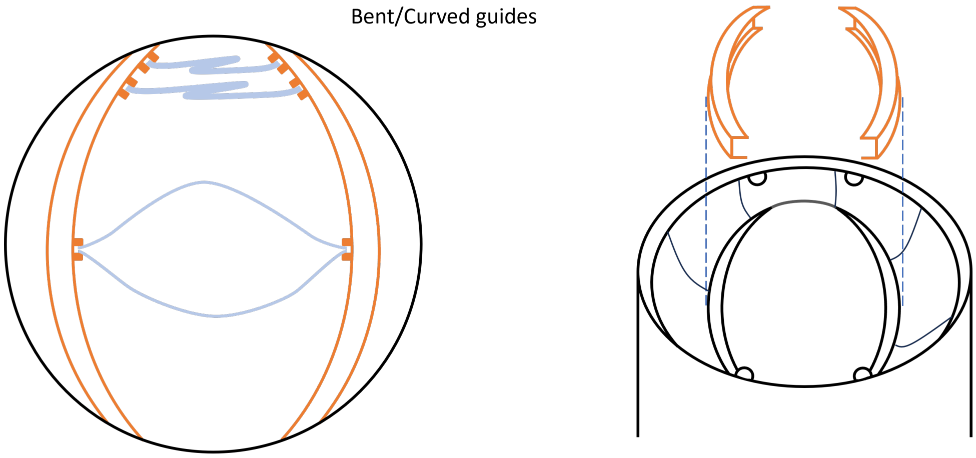


Figure 3.7: Scheme for design 1.2.3

Regarding the guides, their placement must be thought so as not to cover too much the top opening of the jar, because the user needs to have enough space to pick up the pouches from the inside when needed. Therefore, instead of having straight guides, we should have them bent, in order to follow the curvature of the pot's cylindrical shape more properly, and thus leave as much room as possible in the center. Stored pouches can be folded up a bit on the side, while the pouch that is brought into the center to be filled with food can take as much space as possible in order to have a large opening and ameliorate the ease of use.

The guides must lie on a surface, and so for more of a design view this bottom surface could be part of the inner wall, as a terrace sticking out. Moreover, in order to keep the guides in place vertically, we could think of clipping the guides by using snap-fits on top. This would allow easy assembly and disassembly if needed. To position the guides laterally we simply use centering faces as shown in the figure below.

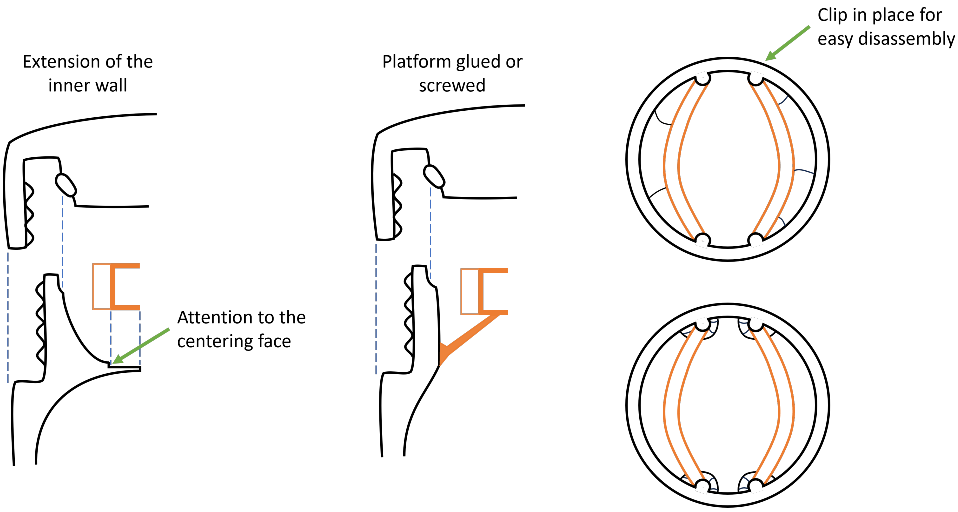


Figure 3.8: Positioning of the guides

Now this bottom surface could be stretched out all along the circumference of the pot, and thus along the whole length of the guides too, or could be thought as small balconies which would be placed only on the ends of the guides, in order to save space and/or material for the inner wall structure. On top of this concern, we could think about its manufacturing, and thus either the terrace could be manufactured with the inner wall, probably by molding or melting, but if it is too complicated to achieve, we could simply have the ledge being screwed to the inner wall, which would require extra components.

One clear disadvantage that we can observe from this solution is regarding the stacking of pouches. As we want to have a large free volume, we can only stack a finite number of pouches on the side. Then that will mean that whenever the stock of pouches is finished, the user has to stack new pouches again. Therefore, this idea requires regularly that the user executes extra steps, which can lower his satisfaction.

1.2.4. Notes on the guides

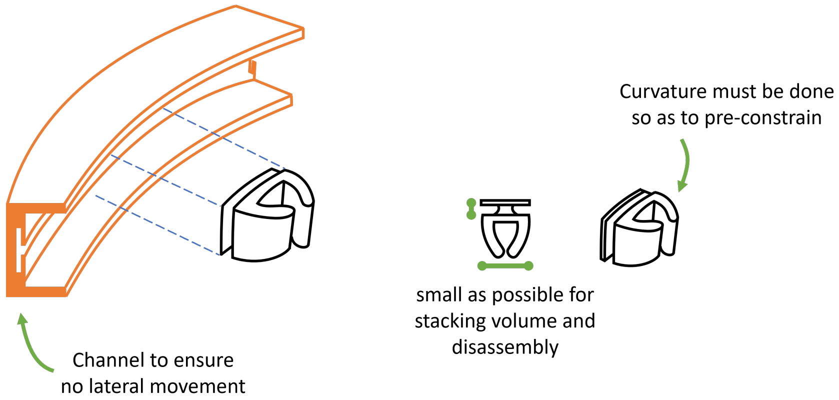


Figure 3.9: Scheme for design 1.2.4.

Now let's analyze the feasibility of the carts sliding along the guides. In order for the carts to move easily along the beams, we could use wheels but in order to simplify to the maximum the number of components and their assembly, we can simply use a system of thin ridges and walls. Is it then by designing the thicknesses with the right tolerances that we can get some sliding instead of friction. Therefore by creating a channel on the inner face of the guide, and a corresponding thin wall on the cart, we can block some degrees of freedom of the cart and let it move longitudinally. For easy assembly and disassembly, the guides' ends are left free so that the carts can be easily placed on the ridges from the side.

Moreover, the actual sizing of the cart must be decided. We want the overall size to be as small as possible so as not to take too much space, but also its width to be the smallest, as this will help with disassembly, let the cart follow the curvature more easily, and more importantly occupy less space when we stack the pouches and so the carts side by side on the side of the container

2. Pump design

The base principle of these designs is to understand how to incorporate an air pump inside the lid, following idea **1.2.**, which could generate vacuum or at least more extensively a lower pressure in the food pot. The concepts presented here could be coupled with the concept "1. Extra pouch" or not necessarily, as they have been thought independently from it.

More on its feasibility, the pump could be thought of as being an entire extra system which could be added inside the lid, in that case being seen as a "black-box", which would not be interesting design-wise but also money-wise as shown already by the KPI of such an idea. The other idea which was presented before would be to ask users to provide an external pump (idea 1.2.2.), and thus some conceptual designs can be drawn and details analyzed, but the concept would still be dependent on the user. Therefore, to solve that, a final concept can also be thought of where the pump would be seamlessly incorporated into the lid and be part of it (idea 1.2.3.).

2.1. External system

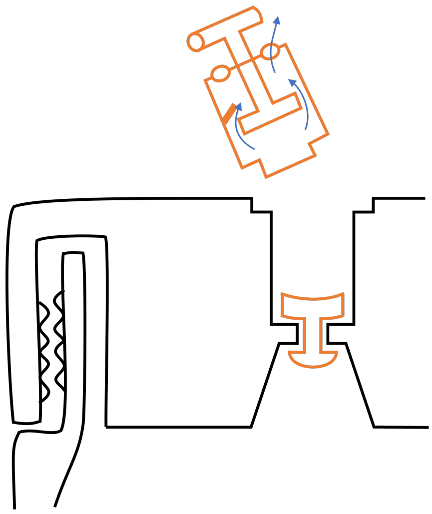


Figure 3.10: Scheme for design 2.1.

As anticipated in the first part of the idea 1.2.3, the integration of a syringe-type mechanism could be analyzed quite quickly. By leaving the responsibility to the user to provide a vacuum pump, we can concentrate on its linking with the pot lid.

With this idea, the simplest way to do it is to get a vertical channel into the lid, which could be centered to help with its manufacturing. Now the main point of concern should be the sizing of the airway, as well as its opening to the top. Indeed, the channel is one region of heat loss, and therefore must not cause too high energy losses compared to the heat retention that the pot is supposed to offer. Moreover, the design requires a valve that will block the air from coming in (indeed the inside of the jar will have lower pressure) but also help with the removal of air when creating lower pressure in the container. The selection of the valve may then influence the space it needs and its assembly into it.

Special care should be given to the external pump, to ensure that it is designed to suck air out of the pot and not push in, as those used to inflate balloons. If needed, the mechanism inside should be reversed. As this concept is pretty simple in design and is more about selling extra pumps to users, then its development is not further pursued.

2.2. Notes on valves

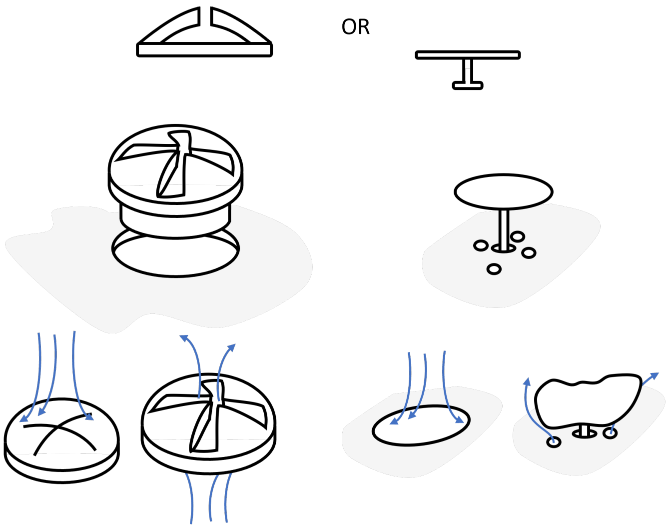


Figure 3.11: Notes on valves

There exists two main types of valves that can be made in silicone: the "duck-shape" and the "umbrella". The first one occupies a larger surface but needs very small depth, while the second has a prong that has to be snapped further down the airway.

Both rely on their material, which is always silicone rubber, such that it has some rigidity when compressed but also has some flexibility when it is deformed, both features being utilized when needed;

- For instance for the "duck shape" valve, its functioning relies on the 4 curved panels that can bend from the outer ring. When air presses from the bottom all panels are pushed apart and the air can flow easily. But when the flow goes in counter direction, then due to the dome shape all panels are pressed against one another while going down, and thus closes off the airway.

- In comparison the "umbrella" valve features a large flat top surface which will lay flat and cover the air channel. When air presses from above, the flat surface is pressed against the floor and no air flows. On the contrary if air comes from below, the valve will deform as it is thin, thus opening up passage upwards.

2.3. Pump as a button

2.3.1. Version 1

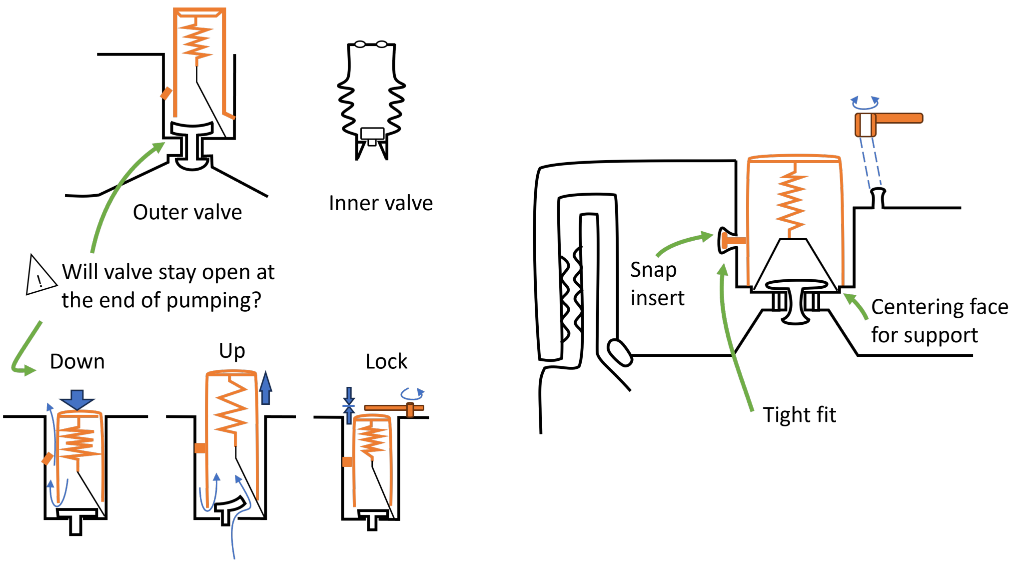


Figure 3.12: Scheme for design 2.3.1.

Now compared to the previous concept, if we want to have the pump at all times linked to the food container then we could think about removing air and decreasing pressure directly from the lid. In this concept we make use of a rubber button which can be pressed down and up by the user's finger to remove air in an intermittent manner. It will be placed centrally to help with manufacturing, and more importantly right above an air channel that begins on the inside of the container and finishes on the top of the lid.

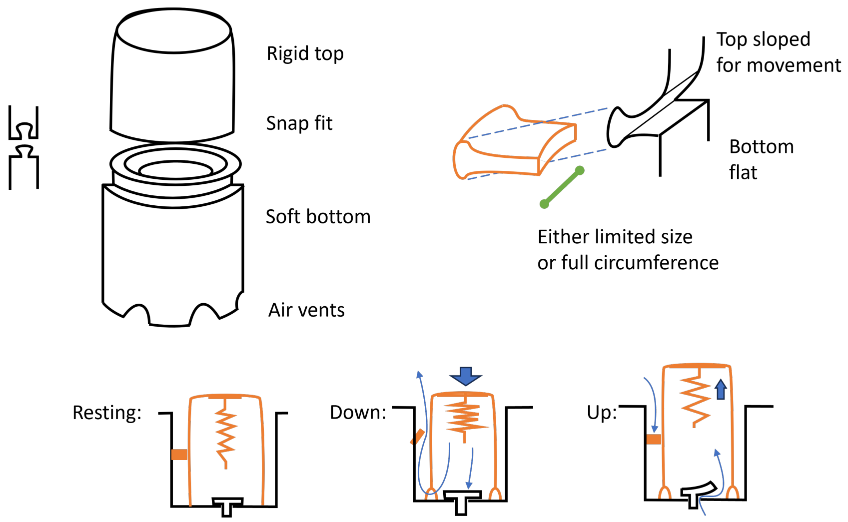


Figure 3.13: Further detailing

The concept relies heavily on the use of one-way valves, which can be useful to close off and open airways in the right order and direction.

Therefore, when the button is pressed down, the air that was kept inside the button will be pressed out and will be able to leave from openings on the bottom of the button to the side and through the “side-valve” which can be opened in that direction (due to the slit shape as shown above). At the same time as we are pressing from the top, the “central-valve” will be kept closed and no air will thus flow towards the inside of the pot.

Then when the button moves up, we finally generate de-pressurization. Indeed, as the volume is small inside the button at that moment, the upwards motion will draw in air from around. As the side valve is closed, no air from outside will be absorbed. Therefore, it is from the central valve that air will come, deforming the valve in the right direction. Note that this phenomenon will be helped by the fact that over time the pressure inside the button will always be lower than the outside pressure, thus attracting the air from inside the pot more easily.

It is important to observe that the button comes up from its down position with the help of a spring system inside the button, and thus needs some structure in order to be assembled and fixed. Along with all the other parts, we are then greatly increasing the complexity of this concept as well as its manufacturing ease. Moreover, a further detailing on the button itself increases the complexity as it would be better for the user to feel a rigid surface under its finger to press down on it, while the bottom needs to be flexible and has to compress, thus requiring the button to be made in 2 different parts or materials.

2.3.2. Version 2

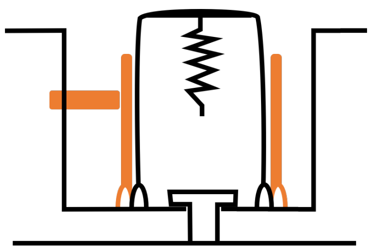


Figure 3.14: Adding walls

As said above, Version 1 has a side valve that presses on the outside of the button to ensure that it seals the air inside the button and does not let any outer air to come in from the top. But one main concern is that when the button moves up after being compressed thanks to the spring, the outer surface also moves up and so by friction the valve may result in deformation and opening. Indeed, as we recall from its structure, the valve can deform upwards because free space is left on the wall. With that situation, outside air can flow inside the button and even through the central valve as it is usually opened during this step, and we lose the absorbing function of our concept.

Moreover, as we said the button's material needs to be flexible on the bottom half in order for it to be able to compress and move down. Therefore, the button may need to be supported laterally in order to stay vertical and rigid for the user to press on it.

For both problems, a solution is to provide supporting walls on the side of the button, so as the latter to stay vertical, and on which the side valve will now be pressed without reacting to the vertical motion of the button since the walls are fixed.

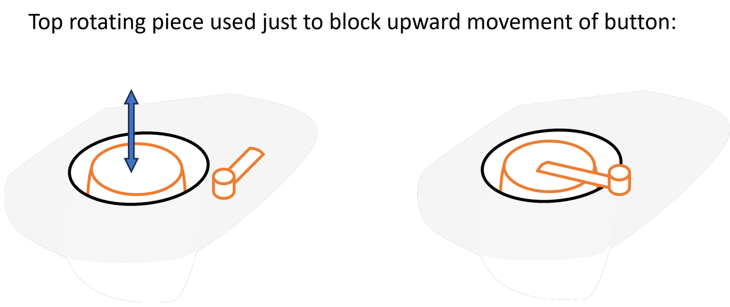


Figure 3.15: Adding a locker

Now as the positioning and closing of the valves is important for our concept, we also need to ensure that the central valve will stay closed even when the user is not acting on the button. Indeed, when the button moves up the central valve opens up, and is closed only when pressed down on it i.e. the button is moved down. Therefore, even if the spring is supposed to be at rest while the button is in top position, we can think about pressing the button a final time so as to ensure that the central valve is well closed and then block the vertical movement of the button with the help of a locking mechanism: this can simply be a small beam that can be rotated over the button and thus prevent its upwards motion.

In summary, even if this concept of a button pump lets the user decrease the pressure inside the pot with a system that is “built-in”, it requires a great number of different pieces and materials, which need to be assembled with taking care of supporting walls or even a locker as presented in Version 2. Finally, as we want all of this to fit in the smallest space possible in order not to lose large amounts of heat insulation, then pieces will also be small and thin, therefore the whole robustness of the concept is uncertain and its life cycle might be limited. It is for these reasons that this concept is not further developed.

3. Flexible parts

Recall that this concept comes from the idea **2.2.**, as we want to see how all different parts and methods to inflate the inner volume of the container can be assembled together. Recall that the main points were the use of a flexible inner wall that could have its vertical surface stretch out and thus expand, then we had that its connection with the inner wall should be made malleable too such that it can extend if over-pressure is generated, and finally a piece inside the lid that would simply slide up so as to allocate an extra volume that could be needed to equalize further higher pressure.

3.1. Silicone rubber membrane

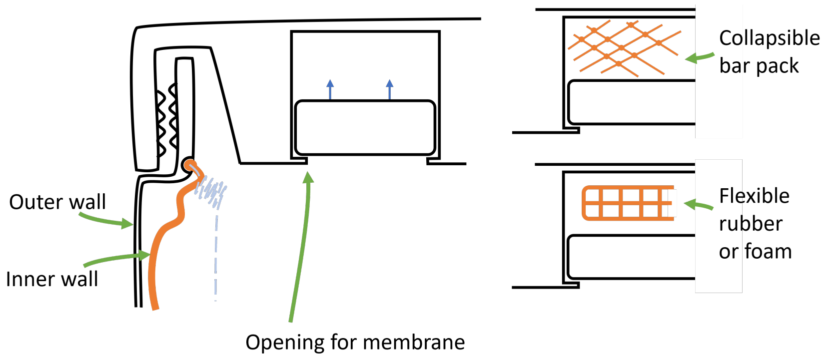


Figure 3.16: Scheme for design 3.1.

The first concept as presented in idea 2.2.1 is simply analyzing the feasibility to introduce all the pieces together inside the food container. As seen above, the inner wall is replaced by the combination of both expanding membrane and flexible connection, which for simplicity and to respond to our KPIs could be produced in the same material. When thinking about flexibility, a first choice could be made towards silicone rubber, for its deformable characteristics but also its great heat insulation properties.

Now about the moving piece, its function is supposed to be to sliding up and down. To increase simplicity and decrease the number of extra components needed, the piece could lie inside a chamber, and with the right tolerances would not need the use of sliders or guides. We can note that the bottom of this chamber is somewhat closed so that the piece has a surface to lie on. Now one concern about this bottom region is that it is linked directly to the inner chamber of the pot, thus could present problems with soup or food falling into the chamber and getting in contact with the piece. In order to avoid that we need to close the opening with a certain material layer that could let air pass through but also block liquids and solids: such materials exist and are called "Gas Permeable Membranes", which can be produced from Silicone, Teflon, Tyvek or even PET. We could then place such a thin membrane on top of any openings which end up towards the inner chamber, and thus avoid having liquids flowing everywhere.

Another concern about the chamber is that it requires a large volume inside the lid, which is then lost to insulating material. As it is mostly void, we may have important heat losses that can happen through the chamber, and thus we need to solve this issue. We can then think about filling up the top of the chamber with insulating materials which are also thin and easily compressed. For instance, using a foam structure can help as it reduces heat losses, but we should pay attention to the fact that its structure has to be changed: a full block would simply block the vertical movement of the piece, while a lattice structure, with supports that are perpendicular or even angled might make the compression of the layer easier. All of this in order to let the piece move up easily against the over-pressure and the latter not having a resistance force.

Note that the concerns surrounding the moving piece and its chamber require an increase in material diversity and the number of pieces, which is not in line with our KPIs, while also entailing assembly considerations. Therefore, the idea of the moving piece is not further developed.

3.2. Origami-based wall

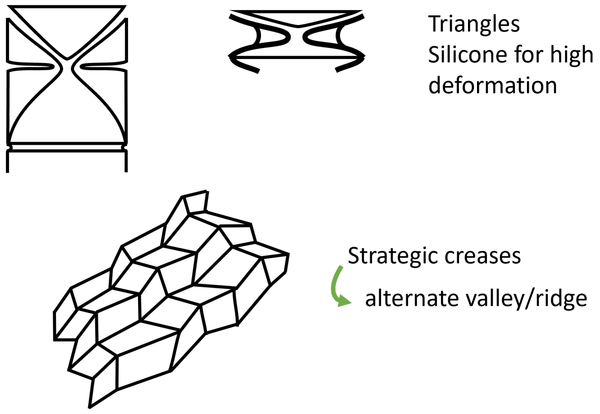


Figure 3.17: Scheme for design 3.2.

As anticipated in idea 2.2.2 there are techniques and methods in order to gain even more space for the walls of the container. Using some strategic folds and crease generation, we can actually reduce the initial volume that the inner wall would take, because then under the action of the over-pressure the wall would need to unfold and then deform in expansion. This could be beneficial because if we assume the same external volume and the same silicone dimensions than in the previous concept, with such a technique we could provide a higher increase of inner pot volume.

The methods are based on origami folding, which is an intelligent way to guide the expansion and compression of 3D volumes simply by its own geometry. It is by placing a crease on a membrane that we manage to introduce a “weak point”, which lets us then control the behavior of the membrane under compression as it will fold along that line. Then whether we perform a ridge or a valley crease will decide towards what direction the membrane will fold.

Origami requires that the membrane in play has to be at least a bit flexible or deformable, and so we could think about using silicone rubber for the inner wall. Stainless steel could also be acceptable if it is thin enough and each crease is somewhat flexible. The structure of an origami folding can be based on basic triangle shapes, as shown on the top of the drawing with this example of a cylinder that can be crushed up into a smaller block, or on basic square shapes, as shown by the bottom drawing representing what could be affiliated to a crumpled sheet. The latter is actually called a "Miura-ori" design [26], which by varying the angle of the ridges compared to the horizontal (from 0° to 60°) can change the projected area by 1/2.

Now the main problem with the Flexible wall concept is the amount of inflation needed. As dictated by the requirements, the external volume of the container cannot be too large, and origami sets requiring large increases in volume this might not be feasible for our concept. Moreover manufacturing-wise such creases and folds are not easy to produce and have exact reactions as needed. It is for such reasons that this design is not further exploited.

4. Springs in the lid

The idea here presented follows idea **3.1.** in the concept that if we place an elastic material between the lid thread and the inside of the pot, we can then alleviate the force generated by the over-pressure as we will have a piece that has the function to absorb all the force. Recall that multiple subdivisions had been done on the type of material to use to create such elastic reaction, and two of them are presented below such as to analyze their feasibility.

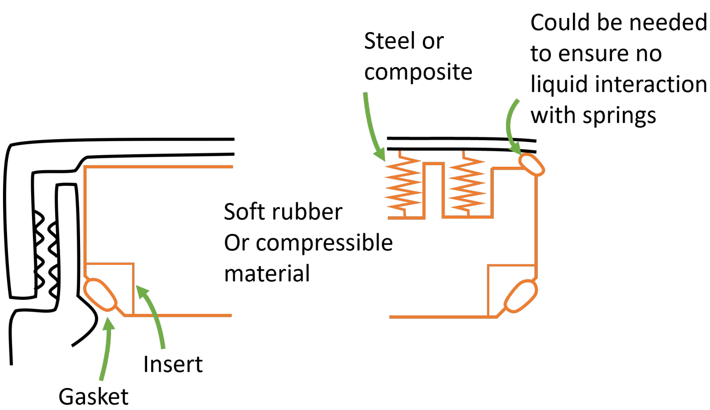


Figure 3.18: Scheme for design 4.

In this concept we have analyzed how to implement and assemble all the pieces necessary for the idea of a rubber elastic material that would absorb the force on the thread. The other objective was also to favor simplicity which is in line with our KPIs.

Therefore, at its simplest configuration we can imagine that the thread links both the container wall and the lid cover. We can think about placing a block of elastic material under the lid, such that when the air inside the pot increases in pressure, the force generated passes first through that material and then goes to the thread, thus acting as a filter.

The block in itself could be made either in one material, such as silicone rubber or any other soft cushion material, or as shown on the right a mix between rubber and springs where the latter works as an added layer between the soft material and the lid in order to increase the elasticity.

Now we could think about some details such as how the gasket should be assembled into the soft material thus needing an insert of a more rigid material to smooth out the differences in rigidity, or even how another gasket could be added between the material and the lid at the top such as to ensure that no food or liquids may spill in places which are hard to clean or may interact with elements such as steel, but the most important problem concerns the sealing provided by the gasket.

Indeed, this concept presents a worry in terms of liquid sealing. To ensure that no food spills out of the container, the gasket ring needs to be pressed against a protrusion of the inner wall. Here in this design, as the block of material is flexible and deformable, we need to compress both the material and the gasket. But we still want the material to be able to deform further when the pressure increases inside the pot, therefore the sealing loses its downwards pressure. As a result, the over-pressure is now presented with an airway that could be used to equalize with the outer air and thus is beneficial, but if sealing is not ensured we can have liquids and food that can fall out where it is not supposed to be, which is very disadvantageous to the basic function of the pot. On the contrary if we decide to select a material that is more rigid and will ensure that the gasket is compressed, then the design feature is lost, and we won't efficiently relieve the pressure on the thread. It is for these reasons that this concept will not be further designed as it is simply not feasible.

5. Pressure valve

Recall from idea **4.** that using a valve inside the container would be an efficient idea. Indeed the valve is a piece of deformable material which acts as a wall and thus can be placed in front of an airway and control whether air passes through or not. As this solution is quite simple in its functioning, here we pushed further into different arrangements and ways to implement such an idea which were anticipated in **4.2.** so as to analyze their feasibility and have a first view into its Design For Manufacturing consideration.

5.1. Lid separation

As presented in solutions **4.2.1** and **4.2.2** we can think of placing a spring over the valve, which can be mounted either horizontally or vertically. We therefore need to understand how to assemble and arrange the different components.

5.1.1. Version 1

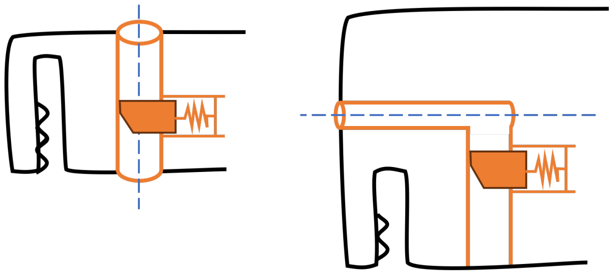


Figure 3.19: Scheme for design 5.1.1.

First, we can concentrate ourselves on the horizontally-mounted spring valve. As presented by the idea 4.2.1, the air channel that connects the inner air with the outside has to be vertical so that the "valve" function is played by a moving piece with an inclined face thus cutting the way when it is pressed to the left, and actioned by a horizontal spring.

From this structure, we already have a concern: installing a horizontal spring requires a hole to be made on the right side of the air channel, and thus we are asking for extra space. In regard to manufacturing, this is not easy to produce, especially since the lid structure is often made out of plastic by injection molding. Therefore, such a problem should be approached with Design For Manufacturing (DFM).

Moreover, one of the requirements for this project was to ensure easy cleaning of all surfaces that may come in contact with food. Coupled with the manufacturing problem, we then understand that this channel has to be accessible, and that can be made possible by separating the lid in two pieces, which can be joined afterwards and have the separation line passing through the length of the channel, as seen in the drawings. That way, simply dissociating both parts lets us gain access to the inside, and helps produce a hollow tube as well as cleaning it during its life cycle. Whether the air channel ends up vertically, or choosing to have its exit to the side so that the flow of air does not end up directly to the user's face, is what differentiates version 1 and 2.

By choosing such solution, we are still choosing to increase the number of different materials which is not in line with our KPIs, as well as needing extra steps by the user when wanting to reach the channel.

5.1.2. Version 2

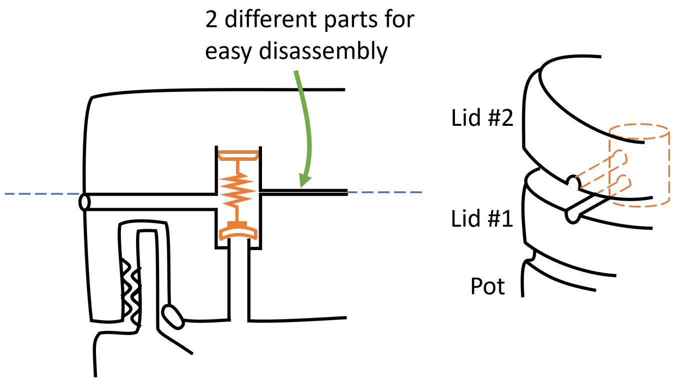


Figure 3.20: Scheme for design 5.1.2.

Let's now look into the feasibility of the vertically-mounted spring valve. As already anticipated the valve here is pushed down onto the opening. The air channel can then also be directed to the side of the lid, as explained above, so as the escaping air not to travel directly to the user.

This structure entails two manufacturing concerns: first in order to access the channel for cleaning, the lid has to be dissociated horizontally into 2 pieces as shown by this image, which will greatly help its injection molding production ease. Compared to the horizontal spring solution, the production of those halves is actually easier as they do not require the use of side pieces.

Second the actual valve and corresponding spring need some extra moving space inside the lid, thus again losing volume for heat insulation and increasing the difficulty of assembling various materials.

5.2. Adding locking mechanism

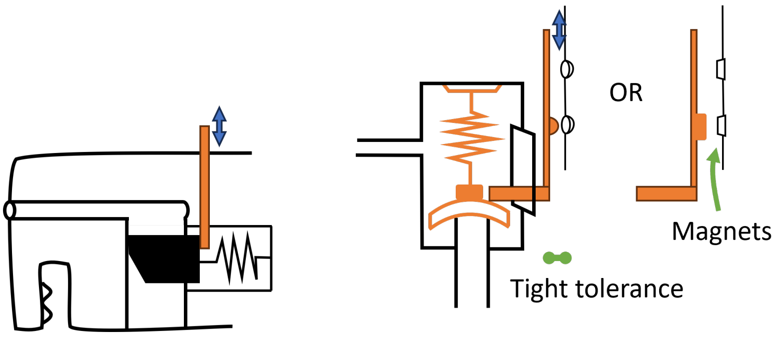


Figure 3.21: Scheme for design 5.2.

Now, the designs presented before rely on springs, which function automatically whenever they are pressed upon, so will open the air channel whenever a difference in pressure between inside and outside the pot provides a force large enough to counter the elastic resistant force. But that means that during the usage of the pot, when food is left to ferment the air channel will stay open periodically which also gives way to heat loss and so we lose the principal function of the insulated container. Therefore, an improvement to the previous designs could be to implement a locking function, as simple as possible in order to respond to our KPIs, and that can let the user decide whether we want the spring to work and the air channel to open.

As we can see from the drawing, implementing this idea on the horizontal spring means that we can think of a small beam whose end touches the back of the channel cover, and can slide vertically when the user pinches the end sticking out from the top of the lid. On the other hand, the application on the vertical spring would consist of a vertically sliding beam that ends in an L-shape so as to touch the top of the cover.

It is thought that to increase the user's grasp of the "locked" and "unlocked" positions, the sliding beam can rely on two resting positions, enforced by either dimples where the beam wouldn't be deformed, or magnets on which the beam would snatch onto. Nevertheless, we are increasing the complexity of the system and the total number of pieces used which is not in line with the KPIs.

5.3. Column design

5.3.1. Version 1

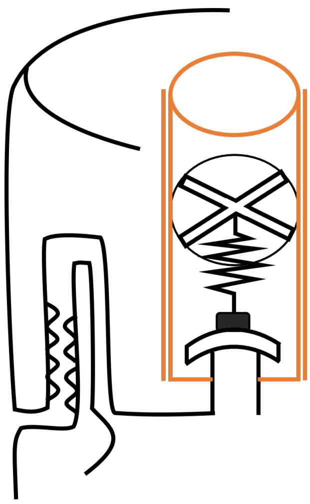


Figure 3.22: Scheme for design 5.3.1.

In order to answer some of the concerns raised previously, regarding manufacturing ease of even cleaning of the channel, another approach can be presented. Instead of dividing the entire lid into parts, the entire channel can be thought as a separate piece, such as a tube, that will be slid in when assembled. Therefore, the whole spring and valve system can be taken apart from the lid and handled easily by the user, who can then clean the spring or the channel as he has an easy access to the different pieces. Recall that this is actually gaining us points according to the requirements.

In order to mount the lid back together, the user simply has to push in the tube, whose closing function is ensured by friction on the entire external surface of the tube. We can observe that the spring is longitudinal to the tube, and so needs to be attached at the top to a bridge like structure, leaving space for air to pass through while still being structural, and easy to manufacture by injection molding process.

This idea is actually a first step into following DFM guidelines, such that instead of having to manufacture two halves of a lid, which needs alignment structure so that the air channel matches on both sides and some tolerances, we here simplified the problem while not demanding large and complicated manufacturing processes.

5.3.2. Version 2

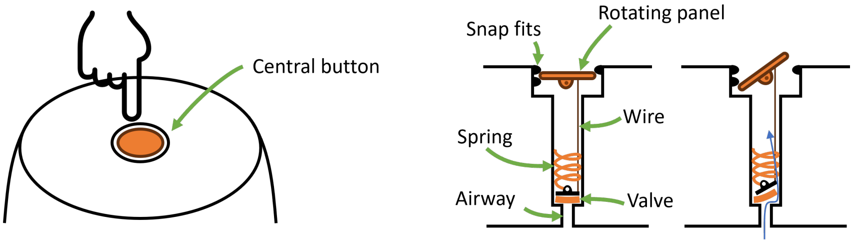


Figure 3.23: Scheme for design 5.3.2.

From what was presented above as well as the “column design”, the air channel seems better if placed fully vertically. But we also have as consequence that the top end of the airway lies on the very top if the lid, directly towards the user and without any cover. In the same time, the “column design” does not incorporate a locking mechanism which could let us have control over when pressure is equalized. A distinct “open” and “closed” position must be defined for the valve.

In order to answer to all of those concerns, we can introduce the solution as seen on the above drawing. Here the air channel is topped with a small lid that is mounted with a hinge to the side walls so that it can rotate around a central axis. Having a small circular lid over the channel helps the design in not having a hole in the middle of the pot lid, but also that circular shape can be utilized into an aesthetic design over the lid cover. The position closed and open are ensured by dimples on the side thus working with “snap fitting”: switching between the two resting positions require a certain force so that the piece can deform over a small obstacle. That motion is then transferred to the valve on the bottom of the channel via thin bars so that the valve is either locked down or left free to deform.

The problem arising from this concept is that we are adding multiple small pieces which are not in line with the Simplicity and Recyclability KPIs, thus we need an improvement from this design and simplify more the system.

Thanks to the drawings of the different designs, we were able to raise some concerns about their assembly feasibility or their manufacturing, as well as putting importance into some details that needed to be analyzed so as to bring the first functional idea into the real world.

By going through the list of ideas in section 2.6 we managed to filter out some details and features that were unpractical and keep ones that can be detailed further.

3.4. Design development

In this section we will continue the same structure as above, namely we will base ourselves on the various features and details that were brought up by the previous drawings, and generate new ones for improvements on the ideas. Indeed, some new concepts can be generated, as we work gradually by noticing problems and finding innovative ways to solve them. Notice that we will use the word "solution" here to refer to the new designs.

3.4.1. Towards inner outer lid dissociation

1.1. From pressure valve

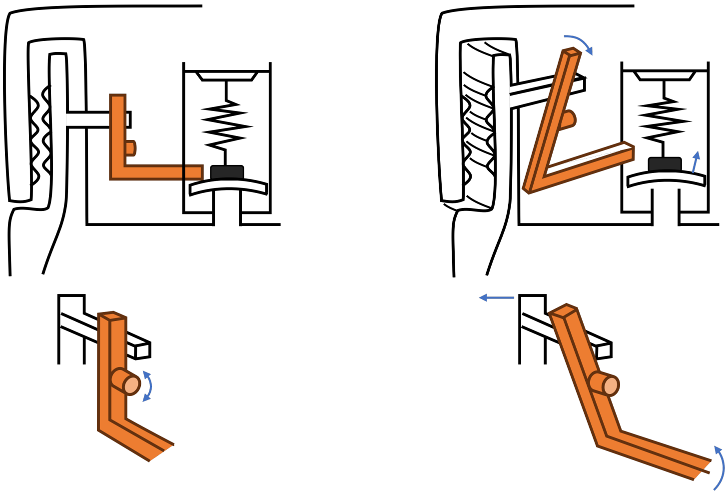


Figure 3.24: Scheme for solution 1.1.

As anticipated with the Ease of Use KPI (section 2.5.6), then an improvement to the solutions can be to add a mechanism which makes it so that the user does not know it is opening valves and releasing pressure, all the while unscrewing the lid. For our latest design, the "Valve with Spring", this means that we can play on the locking of the valve and turn it into unblocking the valve as soon as the lid is rotated.

The first approach to it that was thought of relied on an extra piece that has to move so as to transfer the unscrewing of the lid to unlocking the valve. For the vertically-mounted valve, that means that the beam's end placed on top of the valve has to move out of the way. More precisely, it just has to move up by a couple millimeters such that the valve can deform freely under pressure. Now to make it so that the rotation of the lid modifies a vertical structure (and so static relative to the horizontal rotation) we have to rely on a static support too. To incorporate the mechanism inside the lid, then a rotating L-shape beam was thought to be attached to the inside of the lid and have the static container push it sideways all the while the lid turns. Its center of rotation is not aligned with neither and so when the static "prong" pushes the top end, the lower end also moves; by deflecting in a circular motion, that end moves to the side and upwards, thus relieving the valve of its locking effect.

With such system, we thus have that the relative motion between the lid and the container walls serves as basis for actioning the hidden mechanism. No external action is needed thus the user actually does not know that it is unlocking the spring valve while turning the lid. This unscrewing motion, which starts with the exterior of the lid, is the one to utilize in order to activate our systems. We thus understand that something has to come from the external diameter and reach the central region, either linking both or actuating a system.

The main problem we encounter with this current design is that for the L-shape beam to move freely, a large volume needs to be void inside the lid which is more volume lost for heat retention performances. Moreover, some alignment problems can arise when the lid is taken of the container for the system to be put back into place. We will thus continue improving on this concept with further designs.

1.2. Inner-Outer lid explanation

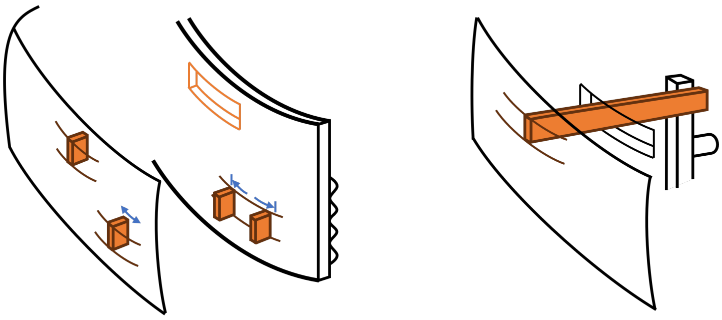


Figure 3.25: Scheme for solution 1.2.

As said above, we want the activation to come from the rotation of the lid, which is executed by the user when unscrewing it from its external diameter. Furthermore, we realize that a system incorporated in the lid must pass through two phases: a first rotation is needed to activate any system, for instance unlocking a valve, and thus letting pressure equalize inside and outside the pot, and then a second rotation is required to mechanically unscrew the lid over the thread.

Indeed, if over-pressure is present then a problem is that the user will not be able to unscrew the lid which is in turn needed to open the valve that will open the airway for pressure equalization, and in turn lets the user open the food container.

The only way to be able to separate such phases and at the same time disconnect the thread from that first rotation, is by dissociating the lid into two concentric lids, connected together so as to transfer torque and unscrewing motion while still having relative motion for the first phase. From now on we will refer to "outer lid" for the exterior lid part and to "inner lid" for the concentric inner lid part.

With this solution, the user is required to grab and turn the outer lid, just like usual and so without noticing the lid is dissociated, which will move freely for the first say 10°. Thanks to a "window" based design, any connection to the inside of the lid can be executed and this without interfering with the inner lid. At the end of those 10° of rotation, torque will be transferred to the inner lid thanks to some prongs or small features, perpendicular to the rotation motion so that the inner lid is also brought into unscrewing the lid. At best we need one block glued to the outer lid, and two obstacles on the inner lid, separated by 10°, such that when unscrewing the lid, the beam pushes on one obstacle, while when screwing the lid, the beam interacts with the other one, which also ensures that locking systems are activated.

Notice that if we want to come back to our previous solution **1.1.** then in order to move the L-shape beam, we need a beam that is attached to the outer lid as this is the one that rotates freely and passes through a hole in the inner lid.

1.3. Improved design

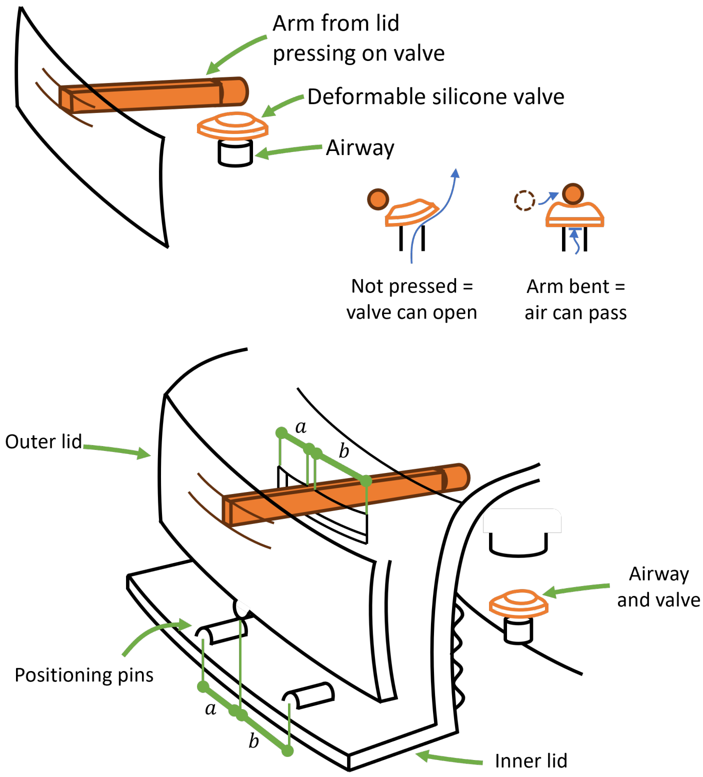


Figure 3.26: Scheme for solution 1.3.

Recalling design **5.1.** we opted for an airway channel inside the lid that is closed by a deformable valve mounted with a spring. The spring is wanted so as to provide a counter force to the over-pressure and the valve will not let air flow out unless the pressure reaches a certain value. On top of that we have decided to add a locking mechanism, as seen with design **5.2.**, in order for the valve to uncover the channel only when needed, i.e., before opening the food pot. But then from this description, why is the spring necessary? When the valve is unlocked, either the pressure inside the container is higher and thus needs to be relieved, or the pressure is at atmospheric value and so the lid can be taken out without any issue. Therefore, in a concern for redundancy and simplicity, it is required to remove the spring and have the locking feature play the role of pushing down on the valve.

Using the idea of the beam attached to the outer lid, as presented in solution **1.2.**, we can have that its end will be the one blocking the opening of the valve. Indeed, when unlocked the beam will not press down on the valve and the latter can deform under pressure forces. But then when turning the outer lid by those chosen 10°, the beam will move over the valve. Along with a proper dimensioning or tolerances, we can decide of the force that the beam will provide by how much it is deflected to move over the valve. This value is easy to find considering the cantilever beam problem.

Moreover, and as shown on the drawing, the window slit by which the beam passes through the inner lid to the valve needs to present an opening to the top. This is a manufacturing concern as without that detail, it seems impossible to assemble the entire inner and outer lid.

One of the main problems with such a design resides in the space it requires. Not only does the beam require a slit to be made into the inner lid, but also the entire volume leading up to the air channel must be void as well as having space on the sides to accommodate for a 10° lid rotation without interference. This is then a lot of volume lost to heat insulation which is crucial for temperature losses trough the lid. Moreover, the design of both inner and outer lid, especially with a beam sticking out perpendicularly to the walls for the latter, is very complex to be produced with conventional or simple machinery, due to having such small dimensions. For both reasons this design needs to be revisited and improved, always considering simplicity and assembly.

3.4.2. Positioning pins

2.1. Positioning pins explanation

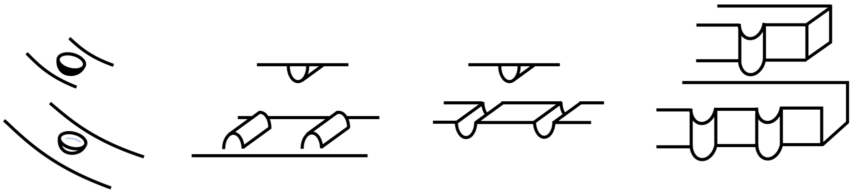


Figure 3.27: Scheme for solution 2.1.

The dissociation of the lid into two parts that have relative motion can bring up some other details to analyze. Indeed, the inner lid shares a thread with the container walls and with such remains in position when the lid is screwed. But in the meantime, the outer lid can rotate with ease for 10° as it does not encounter any obstacle. As a result, systems inside the lid can be activated or not by mistake and sometimes even without the user knowing about (say the food pot is shuffled inside a bag). Therefore, we need to ensure that the outer lid is blocked in place until the user requires it. On top of that, it could be useful for the user's grasp of the concept that we can firmly distinguish between locked and unlocked positions that happen while rotating the outer lid compared to the inner one.

A solution to both of those problems was actually already introduced with design **5.3.2** and relies on snap fitting features. As the function of snap fits is based on the deformation of pieces to arrive to a stress-free resting position, we can utilize it so that the outer lid remains in two different positions symbolizing locked and unlocked until acted on by the user that will input some force in order to come out of those positions.

As shown by the drawing, we need to have small humps where inner and outer lid touch that we will call "positioning pins" for easier future references. They can come in various shapes where the most important design parameters are actually about bump height and angle of attack. Positioning pins can be semi circles searching for their negative counterpart to rest, or semi-cylinders reaching for their negative counterpart or having to deform and bump over other cylinders. That last geometry will be the most used during this research as it increases internal stresses due to deformation only when the positioning pin has to pass over another, and not continuously until it reaches the resting position.

This detail which is simple to manufacture aids greatly the relative positioning of outer and inner lid and thus will be utilized in all following design drawings.

3.4.3. Relieving the gasket

3.1. Version 1

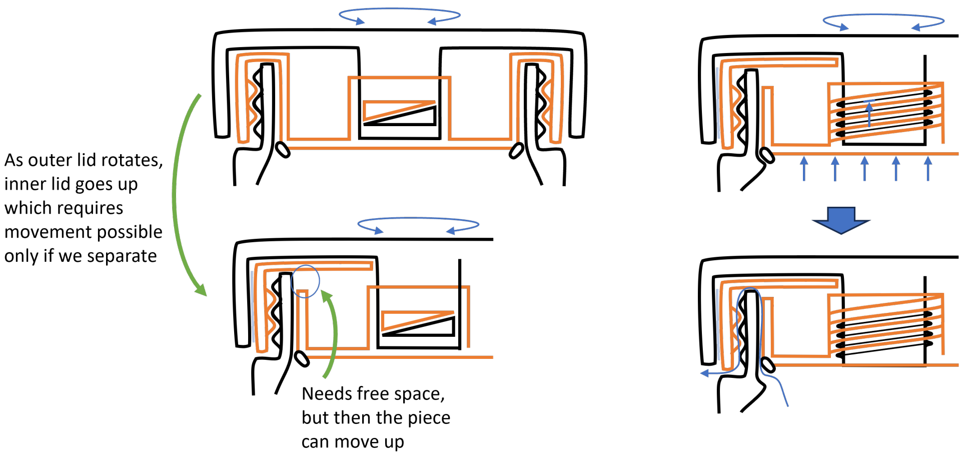


Figure 3.28: Scheme for solution 3.1.

In order to reduce the number of small elements used, and to utilize the actual ventilation system of the food pot without using an extra air channel that has to be drilled, this solution suggests that when rotating the lid in the first phase, the user will unknowingly move up a piece just enough such that the silicone gasket does not ensure sealing anymore. Indeed, the gasket does not let any liquid or gas escape as it is pressed up on a protrusion of the inner wall. But if we displace the section on which it is assembled, then we can generate an airway such that any air inside the pot can mix with the outside, just as if we take off the cover of a container, but here without taking off the whole lid.

Note that in order to translate the rotating motion that the user executes into a vertical motion, we can rely on inclined faces around a circular path. In other words, we have to use a thread, for which the pitch and the slope (also called helix angle) define by how much we move up. Note also that we want the gasket to move up independently to the threading between lid and pot walls, because this system should be activated so as to relieve the latter and therefore cannot rely on moving it. To achieve that, we thus need to separate the lid into 3 pieces all hidden to the eye of the user, based around an extra thread linking two of them; An external shell, that we can call outer lid, will be grabbed by the user and thus giving the input torque. Thanks to a thread found at the center of the lid, the base piece for the gasket will be displaced vertically, that we call inner lid. Finally, thanks to torque transfer features as presented in 6.b, the user will be able to unscrew the lid on the main thread without any issue as the over-pressure will already have been dealt with. The piece that has the principal threaded part is called “middle lid”.

As a result, as shown by the drawing, when over-pressure is generated inside the pot it will create a force pushing up the inner lid. Due to the inner thread, that pressure is transferred by contact to the outer lid and so does not disturb the main thread. But then by rotating the outer lid, we relieve the gasket as the inner lid moves up, air flows out through the main thread, and no forces are applied anymore. With this solution, we thus have diverted the usual stress path and remove the pressure that existed on the main thread.

We may observe that what actually sustains the over-pressure is the inner thread. We then find ourselves with the same situation that is needed to be solved, but in this case we have to recall the equation relating torque and thread pressure (c.f. 3.2.3): the torque to input against friction is directly proportional to the diameter of said thread, therefore if we design the inner thread to be 15mm diameter (against 70mm for the main thread), then the torque reduces down to 1.2Nm which we know is a low value achievable by many people without much problem (c.f. 3.2.1). This way, even if the over-pressure presents a large value, turning the outer lid and releasing the pressure on the gasket so as to open up the airway can be carried out effortlessly by the user.

Some assembly concerns can be raised regarding the different pieces, for instance how outer and middle lid are going to be placed in the lid, but also on the fact that as the inner lid moves up it needs free space available. In order to protect the inside of the lid and the Styrofoam from gases and possible liquids, we can then think about attaching some compressive material to the top of the inner lid and have it compressed while it goes up, but then we are again increasing the number of materials used. More importantly, this solution design seems extremely “good” but is also the one that may have various problems due to manufacturing tolerances, especially on the inner thread as well as the torque-coupling system that has to be assembled.

3.2. Version 2

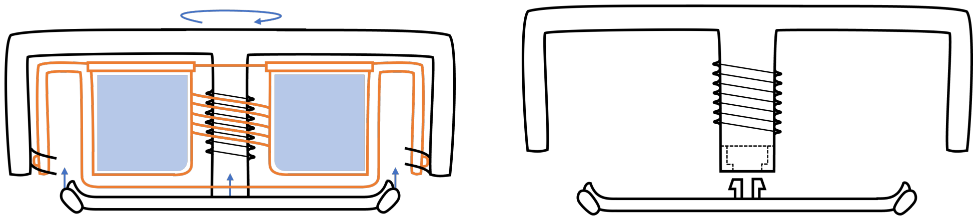


Figure 3.29: Scheme for solution 3.2.

In order to answer the problems listed above this version was envisioned. First of all, the heat retention foam that is found inside the lid will be sealed from the exterior as the middle lid is here enclosed. For assembly purposes, the top lid is a different piece that is placed afterwards, and its locking is ensured by snap fitting elements that are activated as the piece is pressed down. The middle lid keeps the same function by being the one screwed onto the pot.

Secondly, the bottom lid is modified. Not only its shape is changed to serve only as a support for the silicone gasket, but also it is bound to the outer lid so that both move together. For assembly purposes, they are both linked with snap fits so as not to add screws or bolts or other additional elements.

This results in that when the user grabs and rotates the outer lid against the central thread, the bottom lid is also moved up with the same helical motion, thus relieving the gasket. It is important to notice that because of the thread shape, while the lid turns it also moves up, and the torque coupling system between the outer and middle lid has to follow such motion. A proper channel for the obstacles has to be generated that follows the same helix angle.

Still tolerances problems are there and so for its complexity that cannot be ensured by manufacturing, this design is not further analysed even though it could be the object of a secondary research.

3.4.4. Aligning channels

4.1. Version 1

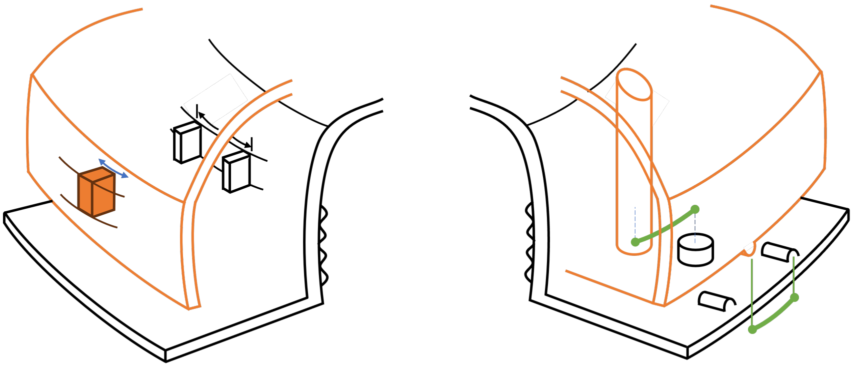


Figure 3.30: Scheme for solution 4.1.

Aside from what was presented up to now, this solution aims to analyze the basic features pertaining to the designs above and take the simplicity of the idea to the fullest. Namely, and following point 17 from section 2.4.3, one can equalize pressures by opening an air channel through the lid. By basing ourselves on the division between inner and outer lid as introduced with solution 1.2. (seen in Figure 3.25), then we can have that the rotation of the lid is what is necessary to open such airway.

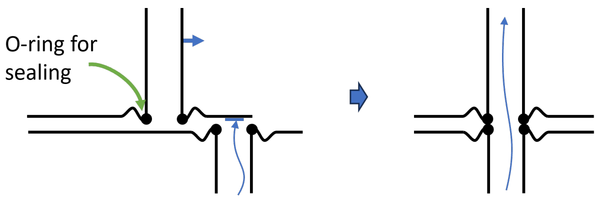


Figure 3.31: Further detailing

To have a distinction between closed and open, we can think for instance of splitting the air channel in two and having both halves align when we reach the end of the chosen 10° turn while the rest of the time those ends are sealed, and air cannot escape. As the inner lid is the one that is relatively static during that first step, then the user has to turn the outer lid so as to bring the columns together. We can think about using sealing rings or rubber materials to ensure that no air escapes while the outer lid is not rotated, by pressing on the opposite wall. Notice the use of Gas Permeable Membranes that could be useful to filter out liquids from the channel. The second step where both lids turn together to unscrew it from the pot is ensured by the torque coupling system, already presented above. We can detect the use of positioning pins which indicates to the user that the channel is opened and holds it snapped in position.

The only problem with such idea relates to the outer lid and its size which raises manufacturing concerns around the column sticking down. Indeed, proper analysis has to be taken for the shape of the outer lid and its assembly with the inner lid without losing too much volume to heat retaining material.

4.2. Version 2

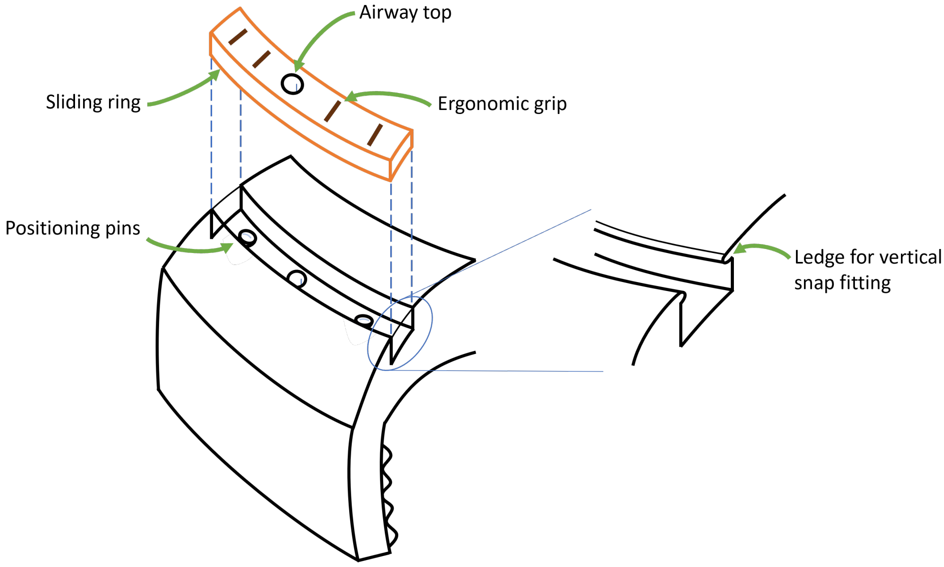


Figure 3.32: Scheme for solution 4.2.

In order to answer such problem about the outer lid, we can think about reducing it in thickness and thus have the function of the outer lid reduced to a single cover to the air channel. Therefore, to have the rotation of the lid to open the airway, and for structural and aesthetical purposes, we can have the outer lid to be a thin circular band turning into its own crevice. We will refer to this component as the "sliding ring".

The assembly then consists of the inner lid having the air channel through its entirety, just a simple tube, which is closed at the top by the sliding ring. The cover will present an opening that has the same function as the top column part from the previous design, so that the airway stays closed as it is shielded by the rest of the ring, whereas it opens up when the orifice is aligned with the rest of the channel. Note that to change between positions the user has to slide the ring along its slit while ensuring sealing of the airway. To achieve that, and in an effort to ease the assembly in line with DFM concerns, we can rely on snap fitting mechanisms and proper choice of tolerances so as not to use extra components. That way, vertical dimensions are to be exact so as to properly shut the airway, and we will rely on protrusions from the inner lid to snap down the top of the sliding ring. On the contrary, radial dimensions will require some clearance such that the ring can turn without any friction limiting its movement.

We can notice that the ease to the user has been improved by selecting a different surface finish for the sliding ring, as well as adding some bumps on the grip surface so as to increase the connection with the user's hand while rotating it. Moreover, the distinction and lock-in of closed and open positions are again enforced with positioning pins, here illustrated with dimples which are then to be placed between the bottom of the sliding ring and the inner lid.

The design of the top of the lid has been somewhat analyzed here, but there are other features to consider with such solution, presented below.

4.3. Version 3

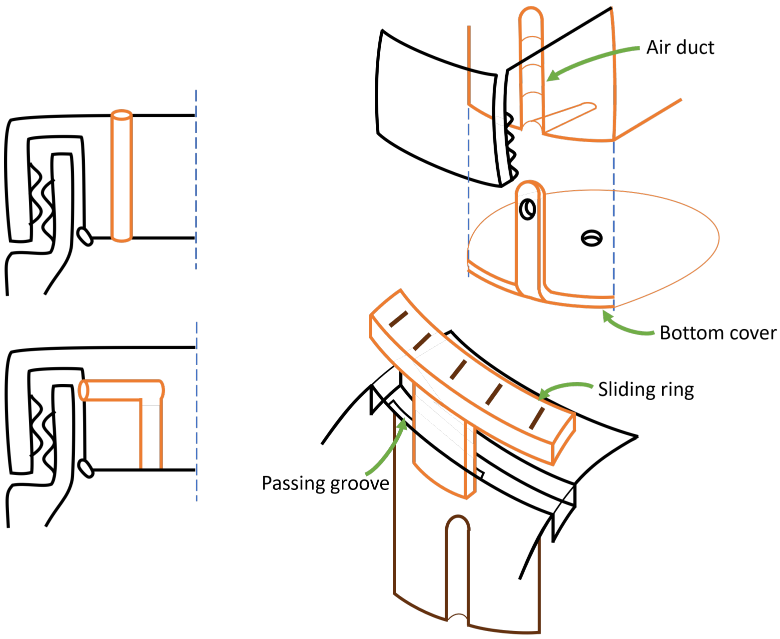


Figure 3.33: Scheme for solution 4.3.

Let us now consider the placement of the air channel. The latter has to pass through the lid and, as presented above, was envisioned as a vertical column whose end arrives either on the top of the lid or towards the side, to avoid having gases discharge in direction of the user.

Now recalling the shape that has the inner lid, and in accordance to being easier to manufacture, we can modify the air channel design to become a crevice placed along the bottom surface of the lid, inside the pot, and follow the bottom surface's angles and corners as shown on the drawing. The crevice becomes a duct since it has to be closed by another piece serving as cover, or second half of the cylindrical channel. This choice is a step towards DFM because instead of having to mill an airway through an entire lid block, we simply have to remove some superficial material to generate half a tube and use a separate simple component to close the other half. Those two reasons are very beneficial especially for plastic materials since the lid is anticipated to be produced by injection molding, which does not work well with manufacturing undercuts.

What is to consider is that the extra piece, or bottom cover as we'll call it, is to be fixed to the bottom of the inner lid with an orifice to the top so that the air escapes above the gasket. But then to actually control the opening of it, we need to use the sliding ring which already plays that role. Therefore, it is thought to modify its shape to incorporate a downwards panel that would be placed in front of said keyhole. That way, turning the ring will make the hole uncover when needed as the panel will be displaced out of the way.

The one problem with such design is that for the panel to work from the top of the lid all the way to the cover, it is needed to pierce the lid to produce a groove through which the panel will pass. Depending on the tolerance chosen, this could result either in sealing problems or assembly problems. In fact, tight dimensions would add friction and thus the ring would not be able to move sideways or even break, while loose tolerances would let gas or liquids pass through that could endanger other components in the lid. Moreover, its alignment with the orifice is not always ensured. We could think about using rubber materials but due to the small size required we would only increase the manufacturing and assembly complexity as well as adding yet again another material. For those reasons, this solution needs to be modified.

4.4. Version 4

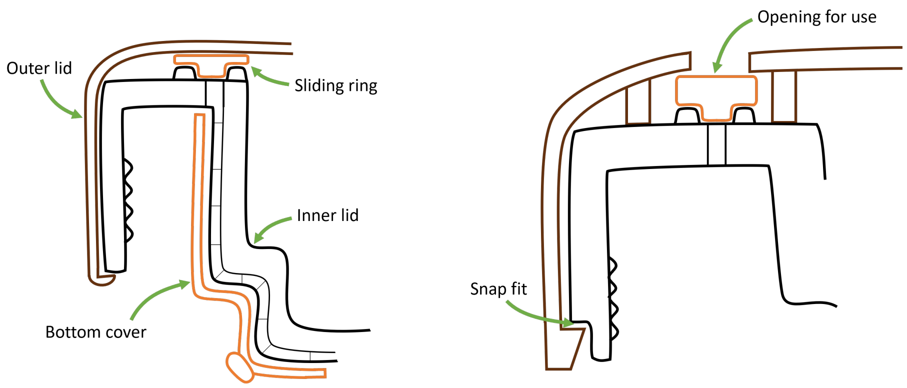


Figure 3.34: Scheme for solution 4.4.

So as to solve the problems listed above, we have to remove the usage of a panel on the sliding ring that goes through the inner lid. Therefore, it is thought to close up the air channel that follows the bottom surface all the way up, and drill a short hole in its continuation through the inner lid. That way, the bottom cover does not require an additional opening and has to provide closure of the air channel along the whole surface. For what accounts the top surface, the tube will be topped by the sliding ring, just as anticipated by solution **4.1.**, which will be able to rotate and close or open the airway. For assembly ease, the ring will lay flat on top of the inner lid, and the groove is actually added on top thanks to thin walls along the circumference, as shown above.

Let us consider how the sliding ring will be kept in position. Recalling from Version**1**, the ring was pressed down from the top, thus the idea analyzed here will consist of using an exterior cover to the lid, or outer lid, that will be snapped above everything and will then weight down on it so as to lock vertically the ring. The outer lid is assembled due to snap-fit features onto the inner lid (which is fixed) and therefore will not move either. As a result, even though the sliding ring is not fixed or screwed to anything, its degrees of freedom are reduced with the thin walls and the outer lid, leaving only the rotational movement.

It is interesting to notice that for the user's grasp of the lid function, when seen from above the outer lid will not be made out of a full cover, but will present a couple hollowed out sections that will let the user touch and action the sliding ring. Consequently, the outer lid ends up having a complex shape, with those openings being complicated to actually reach the sliding ring depending on thickness but also aesthetic choices, and thus all in all raising Design For Assembly (DFA) concerns. This feature thus has to be re-evaluated.

3.5. Final design

3.5.1. Description

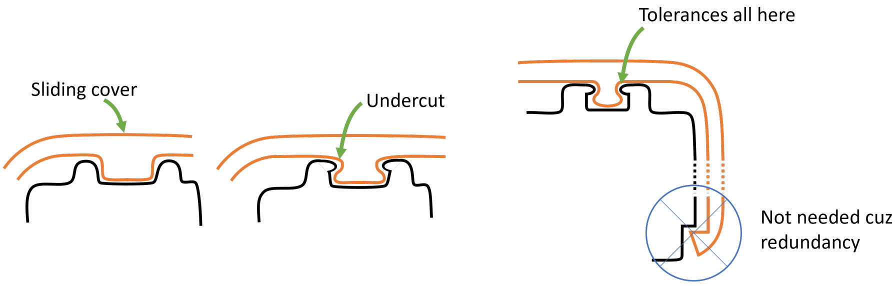


Figure 3.35: Additional modifications

Owing to the previous increments and design choices considering this idea, various details have been analyzed and solutions were found for which we will keep the beneficial features.

At most important, it is decided that the model relies on an air channel, which is made out of two halves: the first pertains to the inner lid and is carved onto its bottom surface and follows its shape upwards until it reaches a tube that has to be drilled into the thickness of the inner lid. The other half is made out of a cover englobing the surface, also called bottom cover, which then closes and seals the channel, as well as being a platform for the silicone gasket.

Moreover, the airway is closed off until a sliding ring is rotated such as to align it with an opening, under the action of the user. Improving from the above Version**4**, we decide here to fuse together both the sliding ring and outer lid, for aesthetic and simplicity purposes, such that the entire exterior surface of the lid is the one that the user has to grab and turn, which is more logical to the user's point of view and conceals the system inside. We can call it the "sliding cover". In order to block its vertical degree of freedom, as we don't want the cover to disassemble spontaneously or not ensure sealing of the air channel, we can use snap fit features inside the groove which will hold that section in place. That region of the sliding cover thus needs the production of undercuts which will be analyzed later as well as proper tolerances. The bottom of the sliding cover does not need the use of snap fits as presented in Version**4** as this would be redundant, thus leaving the path open for assembly problems if the tolerances are not respected. Indeed, due to the large size of the cover, those tolerances are not easily respected with injection molding.

For what accounts the two positions for the sliding cover, which have to be properly defined for the user, we will rely on positioning pins as presented before which will be placed along the groove. Together with the torque coupling system, the sliding cover will be able to stay closed if needed, or switch to the “open” position which will open the airway and then unscrew the entire lid as long as the user keeps rotating the component.

3.5.2. Assembly views

Let us now consider the 3D model that has been created for the solution on SolidWorks, which helps us get a better sense on how the components are assembled together and how they interact. In order to decide on dimensions, the food container walls have been fixed and thus the main thread diameter is locked, from which the rest of the lid has been designed keeping in consideration manufacturing guidelines as well as simplicity.

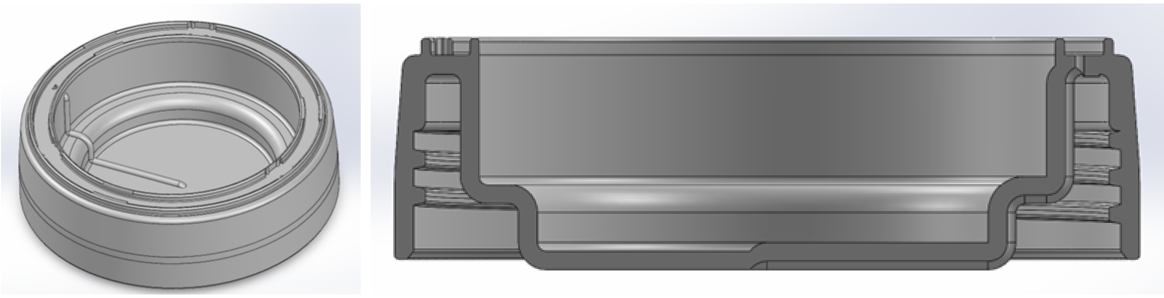


Figure 3.36: View of the inner lid structure

With this view, we can observe and appreciate the shape of the inner lid which echoes the drawing presented in Figure 1.5 such that this component is considered structural. The dimensions follow what was given by the manufacturer in order to fit properly onto the food containers of the brand without issue, thus meaning that the thread diameter, size, and shape were kept and locked. The complete shape was designed to be as simple as possible, thus relying on constant thickness which is also favorable for injection molding production, and a flat top which will receive the groove needed for the sliding cover. Moreover, maximum volume has been given to the Styrofoam for heat retention inside the food pot, which does not need to interact with the outer environment.

With this cut view we can also appreciate how the air channel is made as a groove following the surface, which starts at the bottom center for manufacturing ease and ends with a column drilled vertically through the thickness of the structure. It is interesting to note that in the region where the channel is present and represents an empty space, material is added on the inside of the lid so as to keep a constant thickness as much as possible. This is done in order to reduce the possibility of defects that arise commonly in injection molding processes, when two sections cool down at different rates due to their different sizes.

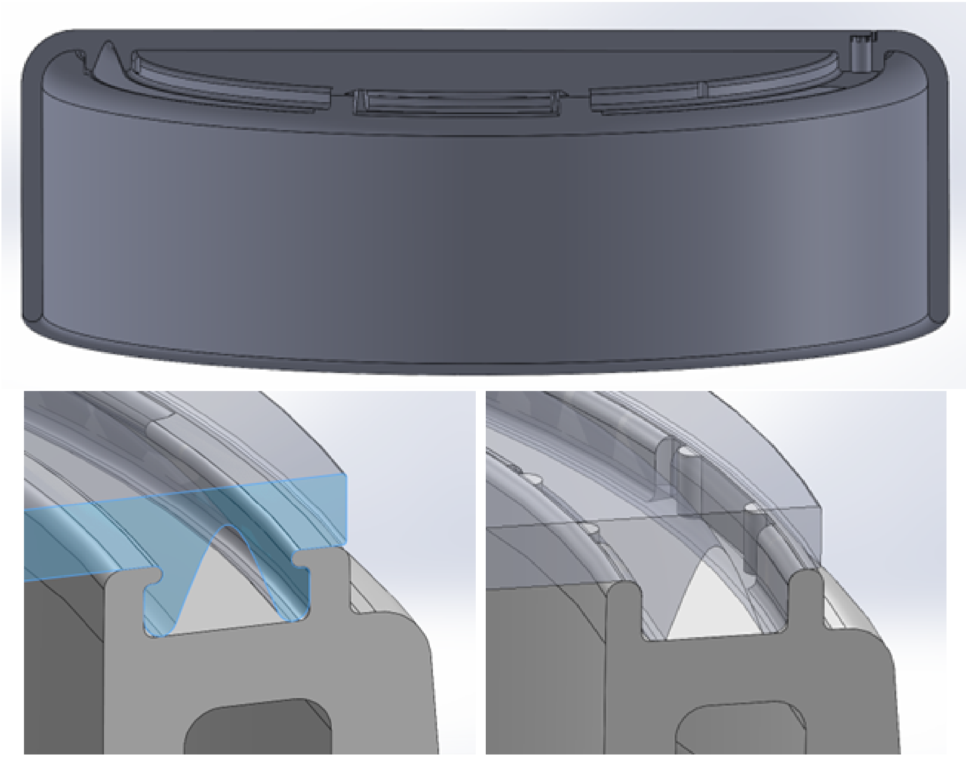


Figure 3.37: View of the sliding cover

For what accounts the sliding cover, this piece constitutes the outer shell of the lid and is connected to the inner lid via the groove. As seen from the side, the overall shape resembles a constant thickness cover englobing the top and sides of the lid, apart from the protrusion that goes into the groove.

This part is inspired by the shape analyzed in Version**2**, namely when sliced up the base is a rectangle that needs to be snap fitted by the top. Further development has been carried out for what concerns production and assembly needs. For instance, all sharp edges have been smoothed out so as to respect injection molding guidelines and remove defects due to corners. Moreover, the walls of the grooves are designed to be thin, their width selected so as not to induce cosmetic and structural defects when producing with injection molding. It is also important to notice that to facilitate the fitting of both pieces in contact as well as the molds, the walls need to be tapered towards the top which is common protocol.

Finally, it is easy to observe how the snap fit features are introduced into the design: horizontal protrusions attached to the sides of the gutter impose the slight deformation of the pieces while we assemble them together, until they reach the location of horizontal slits on the sliding cover marking a resting position. Thanks to the rigidity of the material, once inputting the force needed to clip the components together, it is not easy for the snap fit features to come undone in normal usage of the lid. In the same way we can also observe how the positioning pins are assembled; a small window defining the chosen 10° is cut into the walls of the sliding channel and presented 2 obstacles. The protrusion from the sliding cover thus has to bump over the obstacles in order to fall into "closed" or "open" positions on the far right or far left. Deformation is induced by the fact that both surfaces in contact are rounded and circular, but then as the pin reaches the side walls, the torque is directly transferred to the inner lid.

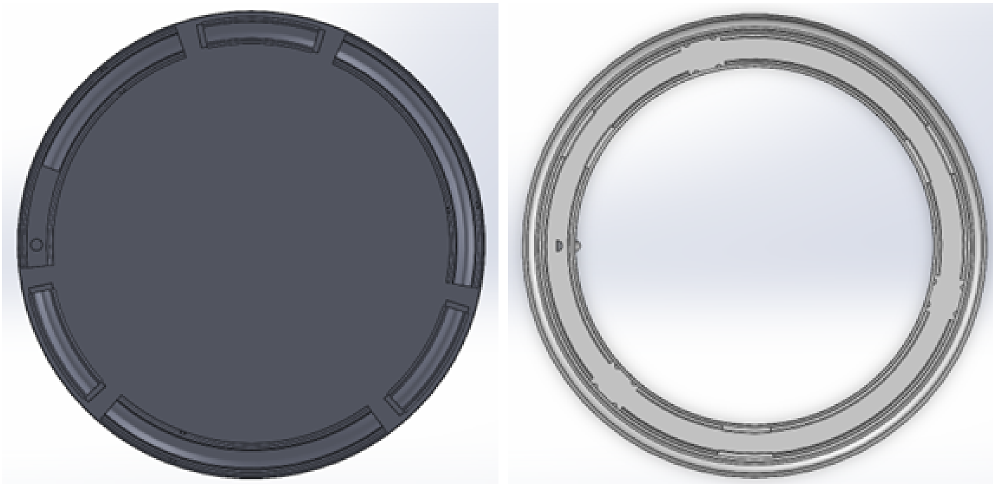


Figure 3.38: View of the linkage

It is important to notice that some details have been thought in order to increase assembly ease and proper repartition of forces. As a matter of fact, when the lid is seen from above, it has been decided that the groove does not present snap fitting features along the entire circumference, but only on 3 sections. Indeed, snap fit mechanisms rely on the small deformation of the components, thus better if the surface in contact is limited. The repetition of the features has been chosen so as to equilibrate internal stresses induced by assembling the sliding cover as well as to balance out the deformations to always ensure sealing along the entire circumference of the groove. Notice that on the sliding cover, those sections are fully cut out from the rest of the perimeter for the sake of proper deformation of the snap fit features, without interaction with the rest of the lid that could limit the displacements or increase the stresses in that region.

Similarly, the positioning pins have been placed on 3 other sections so as not to interfere with the snap fit features and space out the small-sized elements. In the same way, as the pins and the walls are supposed to deform slightly when interacting, the repartition was chosen so as to equilibrate deformation and internal stresses.

For what accounts the top of the air channel, it is important to keep free space on one side to accommodate for the sliding cover's flat section needed for sealing. Indeed, closure of the airway has to be ensured over the entire chosen 10° of relative emotion between the inner lid and the sliding cover, until both tubes are aligned. That region of the sliding cover does not have to interact nor deform with any other feature so as to work accurately, whether we are opening or closing the system. Moreover, the right orientation of the components in play must be chosen, such that the flat section covers the air channel while the user closes the lid, thus following the thread screwing motion (clockwise as seen from above), or moving out of the way until the airway is opened as a result of unscrewing the lid (anti-clockwise as seen from above).

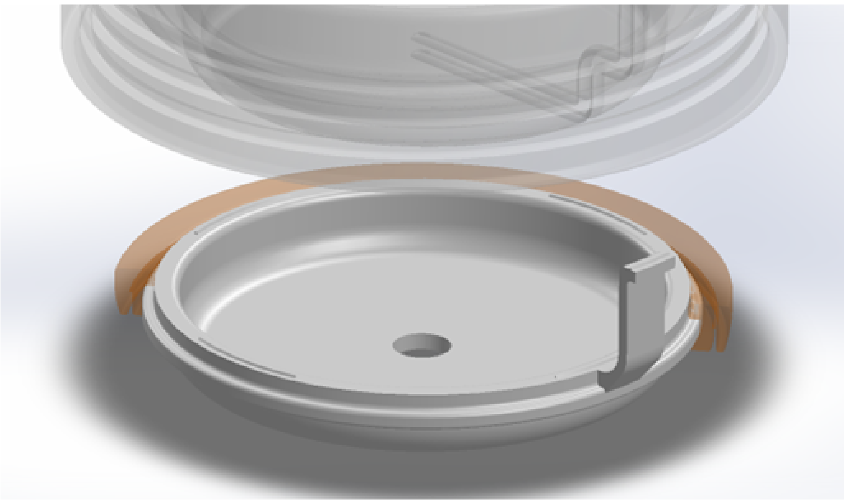


Figure 3.39: View of the bottom cover

Let us now consider the bottom cover, which is the piece that goes over the bottom surface of the inner lid such as to close the air channel. At the same time its function is to be the base for the silicone gasket, the latter being assembled onto the bottom cover and pressed down onto the container's inner wall to ensure sealing. It is important for the bottom cover to present the same shape as the inner lid as we want the air channel to be fully closed, not interacting with the rest of the container, especially so that no liquid or matter gets inside and blocks its basic function but also so that air pressure exchanges are executed solely through the air channel.

Now as the silicone gasket is needed all around the circumference, it has been decided that the bottom cover will be fully circular up until that section. But above, the objective of closing off the airway is needed only over that small section of the circumference due to its small size. As a result, and for assembly ease so as not to increase the probability of components blockage, the bottom cover presents a thin band that stretches up along the inner lid and follows the path of the air channel until it reaches the top opening.

Regarding the material selection, the choice was made to produce the inner lid and sliding cover out of ABS plastic as it is very common and adapted to use it injection molding processes while still presenting tight tolerances and attention to small, detailed elements. Concerning the assembly of the bottom cover, and to ensure the best merging of the pieces, it has been decided to produce it out of ABS plastic too such that we can weld the two pieces together when mounting. More precisely, ABS is often fused using ultrasonic welds, thus requiring that at least one of the components presents indents that serve to concentrate heat. Having the same material increases the quality of the weld, which in turn ensure that the alignment of the features will be perfect. With such link, both components are tightly fused together and sealing of the air channel is ensured, and thus the objective of the bottom cover is fulfilled.

3.5.3. Notes on snap-fit

Let us now analyze the region of interaction between the sliding cover and the inner lid, namely the groove and its snap fit features. Their function is based on the elasticity of the material such that it returns to its original shape after being deformed. As explained before, the feature here was designed such that horizontal protrusions from the walls have to align with a slit on the sliding cover for the two pieces to be assembled. Therefore, while reaching for that position, the components will have to deform and deflect until they adjust. In an effort to facilitate the deformation of the sliding cover, it has been thought to generate a cavity into the block that goes into the groove, as seen on the pictures above, such that the element feels "weaker" vis-a-vis to the force input and thus bends more easily. By doing so, the so-called block is replaced by two prongs or "teeth" which can be considered as separate, while still keeping great structural strength thanks to the curved cavity shape.

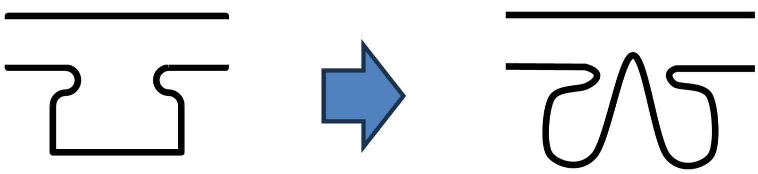


Figure 3.40: Snap-fit feature generation

Now for what regards the load cases, the snap fit feature can be analyzed over two situations: first, the sliding cover is pressed down in assembly and the bottom of the teeth are pressed against the wall obstacles thus generating what can be considered a horizontal reaction force. Second, while the piece is being manufactured by injection molding, it has to be ejected from the mold and due to the slits (also referred to as undercuts in injection molding vocabulary) the former generates a force pressing on the teeth too. Note that the other option to produce undercuts is to introduce moving parts inside the molds which is very expensive to make and adds a step into the manufacturing procedure.

Both scenarios are actually similar as they involve a horizontal perturbation that induces bending of the teeth, as shown by the diagram. The question now is thus to analyze the forces required to assemble the pieces together, therefore calculating what it takes to bend the tooth enough so that the wall ridge can reach its desired position, and deduce the internal stresses generated by such load.

Each tooth can be schematized as follows (with dimensions in millimeters):

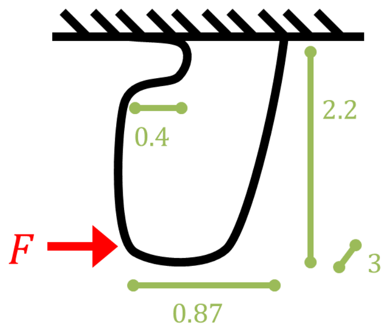


Figure 3.41: Scheme of a single tooth

Further simulation will be detailed in the following chapter.

3.5.4. Notes on PTFE Membranes

This component has already been introduced a couple times, but here we will go into detail over its function and selection.

Gas Permeable Membranes, commonly called Porous Membranes, are thin layers of materials that are often used when liquids must be separated from a section while still keeping breathing capacities meaning air and gases can still travel through the film. Indeed, due to is microscopic structure, the sheet is hydrophobic and blocks out liquid droplets but is permeable enough to be considered breathable. Those membranes are often produced with Silicone, Teflon, Tyvek or even very fine meshes of PET, with the most common being the PTFE Membrane.

This type of component can be extremely useful in our design wherever we want to isolate air channels inside our lid from water, liquids or soups that could be found in the meals inside the food container, thus helping the cleaning ease of the airway. As already anticipated in idea3 Version1, the air channel starts at the bottom of the lid, which is an area possibly in contact with liquids especially if the whole food pot is turned upside down. Therefore, to avoid having water getting inside the duct, the membrane barrier needs to be placed at its entry covering the entire diameter of the aperture. We can notice that according to the dimensions required and the forces involved, as well as the very thin thickness of the film, the assembly of the membrane does not require to be pressed or even manufactured as an insert in the injection molding process ("co-moulded"), but can be cut into circular shape and simply glued onto the bottom cover as follows:

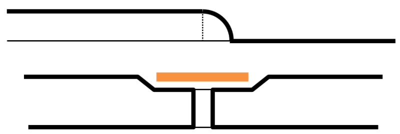


Figure 3.42: View of the bottom cover

Let us now consider the selection process for Gas Permeable Membranes. A couple parameters have to be taken into account in order to choose the right component for the situation.

- The most important one is called the Airflow Parameter, or AP, which is an indicator of how much air flows through the film counted over time and surface, thus expressed in $[l/hr/cm^2]$. It is important to notice that that value is often indicated at a certain pressure level, and both variables are proportional thus the number can easily be found from tabulated values to the one we need at its working level of 0.98 bar.
- The other important variable is the Water Entry Pressure, or WEP, which determines the value of the pressure difference at each side of the membrane at which it loses its water blockage property and allows liquids to pass since the force is too large. Therefore, this value must be chosen to be over 0.98 bar as it has been identified as the over-pressure value thus needs to work as anticipated in all conditions.
- The thickness of the membrane is often a parameter, but it is actually given as a

function of the others as it is defined by the manufacturing company. This value can be found in sheet data and is thus a consequence of the one chosen.

- Another variable is the presence and type of surface finish over the membrane. Specific membranes can have products added to increase its blockage to oil or other types of substances.

Concerning the Airflow Parameter, in order to compute the desired value, we must translate the pressure into volume: Basing ourselves on the ideal gas law $pV = nRT$, we can first relate the pressure to the amount of matter it represents. Recall that the ideal gas constant is expressed as: $R = 8.314 \ \frac{J}{mol \cdot K} = 0.08314 \ \frac{bar \cdot L}{mol \cdot K}$.

Then, we can deduce that the over-pressure of $\Delta p = 0.983 \ bar$ over the atmospheric pressure corresponds to an increase of $\Delta n = 0.0198 \ mol$ inside the food jar.

Now in order to translate such quantity into a volume that needs to be released, we need a constant pressure according to the ideal gas law. But as air escapes through the air channel, pressure decreases from $p_{high} = p_{atm} + \Delta p = 1.996 \ bar$ all the way to $p_{fin} = p_{atm} = 1.013 \ bar$. In consequence, we can only compute a range of values. Namely:

$$\begin{cases} if \ p = p_{high} & \longrightarrow \quad \Delta V = 245.8 \ mL \\ if \ p = p_{fin} & \longrightarrow \quad \Delta V = 484.3 \ mL \end{cases}$$

Indeed, higher pressure means that matter occupies less space and is also discharged faster, since for a circular section of $d = \varnothing 2 \ mm$ and a generic duration of $t = 1 \ min$ the final Airflow Parameter reads:

$$\begin{cases} if \ p = p_{high} & \longrightarrow \quad AP = 469.4 \ \frac{L}{hr \cdot cm^2} \\ if \ p = p_{fin} & \longrightarrow \quad AP = 924.9 \ \frac{L}{hr \cdot cm^2} \end{cases}$$

This suggests that at the very beginning of the gas release process, right as the airway is opened, high pressure answers for the airflow. But as the pressure decreases in the food pot, more airflow is needed and thus to let out entirely the over-pressure quantity in due time, the chosen membrane must present a higher value. Note that for the same volume quantity, if a membrane presents a larger Airflow Parameter, then the latter will be able to discharge air in a shorter amount of time.

It is interesting to notice that further steps can be taken to reduce the Airflow Parameter or get faster release duration. For instance, instead of considering the entirety of what the over-pressure represents, what if we select a Gas Permeable Membrane that effectively reduces the pressure such that the resisting torque on the lid drops down from the computed 5 Nm to say 2 Nm, which is considered to be easy to open by all users (c.f. section 1.5.6).

Coming back to the torque formula, we can relate the value of $M_U = 2\ Nm$ to the amount of pressure inside the container at that moment, which is: $\Delta p_{bis} = 0.351\ bar$.

This pressure value has to be considered as the final over-pressure, which means that we start at $p_{high} = p_{atm} + \Delta p = 1.996\ bar$ and end with $p_{fin} = p_{atm} + \Delta p_{bis} = 1.364\ bar$. Following the same procedure, the quantity of matter that has to be removed thus represents $p_{high} - p_{fin} = 0.632\ bar$ which translates to $\Delta n = 0.0128\ mol$. As a result, we get the range of values as follows:

$$\begin{cases} if\ p = p_{high} & \longrightarrow \quad \Delta V = 157.5\ mL \quad \longrightarrow \quad AP = 300.8\ \frac{L}{hr \cdot cm^2} \\ if\ p = p_{fin} & \longrightarrow \quad \Delta V = 230.7\ mL \quad \longrightarrow \quad AP = 440.6\ \frac{L}{hr \cdot cm^2} \end{cases}$$

Notice that the actual Membrane user on the prototype model was chosen according to what was available in the laboratory of the company, that responds best to these parameters, but that will be detailed further in the next chapter Prototyping.

4 | Prototyping

4.1. Simulation

In the final stages of the design development of our solution, and as illustrated by the figures presented before, a 3D model has been created on a computer aided software, giving us the opportunity to have a virtual representation and version of the features and details analyzed up to now. This model is also useful in performing simulations on any section needed by applying an external disturbance and computing the resulting stresses and deformations, in anticipation to the testing phase and with infinite flexibility over the kind of load case and modifications to the model.

With this technique, it has been decided to verify the functioning of the most critical region of the solution assembly, namely the vertical snap-fitting feature linking the sliding cover to the structure by pressing down the former into the groove and against protrusion obstacles which induce a slight deformation until a resting position, as anticipated in **??**.

For what concerns software, the model has been generated using SolidWorks, while the computations have been executed by an open-source software named Code Aster that includes all steps from geometry meshing, surface partitioning, loads definition, material attribution, to calculation and graphic visualization. It has thus been decided to represent a portion of both "teeth" and evaluate its deformation, as well as the 3D stress tensor, under a forced displacement of 0.4 mm on each tooth just as if the system was inserted in the groove.

Here is an example of graphic resulting from the calculation, with the rest of graphics in Appendix A:

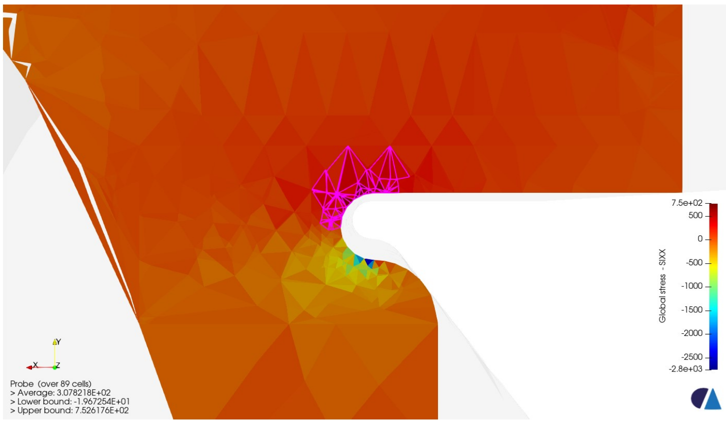


Figure 4.1: Example of a Code Aster stress result

It is important to take into account that the extreme values are a result of node concentration, a phenomenon for which as the mesh is not small enough and generates sharp angles or the link is not well executed between neighboring cells due to a geometric default, then their bad interaction produce a large stress increase locally. Therefore, the values to consider are from verifying values over a larger region, which tells us here that the average around the circular section is 31 MPa with peaks up to 76 MPa.

4.2. Printing with 3D resin

In consequence to the entire development of the concept design, it is needed to evaluate it in real life. As injection molding machines were not available during this internship, and in order to have a fast production of pieces with great flexibility to modifications, the use of a 3D printer was recommended. As a common practice for generating prototypes, 3D printing offers reliable building of models that can helps us get a first glance and understand how pieces interact in the real life, as well as fast production of different versions that do not need preparation of molds and thus help making alterations easier and testing faster.

In order to increase the precision of small features and render details correctly, the choice had been done to use “resin printing” instead of the classic “wire melting”, which also features tighter tolerances and better surface roughness. This type of 3D printing relies on a light source, like a laser, projector, or UV light, to turn different kind of resins into hard plastic, building layer by layer from the base plate into a vat of liquid resin. Pieces are usually printed tilted and separate from the base plate, as it lies over a forest of thin columns. Specific guidelines exist for such techniques, thus needing special considerations; for instance, unsupported structures or overhangs cannot be too long and may require additional pillars, relevant surfaces better be inclined relative to the base plate such as to avoid warp or deformation, typical layer heights are 50 μm and thus defines the theoretical tolerance size which will be changed to 0.1 mm to get a safety margin.

For what accounts software, the preparation of the prints is done in two steps: first, the 3D model (or CAD model for Computer Aided Design) is transferred to the open-source Chitubox program in order to generate a base section and all the supports needed to hold the piece while it is printed. The selection of the support's diameter, tip size and density are decided in this step and follows common practice. For larger components, it is even advised to add more supports over the critical regions.

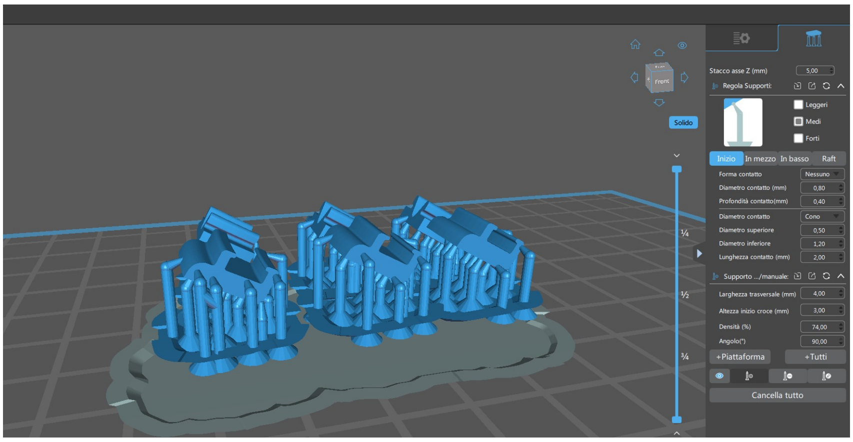


Figure 4.2: Example of a Chitubox window

Then, when the model is done, the file is sent to another program called Anycubic Photon Workshop which is the software related to the resin printer and according to the machine used will slice the model horizontally such as to generate all the layers that need to be printed one by one, and outputs a file readable by the printer.

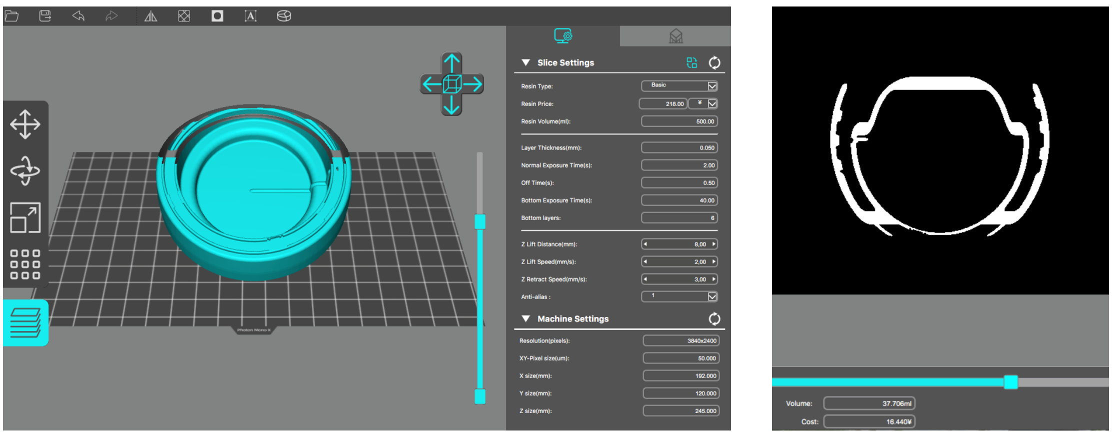


Figure 4.3: Example of a Anycubic window and layer file

In consequence to preparing the model, printing pieces require to pass through three stages: first, the actual printer has to be calibrated, the resin tank needs to be filled, and the printed product has to be unglued from its base plate. Second, it is required to place the component into an ultrasonic washing machine filled with an alcohol solution such as to clean it from remaining resin from the vat. Third, in order to increase the rigidity of the piece and get definite details and clean surfaces, the print is placed into an oven which will cure the resin through heat. Finally, our component is done, and the supports can be cut off such as to release the final element. Some sandpaper can be utilized such as to smooth out the external surface since the supports can leave small protrusions.

Those were then the steps to follow each time a component was printed, using the Anycubic printer available at the company.

4.3. Testing

The quickness of the resin printing helps to generate multiple prototypes but also quick versions of some details to be analysed in our solution. They rely mostly on the tolerance value to be selected that is a consequence of trial and error on the pieces interacting. Therefore, three different tests were performed before printing the entire final design.

4.3.1. Thread diameter

As anticipated, exact dimensions cannot be manufactured by a 3D printer due to their very nature, therefore components that have to interact need to present tolerances on their dimensions. As said before, the main choice has been made to modify all dimensions of the sliding cover while keeping the inner lid unchanged, and to select a base value of 0.1 mm.

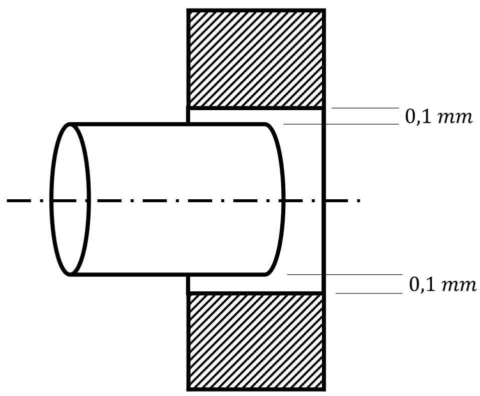


Figure 4.4: Tolerance explanation

For what concerns the threading, which is the main function of the lid, the main objective is that the diameter on the lid's side has to fit without much friction or blockage on the container walls. But on top of some clearance to be chosen, the shrinkage of the entire lid due to its curing stage has to be taken into account. Then, two samples with increasing diameter have been printed out, which are simplified versions of the lid presenting only the cover and the thread compatible with the one already in place in the food container.

It has been observed by trying to screw the print onto the standard aluminum container that the smaller diameter could not be fitted easily and was even blocked halfway down without heavily deforming the lid. The second version proved to be efficient, presenting no friction problem. The resulting dimension choice was thus to increase the diameter by $1\ mm$ (Radius $R = 40.75\ mm \quad \longrightarrow \quad R = 41.25\ mm$).

Figure 4.5: Printed prototype for the thread

4.3.2. Snap fitting features

As some modifications are expected by the curing of the component, especially on small features, dimensions must be analyzed and tested such as to ensure proper snap-fitting as well as no breakage. Trials have thus been pursued with multiple couples of a simplified version of the snap-fitting feature, which are straight and not curved, while also being smaller in length. The idea is then to smooth out the surface of the printed pieces with sandpaper, as resin printing is rougher than injection molding and to remove the bumps left by supports, then press the pieces together until assembled. The tolerance between the pieces is thus made by the amount of material removed by friction.

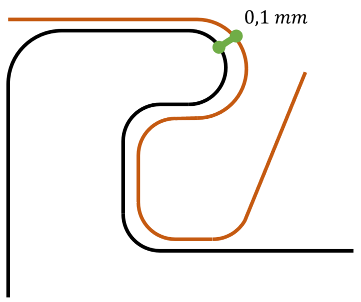


Figure 4.6: Tolerance scheme

Following the steps detailed before to print out the test pieces, this is what the batch looked like:

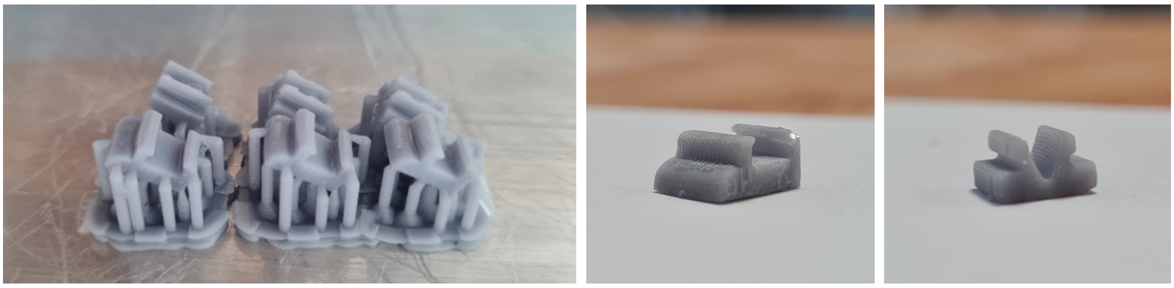


Figure 4.7: Printed prototype for the snap-fit features, as seen with supports, bottom piece, and top piece

And the test is executed as follows:

Figure 4.8: Test results with position, failed, and successful situations

Negative results are observed when the "teeth" breaks due the surface having a large roughness which then increased the friction and interference between components, which in turn increased the internal stresses. On the contrary, positive results were seen when the elements presented smooth circular shapes without sharp edges around the slit or rib regions. Even though injection molding processes are known to give better surface roughness than 3D printing, this type of detail must be analyzed on the machining results, which could be the subject of further research.

4.3.3. Positioning pins

For what concerns the positioning pins, testing was necessary in order to choose the right dimensions and spacing between the elements interacting such as to offer a “closed” and “open” feel to the user, while not necessitating too much force to pass over the obstacles. It is important to notice that for snap-fitting features and pieces that deform overall, the amount of force to input such that the components deform and move is related to the angle the interacting surfaces have relative to each other. The more perpendicular to the motion the angle is, the more force needed and vice versa.

In our case of the positioning pins, the sliding cover presents a circular-shaped bump, while the inner lid showcases two columns, such that their round shape makes the contact easier. On each side, walls are perpendicular so that the positioning pins have less probability to pass over and can actually be used to transfer torque and motion by opposition.

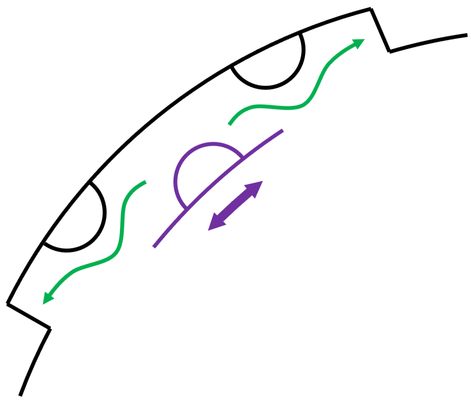


Figure 4.9: Positioning pins scheme

Therefore, the amount of contact (or interference depth) between two pins, or the space given to the resting position (counted as angle between the wall and the first pin), or even the pins’ sizes (in terms of diameter) are variables that can be slightly modified and tested so as to get an optimized feel in terms of ease of opening while presenting the right resistance which is useful to ensure that the “closed” position stays sealed when the food pot is hermetic.

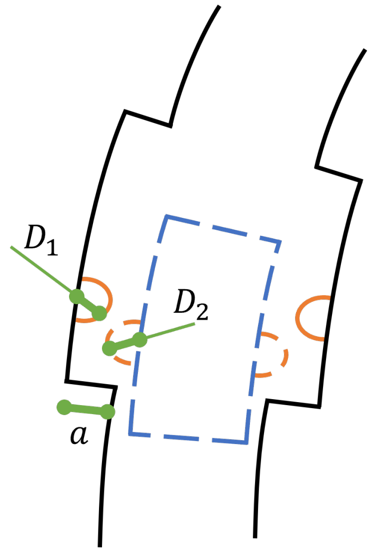


Figure 4.10: Positioning pins variables

Here is a scheme of the variable parameters. A set of tests pieces were printed out with different combinations of D_1, D_2 or a ($for\ the\ contact\ depth$) as follows:

Batch	a $[mm]$	D_1 $[mm]$	D_2 $[mm]$	Observation
#1	0.5	0.4	0.4	selected
#2	0.6	0.5	0.5	too strong
#3	0.6	0.4	0.42	too loose

Table 4.1: Positioning pins test parameters

The test in itself consisted of sliding the sliding cover's part over the fixed inner lid part, and get a sense of how much resistance was presented. It was concluded that the situation with largest diameters required large force input to deform over the positioning pins, while the situation with the largest a showed too loose connection for it to be effective. As a result, a median combination has to be chosen for the final version.

It is interesting to note that the limit to such test relates to the inherent surface roughness of resin 3D printing which would be smoother for injection molding, therefore the positioning pins experimented previously had been slightly sandpapered thus affecting the actual values. Further research using injection molding processes could look into such phenomenon.

4.3.4. Sealing

The last test was performed so as to ensure the functioning of the air channel and that the lid stays sealed when it is placed into "closed" position. As the sliding cover opens, the air channel must be used to discharge the over-pressure.

In order to verify such feature, a prototype was printed for the 3 main pieces, following advice from the previous tests: inner lid with the top groove and all its features, as well as the air channel; sliding cover made simpler by removing the side walls so as to ease its assembly and disassembly; bottom cover needed to close the airway. A fitting silicone gasket was utilized which came from the food pot manufacturer. The assembled lid was finalized by pressing the sliding cover with the snap-fit features, as well as gluing the bottom cover after aligning it with the inner lid to account for the plastic welding. Proper care was taken so as not to place glue into the air channel which would block its functioning.

In the interest of closing the air channel as it would be done in the final manufactured product, it has been decided to include the Gas Permeable Membrane just as anticipated before: a circular cut of the membrane sheet has been placed over the bottom entrance of the airway. Its selection was made according to the membranes available in the company's laboratory, which are samples sent by Porex [23]. They are organized by code names where the same letter base but different suffix characters represent the same material used but with different grid sizes. The list and comparison can be found in the **Appendix B**. From the list, any membrane that presents an airflow parameter higher than 924.9 can be used, which was the most critical values that had been computed. For instance, the $PMV10$ could be considered as an acceptable membrane for our usage. Notice that economical value or simply availability could be reasons to choose other membranes as long as they respect the Airflow Parameter, whether at the over-pressure value or the lower value of 1.364 bar relating to a resisting torque of 2 Nm.

Afterwards, the lid model was mounted onto a standard-sized food pot from the client which was modified such that air and thus pressure could be added inside by means of an air pump. The mechanism used a plastic tube coupled to an opening with a valve drilled into the bottom of the container.

Figure 4.11: Pressure test rig presented and assembled

After ensuring that the lid fitted onto the container, the test consisted in pressing small amount of air with the lid in "open" position and verifying that air did in fact escape through the lid's airway. With the lid in "closed" position, inputting more air also resulted in no air being released, thus speculating that sealing was effective with our solution.

Under values of added pressure much larger than the over-pressure, it has been observed that the prototype lid broke under the effect of a rapid pump, as seen below.

Figure 4.12: Test results with observable defects

With the sliding cover in "closed" position, one can only conclude that the added air did in fact pass though the airway and was blocked by the sliding cover, which can be seen slightly pushed upwards. The snap fit features worked as designed since the cover stayed in placed and thus the element that failed was the inner lid's structural strength. This is observed by the presence of the crack whose beginning is found in the groove.

This last experiment marked the end of the prototyping process, as well as the end of the internship and the research performed in it. The printed model was the only one fully printed in the available time, and was kept afterwards for presentation and illustration purposes.

5 | Conclusions and future developments

In conclusion, this thesis has dived into the universe of pressure-related concerns for food containers, aiming to provide innovative solutions that contribute to the improvement of multiple insulated pots with this common situation. As we recapitulate the main findings, a number of significant conclusions come to light.

From the simple client feedback stating "there is too much force onto the thread for the lid to be opened", this research has understood that the cause comes from the spoilage of food inside the container, which is crucial for food standards and the proper functioning of the food pot.

The study also identified various ideas in how to cope with such obstacles, basing itself on features that exist on the market in order to come up with a brand new concept, combining multiple requirements and performance indicators which highlight the main consideration when designing food container systems.

The main key findings were about designing a simple but effective system, easy to use and providing efficient recyclability of its materials, while following international food contact standards. The principal designs were inspired by limiting bacterial flow and interaction, or volume accommodation by deformation, and even with greater success activating a system that liberates some of the pressure build-up.

Applying various guidelines surrounding Design for Manufacturing, as well as Injection Molding which will be the chosen mean of production, and finally resin 3D printing for the prototypes during the end stage, a great number of designs were drawn and the most innovative solution was kept; by separating the lid concentrically while keeping partial connections, and hiding the system inside, the user unknowingly opens an air channel whose shape blends into the structure and serves to discharge pressure throughout the opening of the lid. This system is quite unusual and with the right research around some details with actual manufacturers, the design could be brought up to production as precise

CAD models and prototypes have already been generated and tested.

This research stands to add a solution to the existing list of ways to tackle and control pressure inside a food container, but it is important to acknowledge its limitations. Future studies could be pursued with even smaller tolerances and knowledge as well as testing performance with regard to the snap-fit features and the positioning pins.

As we conclude, it is imperative to emphasize the proactive steps that can be taken to address pressure problems in food containers. As much as this thesis focused on pure mechanical features, the research into food containers should also pivot towards the integration of smart technologies to monitor and control pressure conditions dynamically. By addressing pressure-related challenges, we contribute to a more sustainable and efficient food supply chain, fostering a future where packaged goods not only meet regulatory standards but exceed consumer expectations for quality and safety.

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A | Appendix A

As explained above, Code Aster computes various stress and strain variables and can generate 3D or 2D plots in order to visualize them in every direction and plane.

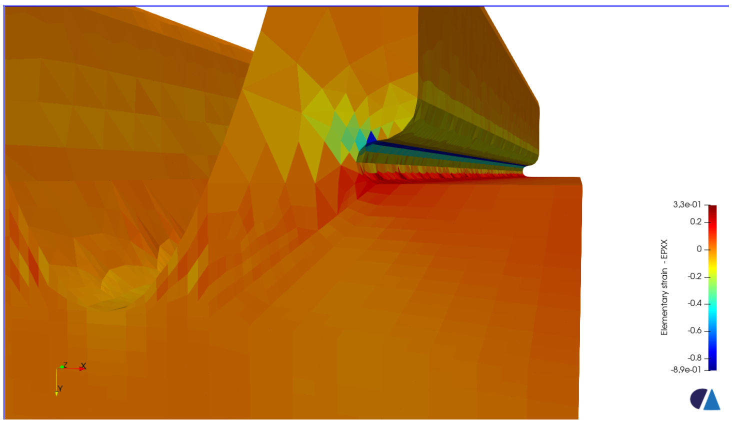


Figure A.1: Example of 3D strain result

Here below are presented the other parameters visualized while simulating our component, placed in the Appendix in order not to overflow the report. They are represented in 2D over a cutting plane placed in the middle of our testing piece. It is important to notice that values are in $[MPa]$ for stresses, and maximal values are subject to edge stress concentration hence the large values that can be observed.

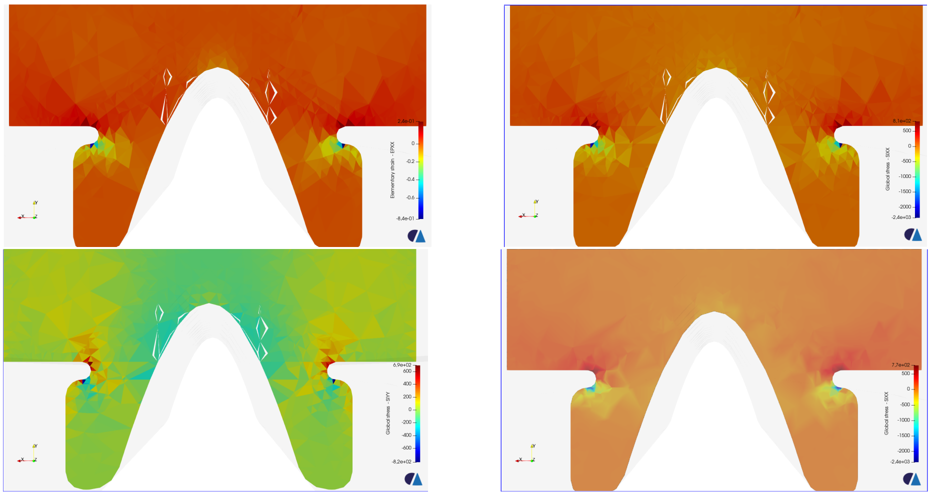


Figure A.2: Simulation results such as the strain, the stress only in XX direction, the stress only in YY direction, or the stress computed on the nodes instead of gaussian points

B | Appendix B

Manufacturers of Gas Permeable Membranes often list their product as follows, thus detailing how they can be produced as well as suggestions for use and what kind of standard test it answers to, but most importantly being classified by a specific code name:

MD25 – POREX VIRTEK® PTFE HYDROPHOBIC MEDICAL VENTING POROUS MEMBRANE SHEETS

Medical Venting Porous Membrane Sheets used to protect, seal, vent, debubble or pressure equalize.

• Can be supplied in format of:
– Master Rolls (330mm ±5mm width) on 75mm (3") plastic core
– Slit rolls on a 75mm (3") plastic core
– Die cut shapes
• Assembly suggestions:
– Ultrasonic welding
– Thermal welding
– Over-moulding
– Pressure Sensitive Adhesive
– Compression seal
• Sterilisation method:
– Steam/Autoclave (repeated use)
– EtO
• Raw material is compliant with:
– FDA 21CFR 177.1550
– USP 28, NF 23, 2005, for USP Class VI Plastics at 70°C
– PFOA Free, Compliant with (EC) No 1907/2006 REACH and Persistent Organic Pollutants (POP) EU 2019/1021
– Operating temperature range: -40 to 260°C

Other:
– Naturally hydrophobic

Figure B.1: Description of a membrane

All membranes differ by their characteristic, thus needing tables to compare their performance, with the most important variables being "Typical Airflow", "Water Entry Pressure" and "Thickness". Examples can be seen below:

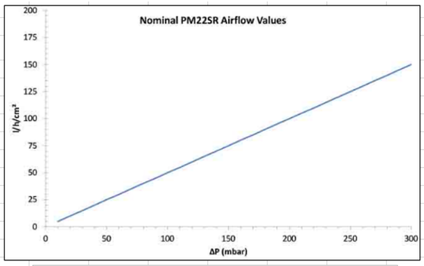
Item Number	IP Rating †	WEP* mbar (Typical)	Typical Airflow l/hr/cm² @70mbar	Filtration Efficiency** >99.99%	Thickness mm	Max Operating Temp °C	Salt Fog$
PMA10‡	64,67	370	75	0.4 μ	0.18	260	No pen.
PMA15‡	65,67,68	520	25	0.1 μ	0.25	260	No pen.
PMA20‡	65,66,67,68	1050	7	0.1 μ	0.19	260	No pen.
Porex Virtek – General Puropse Venting product range (hydrophobic)							
PMV10	64,67	270	107	0.5μ	0.13	260	No Pen.
PMV10L***	64,67	270	85	0.5μ	0.3	100	No Pen.
PMV15	64,67	370	75	0.4μ	0.18	260	No Pen.
PMV15T‡	64,67	370	75	0.4μ	0.18	260	No Pen.
PMV20	64,65,68	520	25	0.1μ	0.25	260	No Pen.
PMV25	65,67,68	765	17	0.2μ	0.1		No Pen.
PMV27	65,66,67,68	1050	7	0.1μ	0.19	260	No Pen.

Product Number	Min. Airflow l/hr/cm2 at 70 mbar	Typical Airflow l/hr/cm2 at 70 mbar	Min WEP* mBar	Typical WEP* mBar	Thickness mm	Max Operating Temp °C	Dry Filtration Efficiency* >99.99%
BM10	14	30	200	360	1	260	
BM15	25	84	30	120	1	260	
BM20	50	90	10	80	1	260	
BM25*	11	20	200	400	1.5	260	
BM30	16	50	120	200	1.5	260	
BM35	25	60	40	140	1.5	260	
BM40*	25	55	20	100	1.5	260	
BM45	8	18	220	430	2	260	
BM50	16	40	80	200	2	260	
BM55	18	50	50	180	2	260	
BM60*	25	50	20	140	2	260	

Figure B.2: Comparison of membranes

An example of parameters comparison that was performed in order to select the membrane was performed on Excel as follows:

	@ 70mbar	@ 1bar	@ 2bar		@ 1bar
Membrane	Airflow parameter	Airflow parameter	Airflow parameter	Water Entry Pressure	Is airflow higher than 924
PMV10	[100-125]	1429	2857	270	TRUE
PMV10L	85	1214	2429	270	TRUE
PMV10C	93	1329	2657	175	TRUE
PMV20	[25-35]	357	714	520	FALSE
PMV20B	20	286	571	520	FALSE
PMV25	17	243	486	765	FALSE
PMV30	4.5	64	129	1000	FALSE
BM20	90	1286	2571	80	TRUE
BM105	2.5	36	71	1000	FALSE



Usually airflow values are linear with the pressure applied on the filter, thus we can compute values at 2bar which is our high pressure in the pot before opening

Figure B.3: Comparison of membranes' parameters

It is important to notice that selection heavily relies on the Airflow Parameter being larger than the one computed in 3.5.4. That value can also be easily computed for other pressure levels which can be useful for broader membrane choice as explained before.

List of Figures

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List of Abbreviations and Symbols

Abbreviations

Word	Meaning
KPI	Key Performance Indicator
CAD	Computer Aided Design
FCM	Food Contact Material
BMP	Biochemical Methane Potential
BPA	Bisphenol-A
OML	Overall Migration Limit
SML	Specific Migration Limit
EFSA	European Food Safety Authority
EU	European Union
EC	European Commission
DoC	Declaration of Compliance
TDI	Tolerable Daily Intake
TWI	Tolerable Weekly Intake
CEN	Comité Européen de Normalisation
FDA	Food and Drug Administration
GMP	Good Manufacturing Processes
HPP	High Pressure Processing
DFM	Design For Manufacturing
DFA	Design For Assembly
ABS	fluid displacement
PTFE	fluid displacement
AP	Airflow Parameter
WEP	Water Entry Pressure

Symbols

Variable	Description	SI unit
$\boldsymbol{p}$	pressure	bar
$\boldsymbol{V}$	volume	L
$\boldsymbol{n}$	mole quantity	mol
$\boldsymbol{R}$	universal gas constant	$J/(mol \cdot K)$
$\boldsymbol{T}$	temperature	K
$\boldsymbol{M}$	screwing torque	Nm
$\boldsymbol{d}$	thread diameter	m
$\boldsymbol{F}$	vertical force	N
$\boldsymbol{\alpha}$	thread angle	rad
$\boldsymbol{\mu}$	friction coefficient	-
$\boldsymbol{\rho}$	liquid density	g/mL
$\boldsymbol{g}$	gravity	$\mathrm{m/s^2}$
$\boldsymbol{h}$	height	m
$\boldsymbol{m}$	mass	kg
$\boldsymbol{A}_i$	area	$\mathrm{m^2}$
$\boldsymbol{\sigma}$	stress	$\mathrm{N/m^2}$
$\boldsymbol{\delta}$	pouch thickness	m
$\boldsymbol{E}$	Young's modulus	GPa
$\boldsymbol{I}$	moment of inertia	$\mathrm{N/m^4}$
$\boldsymbol{AP}$	airflow parameter	$\mathrm{L/(hr}\cdot cm^2)$

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