Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

Laia Casals

Developing of the packaging design for SGS technology

Bachelor's thesis in Mechanical and Industrial Engineering
Supervisor: Anna Olsen
June 2023

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Preface

First of all, I would like to express my deepest gratitude to my supervisor Anna Olsen for all the support that has provide me with this thesis, without her feedback, advice, motivation and guidance the accomplishment of the thesis couldn't have been reached.

I would also like to extend a special thanks to Karianne Hjortland from the Department of Biotechnology and Food Science who went above and beyond to help me with my work and provide me helpful suggestions and also her expertise on the theme.

Finally, I am grateful to Norges Teknisk-Naturvitenskapelige Universitet (NTNU) for giving me the opportunity of developing my bachelor thesis as an exchange student in the Department of Mechanical and Industrial Engineering.

Abstract

This thesis addresses the significant problem of food waste, with a specific focus on the food industry, which is one of the major contributors to this issue. By extending the shelf-life of food products, it is possible to reduce food losses throughout the production and supply chains. Consequently, this study aims to develop a packaging solution that can effectively preserve a certain quantity of SGS-treated food, particularly salmon, for an extended period while maintaining its quality.

To achieve the goal of developing an optimal packaging for SGS-treated salmon, a comprehensive concept development study was conducted. Additionally, a packaging model was created and subjected to strength analysis using SolidWorks software. Through these efforts, it was determined that the most suitable packaging material is polyethylene (PE), based not only on specific functional criteria, but also, a strength analysis considering factors such as its ability to withstand the pressure exerted by CO_2 within the packaging, ensuring the desired level of deflection.

By developing an innovative packaging design for SGS-treated salmon, this thesis contributes to the larger objective of reducing food waste in the food industry. The findings of this study provide valuable insights for industry professionals and researchers interested in enhancing the shelf-life of perishable food products through effective packaging solutions.

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1. Introduction

1.1 Background

Climate change is already an undeniable reality, not only is it causing the destruction of ecosystems and negatively impacting the climate by causing droughts, floods, melting glaciers, but also, between 2030 and 2050, climate change is expected to cause approximately 250.000 additional deaths per year [1].

This problem is mainly due to deforestation, the disproportionate increase of greenhouse gases and accelerated population growth, so humans are therefore primarily responsible for climate change.

Food loss and waste also exacerbates the climate change crisis with its significant greenhouse gas (GHG) footprint. Is estimated to be roughly waste one third of the food intended for human consumption. When food is discarded, all inputs used in producing, processing, transporting, preparing, and storing discarded food are also wasted [2].

In Norway, a minimum of 417,000 tonnes of edible food were thrown away in Norway in 2019. This corresponds to approx. 78 kg per inhabitant per year, a financial loss of about NOK 20.7 billion and 1.26 million tonnes of CO2 equivalents. The household sector accounts for more than half of the mapped food waste (55%), followed by the manufacturers (22%), the retail sector (15%), the hospitality industry (7%) and the wholesale sector (1%)[3].

In the EU, nearly 57 million tonnes of food waste (127 kg/inhabitant) are generated annually with an associated market value estimated at 130 billion euros [4]. Eurostat roughly estimates that around 10% of food made available to EU consumers (at retail, food services and households) may be wasted. At the same time, some 36.2 million people cannot afford a quality meal every second day [4].

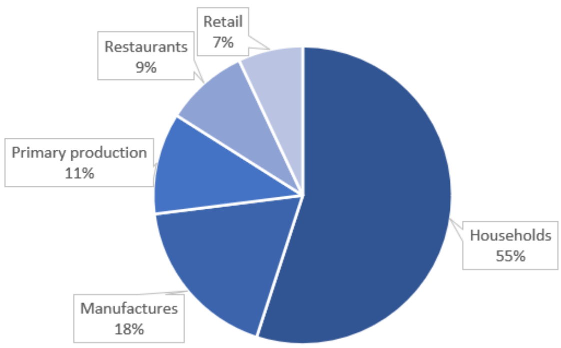


Figure 1: Food waste in the EU by main economic sectors, 2020 [4]

Globally, approximately a third of all food produced for human consumption is lost or wasted [5]. According to the UNEP Food Waste Index 2021, around 931 million tonnes of food waste were generated in 2019 – 61% of which came from households, 26% from food service and 13% from retail – suggesting that 17% of global food production may be wasted at these stages of the food supply chain.

Many policies and also individual measures are trying to combat the problem of food waste. According to the 12.3 Sustainable Development Goal Target, on the Agenda 2030, issued by the United Nation to tackle climate change, halve per capita global food waste at the retail and consumer level, and reduce food loses along production and supply chains by 2030 [6].

Figure 2: 12.3 Sustainable Development Goal Target [6]

Covering the entire value-chain, this innovative agreement involves all key stakeholders from primary producers to consumers, including food manufacturers, restaurants, supermarket chains, convenient stores, kiosks and gas stations. That's why food industries are showing a growing interest in developing technologies to extend the shelf life of products and contribute to lower food waste and the possibility of widening distribution outreach in the food value chain, always taking into account that the nutritional quality is not diminished and ensuring safety.

One of these technologies is the soluble gas stabilization (SGS), which is a pre-step process of dissolving carbon dioxide (CO_2) into the product before packaging. This technology is showing promising results on the lab-scale to limit microbial growth and other deteriorating mechanisms in food products [7]. Nevertheless, as it's still in research, has not been developed a packaging solution for the treated salmon.

This bachelor thesis focuses on the developing of a sustainable packaging to preserve a certain amount of SGS-treated food, especially salmon, for a certain time in a good quality.

1.2 Goals and Scope

As a result of the constantly growing need for food and consequent need for sustainability in the food and packaging industry, this bachelor thesis aim is to develop a packaging design for soluble gas stabilization (SGS) technology, specifically for the salmon. Specific objectives are listed below:

- Make a map existing solution of salmon packaging.
- Make a study of all the materials and their properties that could be used in an SGS technology packaging for salmon.
- Conduct a concept development study for the packaging developed.
- Model the final packaging design in 3D software and perform strength analysis.

On the other hand, the scope of this project is to analyse only the salmon packaging.

Consequently, with this project I want to make a little contribution to get a step closer to reduce food waste.

1.3 Limitations

This thesis has one potential limitation and it's the fact that it is only a theoretical study about how should be a packaging for containing SGS treated salmon, so it will not provide experimental data and results.

2. Product development methodology

To achieve the general aim of developing an optimal packaging for SGS-treated salmon a concept development study was conducted to enable an industrial implementation of the product. The concept development study it expands into the "front-end process", which contains many interrelated activities [8].

The concept development process includes the following activities:

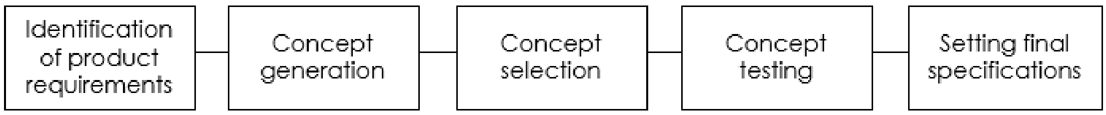


Figure 3: Concept development phases [8]

Identifications of product requirements: The goal of the identification of the SGS treated salmon packaging is to understand the products functionalities and needs in terms of suitability. That's why a huge theoretical investigation of the SGS technology and the existing packaging will be done and also a market analysis about what packaging can be found. Finally, a functional analysis using Octopus diagram a graphic will be done and where the functions will be translated into measurable assessment criteria and then compared with the packaging materials

Concept generation: The goal of concept generation is to thoroughly explore the space of product concepts that may address the product requirements. In this case, several packagings have been sketched according to different materials, sizes, and shapes that could suit to pack salmon.

Concept selection: In this activity various products concepts will be analysed to identify the most promising concepts. To recognize the best concepts in this case, the packaging materials, they will be compared to the functional criteria for packaging of SGS-treated salmon.

Concept testing: The concepts selected are now tested to verify the products requirements. To test them, a 3D model of SolidWorks will be done and also a stress and deflection analysis of every material selected.

Setting final specifications: To conclude the product development method, limitations of the packaging will be identified and some recommendations of how should be the most suitable packaging of SGS treated salmon will be provided.

3. SGS technology

It is indispensable to understand what is and how it works the technology used to extend the shelf life of the salmon that we will be packing.

Soluble gas stabilization, known as the SGS technology, is used to increase the shelf life of perishable food products and thereby reduce food. The technology itself consists of dissolving CO_2 into the product before packaging, and relies on the bacteriostatic effect of CO_2, limiting microbial growth and other deteriorating mechanism in food products. [9]

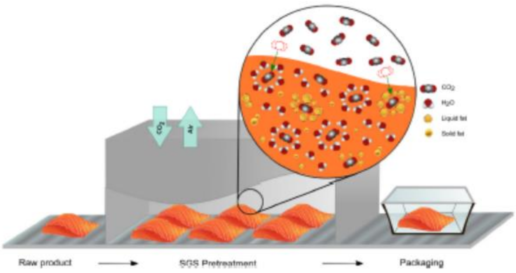


Figure 4: SGS technology procedure [9]

The effect of the SGS technology and dissolve CO_2 on food has been studied in some of recent research studies. Has been checked the texture, colour, drip loss, lipid oxidation, ATP degradation and microbiological load and composition. Also has been investigated the behaviour of this technology in combination of thermal technologies, and an overview of advantages and disadvantages on different foods is provided [10].

This research has shown promising results on deteriorating mechanism in seafood such as fish patties [11], MA-packed sardines, MA-packed Farmed Gilthead Sea Bream and European Sea Bass [12], and vacuum-packed salmon [13]. Nevertheless, as it's still in research, has not been developed a packaging solution for the treated salmon, that's why the main aim of this bachelor thesis is to develop that packaging.

4. Mapping of existing solutions

Getting knowledge of the existing packaging solutions for salmon will be practical for the thesis development and setup also the best product requirements that will have to reach the product.

That's why not only has been done an investigation through the literature, but also, a supermarket survey was conducted to investigate the existing packaging solutions in the market of fresh filleted and portioned salmon in Norway today.

4.1 Atmosphere inside the packaging

There are many different types of packaging for salmon, but all of them can be overall classified in MA-packaging or vacuum packaging according to the atmosphere inside the package in which the salmon is placed.

4.1.1 Modified atmosphere packaging (MAP)

Modified atmosphere packaging (MAP), also known as gas flushing, is a way of maintaining the freshness and attractiveness and extend the shelf life of fresh food products as for example, salmon. The technology substitutes the atmospheric air inside a package with a protective gas mix. The gas in the package helps ensure that the product will stay fresh for as long as possible.

Oxygen produces lipid oxidation reactions and encourages the growth of aerobic spoilage and the formation of other unwanted microorganisms may also occur. By reducing the amount of oxygen and replacing it with other gases, it can be reduced or delayed unwanted reactions. [14]

Figure 5: Example of a MAP packaging

Advantages

- Longer shelf life compared to other conventional storage methods.
- Enhanced visual appeal.
- Elimination of chemical additives/preservatives.
- Shelf-life extension often provides long-distance export options.

Disadvantages

- Does not slow the growth of some harmful bacteria. Usually used with refrigeration.
- Once these food packages are open, the food has a normal shelf life.
- Added cost for gases, packaging materials and machinery.

In the following table some examples of the MA-packaging found it in the supermarket are shown.

Table 1: MAP packaging founded in Norwegian supermarkets

LERØY

Size: 24x16x4 cm

Volume: 1536 cm³

Content amount: 400 g

Producer: Lerøy Seafood AS

FISKERIET

Size: 24x16x4 cm

Content amount: 500 g

Volume: 1535 cm³

Producer: SalMar AS

COOP FRA HAVET

Size: 24x16x4 cm

Volume: 1536 cm³

Content amount: 400 g

Producer: SalMar SA

COOP FRA HAVET

Size: 24x16x4 cm

Volume: 1536 cm³

Content amount: 600 g

Producer: Coop Norge SA

XTRA COOP

Size: 24x16x4 cm

Volume: 1536 cm³

Content amount: 400 g

Producer: Coop Norge SA

4.1.2 Vacuum packaging

Vacuum packaging is an alternative natural preservation packaging technique that can extend the shelf life and improve the overall quality from the salmon. Vacuum packaging, is pointed as skin packaging include elimination of the pack inner air completely and improving food product under vacuum method, so that oxygen used for the microbial growth and oxidation will be decline pulling the packaging material into intimate contact with the product. [15]

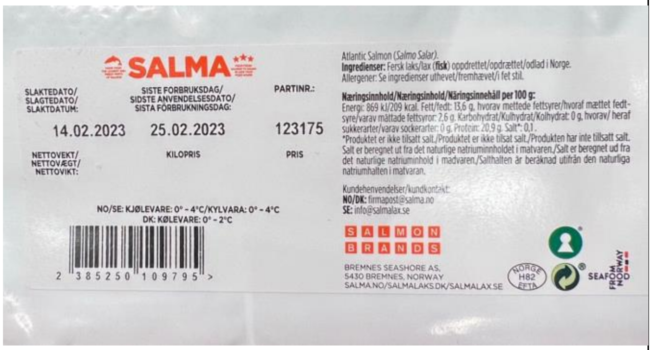
Figure 6: Example of a vacuum packaging

Advantages • Longer shelf life. • Barrier from external elements. • Clear and visible external packaging. • Minimal need for chemical preserves. • Quick and efficient. • Reduced product loss. • Minimal Up-front cost.
Disadvantages • Bad shape to stacking packages on top of each other. • Proper gas levels and oxygen levels must be known to increase shelf life. • Loss of preservation once the packaging is opened. • Additional sealers attachments. • Additional labelling often needed. • Can be difficult to open de vacuum packaging.

In the following table some examples of the vacuum packaging found it in the supermarket are shown and also which materials are founded on it, the producer of the product, the sizes and also the salmon amount the packaging contains.

Table 2: Vacuum packaging founded in Norwegian supermarkets

SALMA



Size: 24x11x2 cm

Volume: 528 cm³

Content amount: 190 g

Producer: Bremnes Seashore AS

Size: 48x11x2 cm

Volume: 1056 cm³

Content amount: 1000 g

Producer: Bremnes Seashore AS

FRØYA

Size: 19x9x8 cm

Volume: 1368 cm³

Content amount: 300 g

Producer: Frøya Salmon AS

From the study of supermarket salmon packages in Norway, it can be concluded that the packaging solution for MAP used are aluminium trays and flexible plastic cover film, in the weight range of 400-600g per package. All the trays size happens to be identical; 24 x 16 x 4 cm (volume: 1536 cm^3), independent of the amount of salmon inside. The aluminium tray enables consumer convenience by the possibility to remain the fillets in the tray when cooking in oven or microwave nevertheless is not the preferable tray in terms of being environmentally friendly. The vacuum packaged generally are ready-to-eat products with sushi/sashimi quality, in the weight range of 190-300g and even up to 1000g. Finally, information about the product is usually given on paper attached to the outside of the MA-packaging, while it is printed directly on the plastic film of vacuum packages.

4.2 Manufacturing of the packaging

Nowadays there are many ways of manufacturing a packaging so depending on it, different types of packages can be created.

4.2.1 Thermoforming packaging

Thermoforming is a manufacturing process that uses heat, vacuum, and pressure to form plastic sheets into three-dimensional shapes determined by a mold. After coming in contact with the mold, the shapes are then cut, inspected, and assembled into packaging. [16]

Figure 7: Illustration of a thermoforming machine [17]

Advantages
• Low cost of tooling and production. • Quick and inexpensive prototyping, • Parts with enhanced stress crack resistance. • High impact strength. • Good rigidity.

• Can be used with vacuum and MAP packaging. • Can work for huge plastic projects. • Nearly all types of plastic are suitable. • Higher quality products are created in a short period of time.
Disadvantages • The thickness of the part may be uneven in spots, causing weak points • Thermoforming uses more plastic than other methods. • Not environment friendly format of packaging.

4.2.2 Flow wrapping packaging

In packaging industry form, fill and seal machines (FFS) are equipment that offer complete solution from forming packages to filling product and sealing them in primary containers.

It exists two types of working operations of FSS, in vertical (VFFS) or a horizontal (HFFS) direction. [18]

4.2.2.1 VFFS

Vertical Form Fill Sealing (VFFS) is a packing method that forms and packs bags at the same time, in a vertically direction with a triple heat-sealed seam to guarantee the quality, conservation and safety of the product. [19]

The automatic packaging process on the machine starts with a large single roll of film (normally transparent). The film is unwound and runs through the machine to the shoulder where it is formed into a bag and filled at the same time, with three seams, two transversal and one longitudinal. [20]

Figure 8: Illustration VFFS machine [21]

Advantages
• Machines require less space. • Low maintenance requirement, less operational cost. • Can have multiple lanes there by increasing the production. • Various widths can be processed on these machines at high speeds. • Perfect for sealed sachets and pouches. • highly cost-effective system. • Can be used with vacuum and MAP packaging.
Disadvantages
• Do not have multiple fillings stations and can only form one type of packaging. • Small to medium business, not large.

4.2.2.2 HFFS

HFFS packaging is also known as flow wrapping, and its commonly used to pack food as fresh salmon. Is a bag sealed by a triple seam, in the form of a pillow, which guarantees the quality and safety of the product, a good finish and an inviolable seal. The closure of this bag is made by a heat seal that not only guarantees the conservation of the product in the best conditions, but also, both of its components and its structure. Horizontal filling can be combined with gas flushing to ensure that all oxygen is removed from the bag before being sealed, which is well suited for the salmon being fresh. [22], [19]

Flow pack horizontal machines are automatic machines for high productions that perform three tasks in a continuous operation: 1) forming a bag, 2) filling it with the salmon, 3) sealing and discharging the finished package. This machine uses a single film coil with three weldings, two cross-weldings and one longitudinal welding. [23]

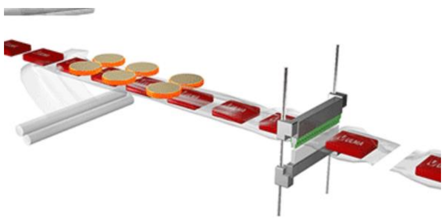


Figure 9: Illustration HFFS machine [24]

Advantages
• Minimal material waste. • A very cost-effective option for creating promotional items or samples.

- The packaging's shape and construction lend itself to strong brand visibility when combined with our labelling service.
- Less weigh than other packing methods, which can reduce transit costs.
- Bags are available in a range of sizes and can be square or rectangular.
- Can be used with vacuum and MAP packaging.
- Better for heavier products and large-scale business, as they travel along a conveyor belt rather than being fed from a feeding spout.
- Fast and can deliver heavier bags with zippers and nozzles.
- Multiple filling stations and can produce more than one type of packaging.

Disadvantages

- Requires more floor area during the packaging due to the process being carried out horizontally.
- More complex machines with high maintenance requirement.

4.2.3 Preformed packaging trays

With preformed food packaging trays, can be created all types of case-ready packaging for overwrap, MAP, and vacuum skin applications. Trays are available in PET, PP, HIPS, C-PET materials.

4.2.4 Traysealers

Traysealers are machines that apply plastic film lids to trays of varying materials, sizes, and depths for vacuum and/or gas injected packages [25].

There are automatic traysealers and semiautomatic ones.

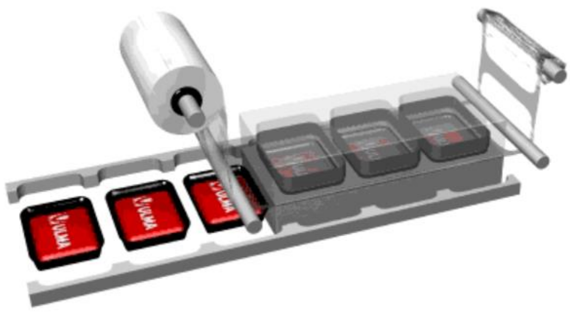


Figure 10: Illustration traysealers machine [26]

4.2.5 Stretch film wrappers

Stretch films are flexible, sticky and strong films for wrapping products which are protected loads against mechanical damage and weather conditions. Stretch films are transparent or can be coloured [27]. The machines used to pack fresh products with the stretch film wrappers are highly flexible automatic machines [28].

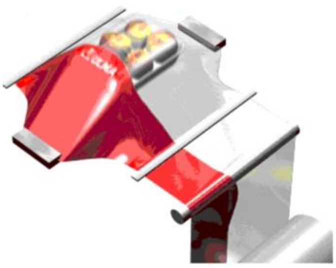


Figure 11: Illustration stretch film wrappers machine [28]

4.2.6 Shrink-sleeve wrapping-shrink tunnels

This machine first does a shrink film packaging with a wrapping machine, and after it uses shrink tunnels and side seal L sealers to shrink materials like polyolefin films which have been sealed around the product.

Figure 12: Shrink-sleeve wrapping-shrink tunnels [29]

4.3 Salmon packaging machinery

Nowadays in Norway the most common brands used for the salmon factories in terms of salmon packaging machines are Marel, Baader and Optimar.

4.3.1 RoboBatcher Thermoformer from Marel

The RoboBatcher Thermoformer packs and styles salmon portions, whole fillets and slices into thermoformer pockets, directly after cutting. It can process up to 120 pieces per minute depending on the type of product [30].

The system uses a unique combination of innovative robotic technology and state-of-the-art batching software, to create fixed-weight retail packs so close to target weight that giveaway is always minimal. Pieces within particular weight ranges can be diverted into certain packs to meet specific customer requirements, helping you fulfill orders efficiently and cost-effectively. Any pieces that are out of spec can be bypassed, improving quality control. The system can also create fixed-count retail packs, with up to 200 picks per minute, ensuring you get the most value possible from your raw material. The system virtually eliminates manual handling from the packing process so you can create salmon products of the highest quality and hygiene [31].

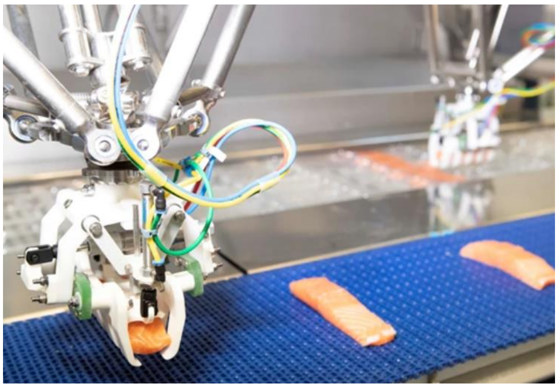


Figure 13: RoboBatcher Thermoformer from Marel [31]

4.3.2 RoboBatcher Box from Marel

The RoboBatcher Box uses a unique combination of state-of-the-art batching software and innovative robotic technology. Knowing the fish's precise measurements, the RoboBatcher picks up the product and gently places it into one of the boxes, packing according to catchweight or fixed-weight requirements and a predefined styling pattern. The fully automated dispatch process ensures that once a box reaches the set target weight, it is immediately conveyed out for final packing and swiftly replaced by a new box to pack. The packing process is completed hands-free with an automated solution that includes a foil applicator, checkweigher, labeler, IceDoser and lid applicator, securing the end product's hygiene and safety [31].

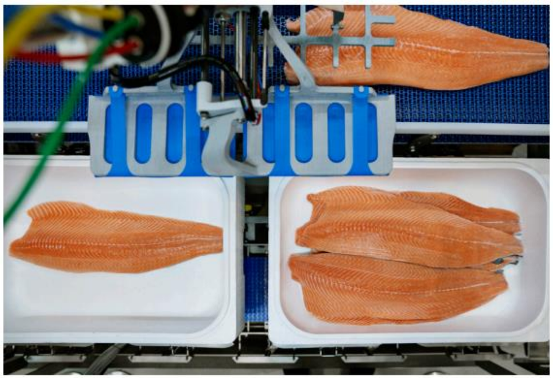


Figure 14: RoboBatcher Box from Marel [31]

4.3.3 BAADER 1850

This machine covers the entire value chain from harvesting to consumer packaging and dispatch as fillet grading, packing and also inspection. It provides reduced labour costs due to automation, higher product quality due to less handling, tracking of individual fillets into each box and high hygiene standards [32].

Is a processing line its working range is approximately up to 750 mm fillet length and throughput up to 50 fish/min. Generally, this machine has to be combined with the bag placing machine provided by their partner Niverplast, and also BAADER 1860 Fillet Inspector [32].

Figure 15: BAADER 1850 [32]

4.3.4 Automatic packing line from Optimar

The company Optimar also provides an entire packaging line that also covers the entire packaging process [33]. In this case, the automatic packing line for salmon consists of the following units:

- Bulk feeder (wet/dry) which feeds and regulates the flow of salmons.
- Optimar DB-8 batch weight or Speedbatcher that creates large-volume fixed-weight batches with low shrinkage.
- Automatic carton (bottom/lid) erecting and feeding which brings the cartons into right position under the Optimar DB batch-weight.
- Automatic plastic feeder or Optimar Plastic Bagger is a mounted roll of polyethylene film that automatically measures, cuts and inserts a bag into the carton.
- Automatic Lid applicator that will add lid to the bottom carton in one continuous motion.

- Automatic Rackloader that can load various size trays, pans, boards and even strap pans, onto single or double racks, without each being handled by employees.
- Roller conveyors and strapping machine.

Figure 16: Automatic packaging line from Optimar [33]

5. Materials used in salmon packaging

5.1 Polyethylene

Polyethylene abbreviated as PE is a polymer widely used in food packaging, both as film and rigid packaging material [34]. It is found both as low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE) and high-density polyethylene (HDPE).

HDPE is the strongest material so it is often used in rigid/semi-rigid form [35]. Has higher tensile strength, better resistance to oils, but reduced transparency and heat-sealing properties compared to LDPE [35].

LDPE is also a strong material with high tensile strength and tear resistance, often used in multilayer with other polymers, and offers good moisture barrier and heat-sealability [36]. It is not a good barrier to gases and is sensitive to oils, which can make the polymer swell.

LLDPE have advantage over LDPE in terms of improved performance at low and high temperatures, improved chemical resistance, and improved puncture strength and tear strength [35].

Is not biobased and biodegradable but can be recycled.

5.2 Polypropylene

Polypropylene abbreviated as PP has high barrier to water vapor, medium barrier to gases, good resistance to oils and greases, high-temperature stability and good transparency and printability [37]. PP has a T_g of -10°C, thus becoming brittle in freezing temperature [38]. Usually in food packaging unoriented PP (OPP) is used and it has a stiff feel and is not a good barrier to gases. It is often coated with poly vinyl chloride (PVDC) to increase gas barrier properties and coated with PVDC or PE to enable heat-sealing without shrinkage. Is not biobased and biodegradable but can be recycled [38].

5.3 Polyethylene terephthalate

Polyethylene terephthalate abbreviated as PET has a T_g between 73-80°C, and is used in its bioriented form, offering excellent transparency and mechanical properties and a good barrier to gases [34]. PET films have great tensile strength, elasticity and stability over a wide temperature range (-60°C to 220°C). Is often used as the outside support in a multilayer with LDPE, where LDPE enhances the sealing-properties and toughness. Is not biobased and biodegradable but can be recycled [34].

5.4 Polyamide

Polyamide abbreviated as PA or commonly called nylon is a strong material with good oxygen barrier but poor water vapor barrier [38]. It is widely used in multilayers due to thermal and mechanical properties such as thermoformability, transparency, thermal stability, puncture resistance and strength, similar to PET [37]. It is inert and nontoxic, and has a T_g of 60°C. Is not biobased and biodegradable but can be recycled [38].

5.5 EVOH

Ethylene-vinyl alcohol (EVOH) has high mechanical strength and elasticity, and has excellent barrier to gases, especially to oxygen. EVOH is used to maintain product quality for oxygen-sensitive products [38]. Usually, EVOH films are laminated in the order of 5 µm film thickness [39]. The superior barrier properties of EVOH in plastic containers has allowed for replacement of glass and metal containers as food packaging. In gas-packaging EVOH resins effectively retain CO_2 and nitrogen and it has a T_g between 55-69°C. Is not biobased and biodegradable but can be recycled [38].

5.6 Aluminium

Aluminium is one of the most versatile packaging materials available, there are available in a variety of shapes and sizes and also support heat to be used in the oven. Aluminium foil can be used to form rigid and semi-rigid trays which shows absolute barrier effects to vapor and gases, as well as visible and UV light. Is not biobased and biodegradable but can be recycled [40].

5.7 Cardboard (coated)

Cardboard is recently started to use as a material in food trays for being a biodegradable and biobased material. But, the hydrophilic composition of cellulose cardboard makes it likely to absorb water when in contact with high-moisture food. This is overcome with the application of hydrophobic coatings, e.g., paraffin or polyethylene. Nevertheless, this makes recycling difficult [41].

6. Identification of the SGS salmon packaging requirements

To identify the packaging requirements, has been done a functional analysis using Octopus diagram a graphic tool of the APTE® method. The diagram allows enumerating functions that the packaging must answer to, or functions it must perform to reach the need of a user [42]. The functions identified are denoted as primary functions (PF) and constrain functions (CF) that exist between the packaging and its environment. PF's exist between the packaging itself and two elements in the environment, while the CF's are seen as a link between the packaging and one element alone [43]. The PF's and CF's are described in table 3.

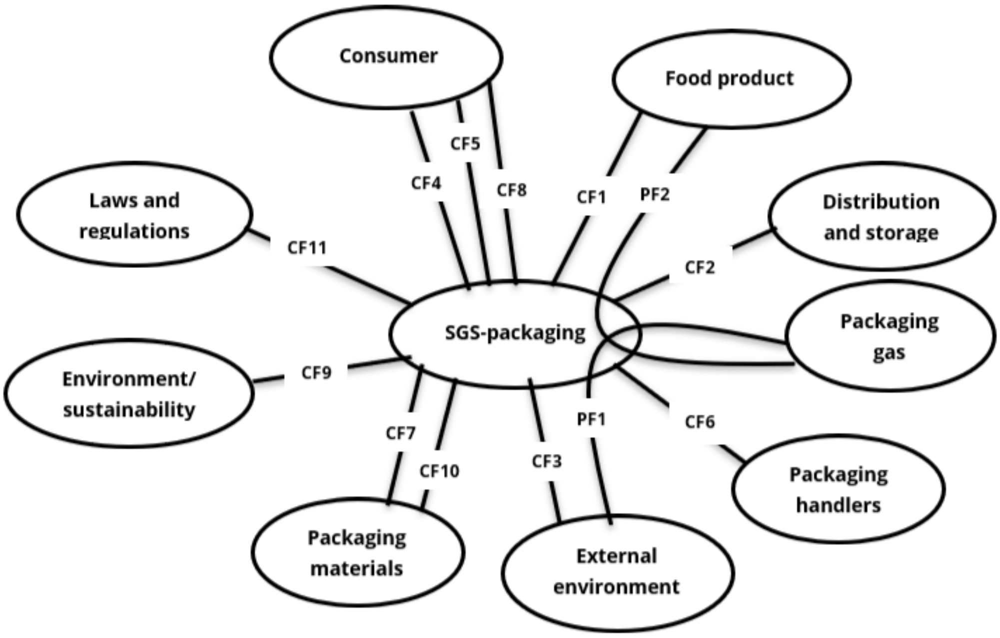


Figure 17: Octopus diagram [44]

Table 3: Description of primary functions and constraint functions [44]

Function	Description
CF1	Contain the food product
PF1	Be a barrier to the loss or gain of moisture and gas
CF2	Physically protect the food product from damage in distribution and storage (e.g., vibration, tearing, friction, temperature)
PF2	Preserve the food product from natural deterioration
CF3	Protect the food product from external environment (dust, UV-light, etc.)
CF4	Communicate information about the food product, such as legal requirements, ingredients, manufacture, weight, price, recyclability
CF5	Present the food product so that it is appealing to the consumer (design, transparent material, size, etc., absorbent pad.

CF6	Be convenient and easy to handle for the packaging handlers in the value chain
CF7	Consist of materials that are compatible with food and nontoxic
CF8	Be convenient for consumers by being easy to open, empty and sort for waste management
CF9	Limit environmental impact
CF10	Have an adequate sealing
CF11	Follow laws and regulations (country dependent)

To decide on which PF' and CF's are the most important to focus on each function was weighted according to their importance in relation to each other using Analytic Hierarchy Process (AHP).

		j												
		CF1	**PF1**	**CF2**	**PF2**	**CF3**	**CF4**	**CF5**	**CF6**	**CF7**	**CF8**	**CF9**	**CF10**	**CF11**
i	**CF1**	1,00	1,00	3,00	1,00	3,00	5,00	3,00	9,00	1,00	5,00	5,00	2,00	1,00
	PF1	1,00	1,00	3,00	1,00	1,00	7,00	5,00	9,00	1,00	7,00	5,00	1,00	1,00
	CF2	0,33	0,33	1,00	0,20	0,20	5,00	1,00	5,00	0,20	7,00	5,00	2,00	0,11
	PF2	1,00	1,00	5,00	1,00	3,00	5,00	5,00	9,00	1,00	7,00	3,00	1,00	1,00
	CF3	0,33	1,00	5,00	0,33	1,00	7,00	5,00	7,00	1,00	7,00	3,00	0,33	1,00
	CF4	0,20	0,14	0,20	0,20	0,14	1,00	3,00	5,00	0,14	1,00	0,14	0,11	0,11
	CF5	0,33	0,20	1,00	0,20	0,20	0,33	1,00	5,00	0,11	1,00	0,14	0,11	0,11
	CF6	0,11	0,11	0,20	0,11	0,14	0,20	0,20	1,00	0,11	0,14	0,20	0,14	0,11
	CF7	1,00	1,00	5,00	1,00	1,00	7,00	9,00	9,00	1,00	9,00	3,00	5,00	5,00
	CF8	0,20	0,14	0,14	0,14	0,14	1,00	1,00	7,00	0,11	1,00	0,14	0,20	0,11
	CF9	0,20	0,20	0,20	0,33	0,33	7,00	7,00	5,00	0,33	7,00	1,00	0,14	0,11
	CF10	0,50	1,00	0,50	1,00	3,00	9,00	9,00	7,00	0,20	5,00	7,00	1,00	0,11
	CF11	1,00	1,00	9,00	1,00	1,00	9,00	9,00	9,00	0,20	9,00	9,00	9,00	1,00

1: Function i and j are of equal value

3: Function i has a slightly higher value than j

5: Function i has a strongly higher value than j

7: Function i has a very strongly higher value than j

9: Function i has an absolutely higher value than j

Reciprocals: If function i has a lower value than j

Figure 18: AHP [44]

Finally, a diagram has been made to see clearly the importance of every functions according to their weighted priority.

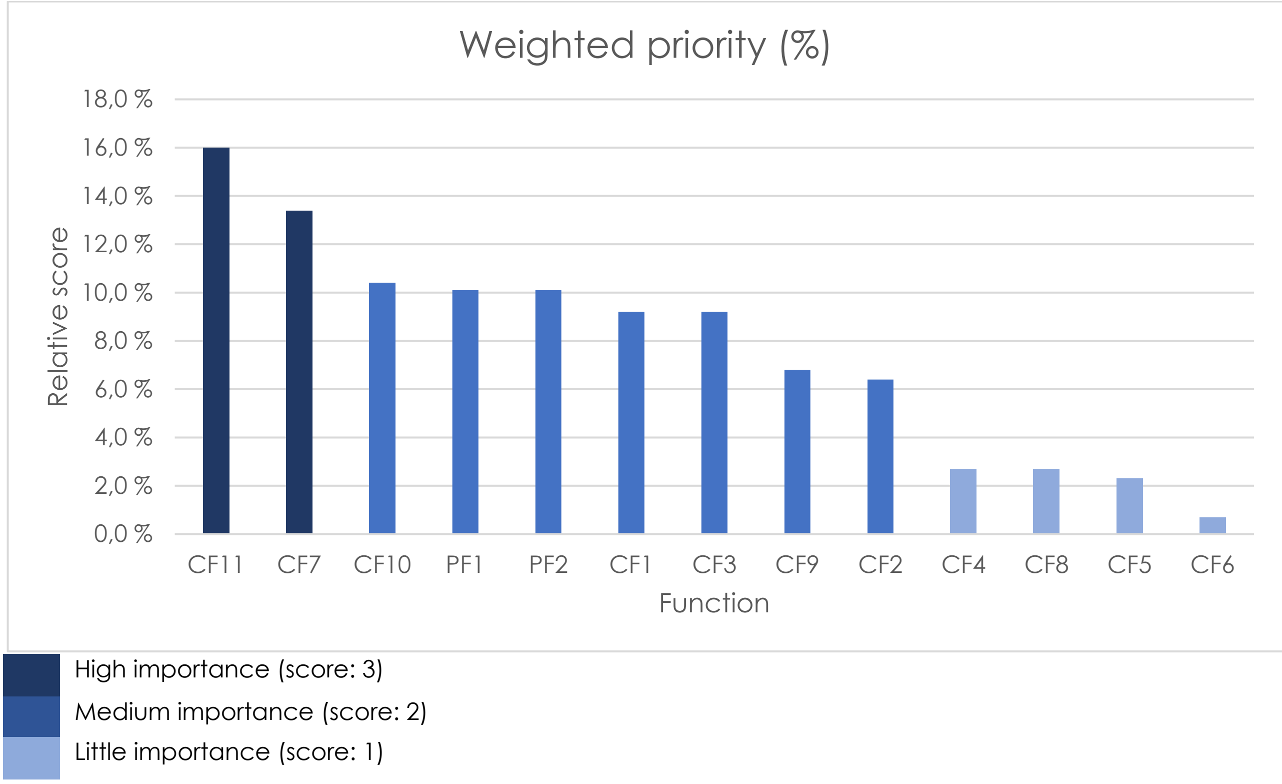


Figure 19: Distribution of the importance of functions according to their weighted priority [44]

As a conclusion, it can be seen that CF11 "Follow laws and regulations" and CF7 "Consist of materials that are compatible with food and nontoxic" are functions related to safety and are weighted most important. Moreover, functions regarding the packaging's ability to hold on its content and have good barrier properties and sealing properties, in addition to protective functions, are of high importance. These are functions that will be in focus during the packaging development.

Further, the needs and functional requirements were translated into measurable assessment criteria, which then were compared with commonly used packaging materials in terms of suitability.

Table 4: Table of the different functions, their assessment criteria, their level of criteria and their flexibility. [44]

Function	Level of importance	Function assessment criteria	Level of criteria	Flexibility
CF1 Contain the food product	2	C1 Volume	~238 cm^3	1
PF1 Be a barrier to the loss or gain of moisture and gas	2	C2 Leak free seal	Heat-sealable material Sealing width $\sim 10\ mm$ Film thickness $\leq 0{,}5\ mm$	0 1 1
		C3 High moisture barrier	WVTR $< 20\ \mathrm{g}/m^2\ 24h$ (38 °C, 90% RH, $25\ \mu m$ thickness)	0
		C4 High gas barrier	OTR $< 40\ \mathrm{cc}/m^2\ 24h\ atm$ (25 °C)	0
		C5 High density	Density $> 0{,}93\ g/cc$	1
CF2 Protect the food product from damage in distribution and storage	2	C6 Strong film material	Tensile strength $> 8\ \mathrm{MPa}$ Elongation at break $> 200\ \%$ ($25\ \mu m$ thickness)	1 1
		C7 Withstand freezing temperature	Service temp. -20°C to 10°C Glass transition temp. < -20°C	0 1
PF2 Preserve the food product from natural deterioration	2	C8 Drip loss control	Absorbent pad	2
CF3 Protect the food product from external environment	2	C7 Withstand freezing temperature	Service temp. -20°C to 10°C Glass transition temp. < -20°C	0 1
CF4 Communicate information about the food product	1	C9 Mandatory information	Ingredients, manufacture, weight, allergens	0
		C10 Printable	Printable material	2
CF5 Present the product so that it is appealing to the consumer	1	C11 Visualizes the food content	Transparent film material	0
		C8 Drip loss control	Absorbent pad	2
CF6 Be convenient and easy to handle for the package handlers	1	C1 Volume	~238 cm^3	1
		C12 Weight	~250g	2
CF7 Consist of materials that are compatible with food and nontoxic	3	C13 Nontoxic	Nontoxic material	0
CF8 Be convenient for consumers by being easy to open, empty and sort for waste management	1	C14 Easy sorting of materials for waste handling	1-3 material types	1
CF9 Limit environmental impact	2	C15 Biobased	Biobased material	2
		C16 Recyclable	Recyclable material	2
		C17 Biodegradable	Biodegradable material	2
CF10 Have an adequate sealing	2	C2 Leak free seal	Heat-sealable material Sealing width $\sim 10\ mm$ Film thickness $\leq 0{,}5\ mm$	0 1 1
CF11 Follow laws and regulations	3	C18 Follow EU Compliance for Food Packaging Regulations	Regulation (EC) No. 1935/2004	0
			Regulations (EC) No. 2023/2006	0
		C19 Follow Norwegian laws and regulations	The Food Contact Regulation/ Matkontaktforskriften	0

Level of flexibility:
0: Not flexible
1: Not very flexible
2: Flexible

7. Concept generation

In the literature and also investigating the existing packaging solutions we have seen that there are plenty of different packaging regarding to colours, materials, sizes, and shapes that could suit to pack salmon.

For being practical it is obvious that the new designed packaging will have to be manufactured in the existing machines, otherwise another machine should be designed with the effort and also economical cost that this implies. Nevertheless depending of the country that the product is sold would be a good consideration to diminish the size of the packaging due to the salmon prices and also cultural habits as the younger consumers and single-households [45].

Also, it is seen that aluminium trays are comfortable because enables the consumer to remain the fillets in the tray when cooking in oven or microwaves. Despite of that, they are not the best in terms of being environmentally friendly so is good to consider using eco-friendly materials for your packaging trays such as biodegradable plastics, recycled paper, or even plant-based materials. This will not only be good for the environment but will also appeal to environmentally conscious consumers.

With all the data collected several packaging have been sketched and are showed in the images below.

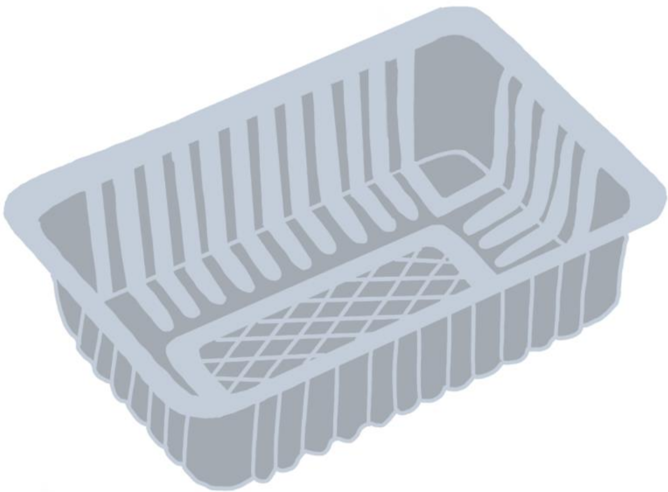


Figure 20: Sketch of a plastic/aluminium tray with a film barrier

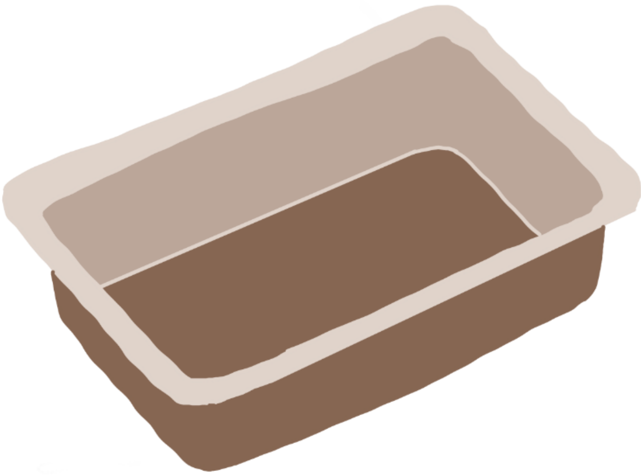


Figure 21: Sketch of a cardboard tray with a film barrier

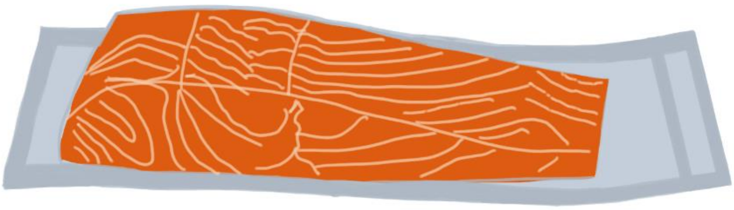


Figure 22: Sketch of a plastic vacuum packaging

8. Concept selection

Different packaging materials were compared to the functional criteria for packaging of SGS-treated salmon to identify the most promising concepts. The materials were assigned a score between 1 and 3 depending on whether the material meets the assessment criteria or not. Then, the scores were multiplied with the importance score of the different criteria. The total score for each solution allows for determine the most suitable materials to use in vacuum packaging and MAP.

8.1 Film material for MAP and vacuum packaging

Table 5: Assessment of suitability of cover film material [44]

Functional criteria	Level of importance (a)	LDPE		LLDPE		HDPE		OPP		PET		PA		EVOH	
		Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b
C2 Leak-free seal	2	3	6	3	6	2	4	1	2	1	2	2	4	-	-
C3 High moisture barrier	2	3	6	3	6	3	6	3	6	2	4	1	2	1	2
C4 High gas barrier	2	1	2	1	2	1	2	1	2	1	2	3	6	3	6
C5 High density	2	2	4	2	4	3	6	1	2	3	6	3	6	3	6
C6 Strong and flexible film material	2	2	4	3	6	2	4	3	6	2	4	2	4	2	4
C7 Withstand freezing temp.	2	3	6	3	6	3	6	1	2	2	4	2	4	2	4
C10 Printable	1	1	1	1	1	1	1	3	3	-	-	-	-	3	3
C11 Visualizes the food content	1	3	3	3	3	2	2	3	3	3	3	3	3	3	3
C13 Nontoxic	3	3	9	3	9	3	9	3	9	3	9	3	9	3	9
C15 Biobased	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
C16 Recyclable	2	3	6	3	6	3	6	3	6	3	6	3	6	3	6
C17 Biodegradable	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Total score			51		53		50		45		44		48		47

Level of importance score: 1-3 (1: Little importance, 2: Medium importance, 3: High importance)
Material suitability score: 1-3 (1: Unsuitable, 2: Suitable, 3: Very suitable)

It can be seen that PE, with LLDPE contributing to the highest score, is the most suitable alternative when all functional criteria in regard to film material are considered. Nevertheless, as PE have bad barrier to gases, it will not be sufficient to use as monolayer. PA contribute to the second highest score, behind the PE materials. As it offers high barrier to gases, a multilayer film of PA and PE would contribute to barrier both for vapor and gases.

8.2 Tray material for the MAP packaging

Table 6: Assessment of suitability of tray material [44]

Functional criteria	Level of importance (a)	Aluminum		HDPE		PET		OPS		Cardboard (coated)	
		Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b	Material score (b)	a*b
C4 Leak-free seal	2	3	6	3	6	1	2	3	6	3	6
C5 High moisture barrier	2	3	6	3	6	2	4	1	2	1	2
C6 High gas barrier	2	3	6	1	2	2	4	1	2	1	2
C10 Withstand freezing temperature	2	3	6	3	6	3	6	3	6	3	6
C18 Nontoxic	3	3	9	3	9	3	9	3	9	3	9
C20 Biobased	2	1	2	1	2	1	2	1	2	2	4
C21 Recyclable	2	3	6	3	6	3	6	3	6	1	2
C22 Biodegradable	2	1	2	1	2	1	2	1	2	1	2
Total score			43		39		35		35		33

Level of importance score: 1-3 (1: Little importance, 2: Medium importance, 3: High importance)
Material suitability score: 1-3 (1: Unsuitable, 2: Suitable, 3: Very suitable)

It can be seen that the aluminium tray has contributed at the maximum score, is the most suitable alternative when all functional criteria in regard to tray material are considered. Otherwise, the carboard coated although been the most eco-friendly option, has reached the lowest score in the functional criteria.

9. Concept testing

Based on the results of material properties and suitability, as well as market analysis and research findings from SGS-studies, packaging concepts are modelled using SolidWorks.

In recent studies has been seen that effectiveness of MA packaging is generally determined by the amount of available CO_2 that can dissolve into the food, as given by the partial pressure of CO_2 inside the package [46]. And as a consequence, when CO_2 dissolves into the salmon a volume contraction is often observed due to the flexibility of the package [46]. So, it is going to be check whether the package may experience the collapse or may blow up when the modified atmosphere in the package changes because of the dissolved CO_2 in the food.

A typical MAP packaging has been sketched in SolidWorks and consists of a semi-rigid tray 24 x 16 x 4 cm, to fit todays packaging machinery and a flexible cover of 0,1mm of film. The major part of the contraction by the pressure of the CO_2 will take place in the most flexible part, in which a strength and deformation analysis is been conducted.

To make the strength analysis an overpressure of 0,1 bar has been used. This is not the real overpressure that you have inside the packaging provided for the CO_2, but it is just a referential value to make a comparison of all the film materials studied in the concept development study and make a selection of it. Knowing which is the material with less deflection will provide information to be sure that the film stands the load and does not blow up and looks bad for the consumers when buying the package.

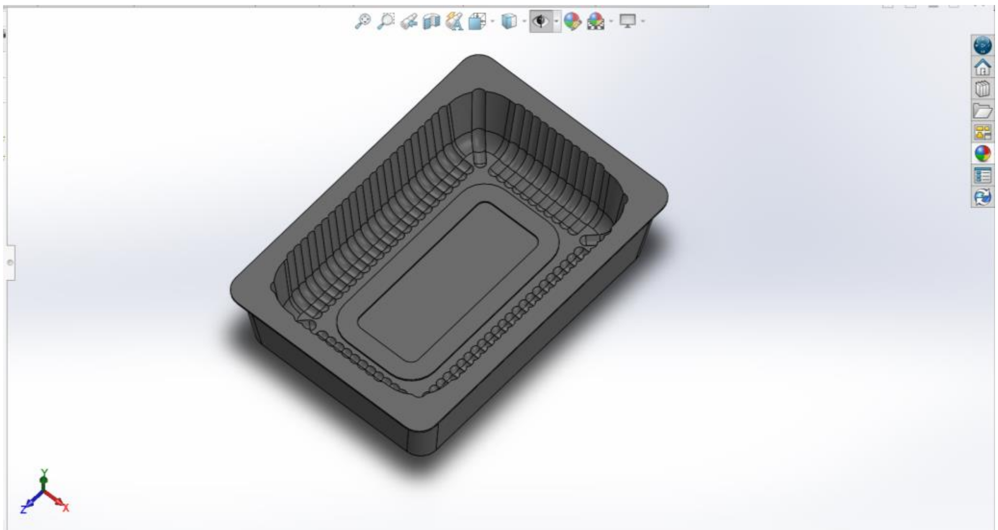


Figure 23: 3D sketch of the tray of the MAP packaging in SolidWorks

The strength and deformation analysis caused by the pressure, has been made introducing the following simplifying assumptions:

- Systems follow ideal gas law.
- There is no permeability of gas through the package material.
- Dissolution of CO_2 into the foodstuff is the dominating reaction happening within the system and neglecting solubility of O_2 and N_2.

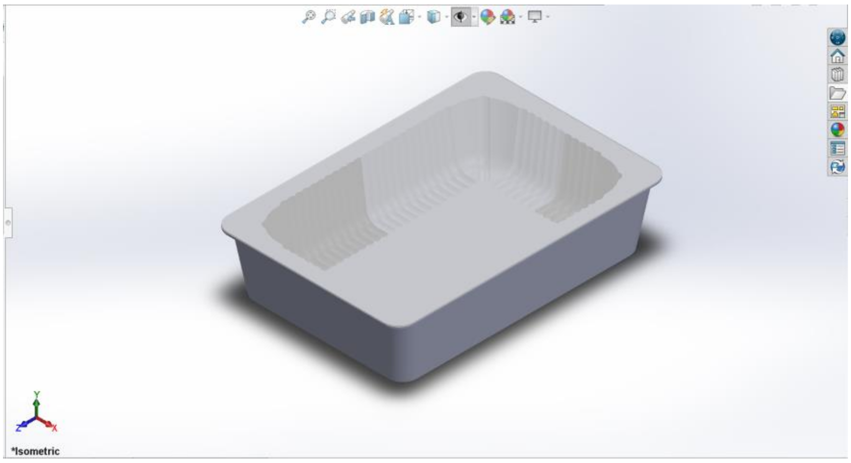


Figure 24: 3D sketch of the tray covered with film of the MAP packaging in SolidWorks

In this study boundary conditions have been defined. In this case the rigid part of the tray in the packaging has been fixed and also the part of the film that is sealed in the tray.

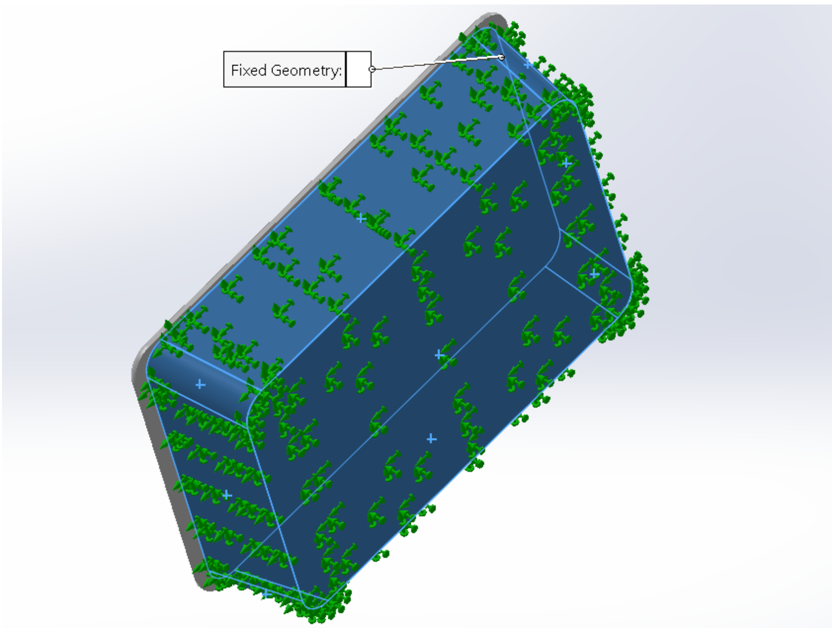


Figure 25: Boundary condition of fixed geometry in the tray

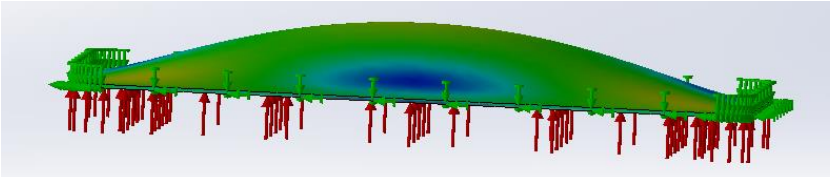


Figure 26: Fixed geometry in the sealed film (green) and the pressure inside the packaging (red)

With these assumptions and the boundary conditions the simulation in SolidWorks runs and the following plots are obtained. With them, the maximal stress and deflection for 0,1 bar of pressure can be determinate.

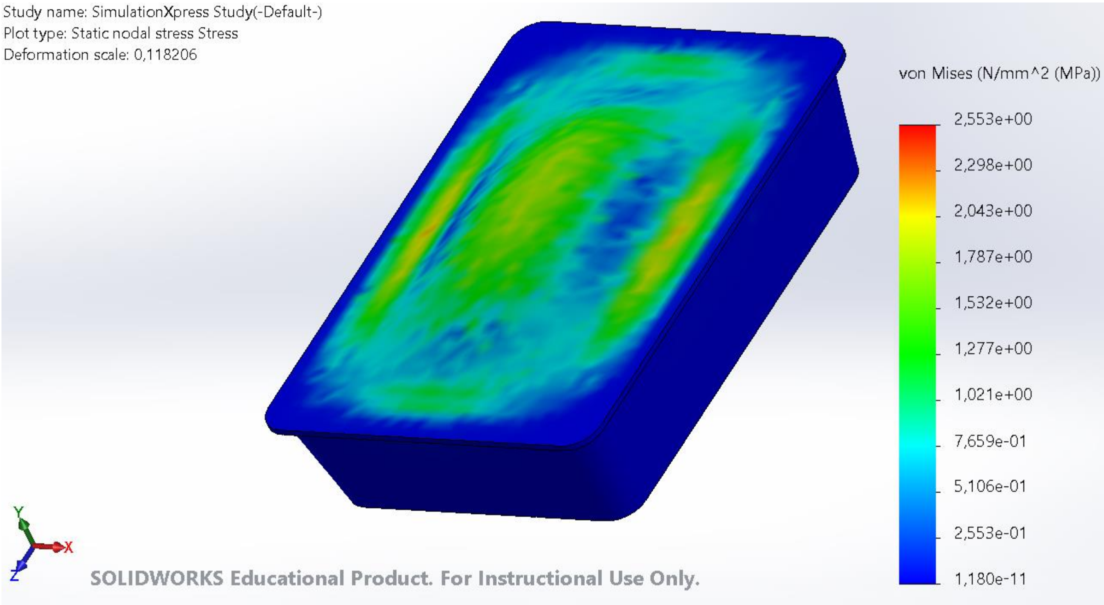


Figure 27: Example of a stress analysis in SolidWorks

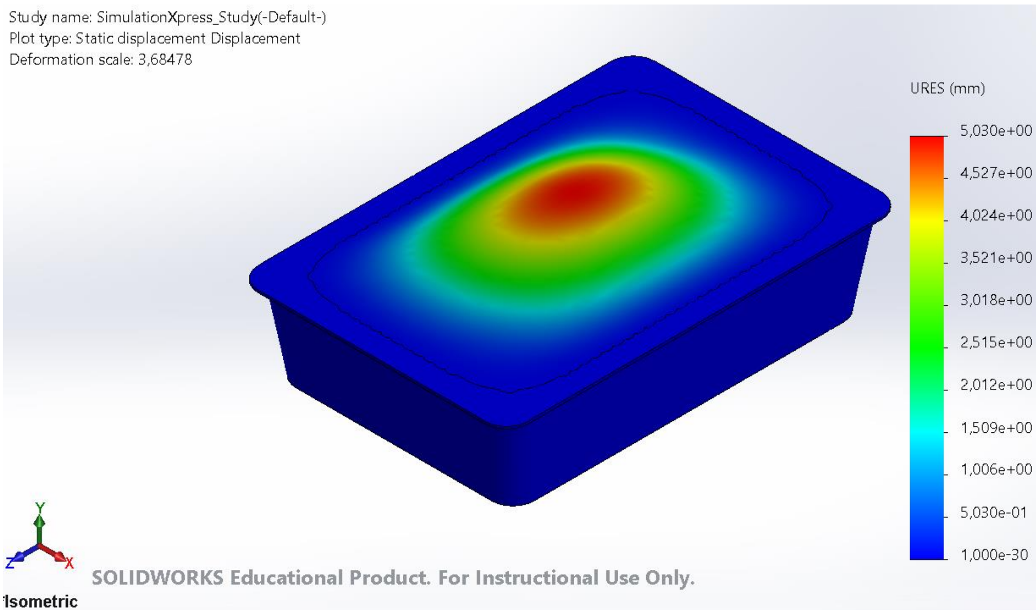


Figure 28: Example of a deflection analysis in SolidWorks

Table 7: Resume of the data obtained in the strength analysis

	LDPE	LLDPE	HDPE	OPP	PET	PA	EVOH
Tensile strength (MPa)	17	23	31	34	57,3	90	60
Young's modulus (MPa)	1290	1070	1860	1530	2960	2620	1127
Maximum stress for *P* = 0,1 bar (MPa)	1,33	1,69	2,18	1,55	2,24	2,55	1,43
Maximum deflection for *P* = 0,1 bar (m)	$2,22 \cdot 10^{-3}$	$1,52 \cdot 10^{-3}$	$2,43 \cdot 10^{-3}$	$3,48 \cdot 10^{-3}$	$7,72 \cdot 10^{-3}$	$5,03 \cdot 10^{-3}$	$1,65 \cdot 10^{-3}$

It can be seen that in terms of strength PA is the one that has the maximum amount of stress that can tolerate followed by the PET and HDPE, nevertheless the PET it also has the maximum deflection for 0,1 bar of overpressure. If we have a look on the PE, specially the LLDPE which is the one with a better score in the functional criteria we can see that in terms of deflection is also one of the bests materials.

To give greater credibility to this data obtained with the SolidWorks, a study of convergency has been done. It doesn't take much for a finite element analysis to produce results. But, for results to be accurate, it must demonstrate that results converge to a solution and are independent of mesh size. As the strength analysis is conducted in the flexible part of the packaging, the film, the mesh of the study is also there and, in this case, will be made by shells.

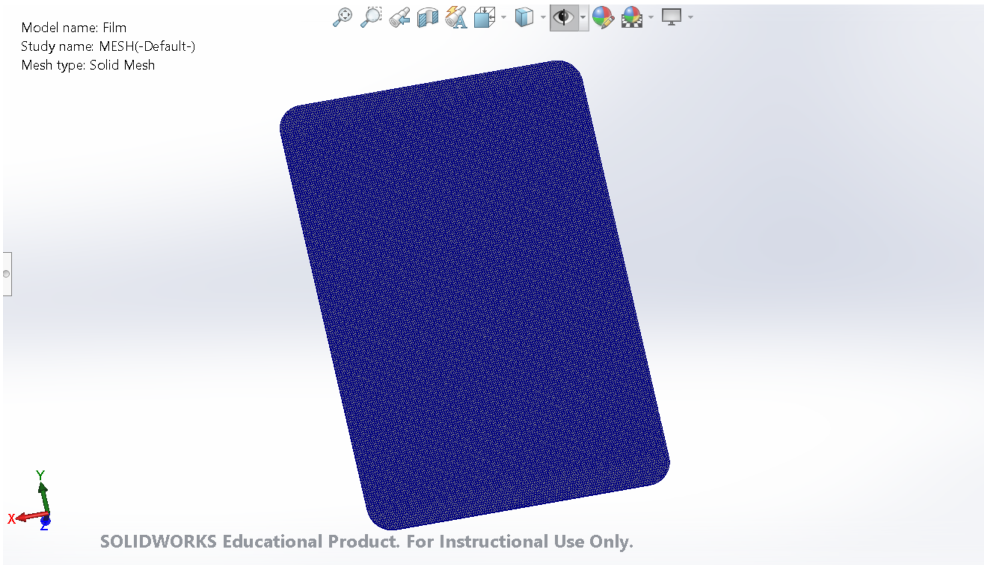


Figure 29: Film mesh with sells of 1 mm

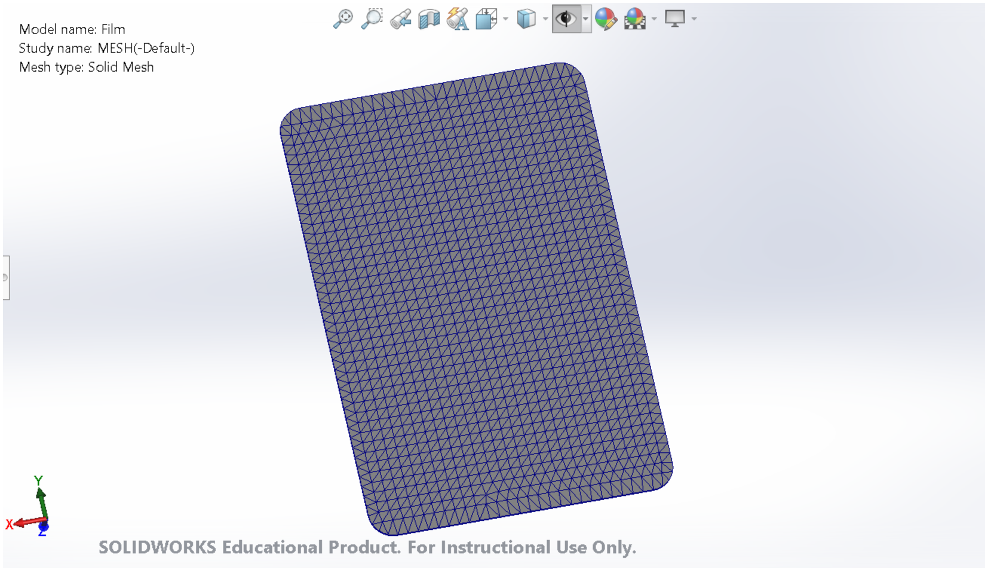


Figure 30: Film mesh with sells of 10 mm

To make the study of convergence the data of several stresses and mesh sizes will be taken with the LLDPE the material most suitable in terms of deflection and with the central point of the film in the packaging, because its where it reaches the maximum stress and deflection made by the pressure. The data collected with this study is shown in table 8.

Table 8: Data collected in the study of convergency

Number of elements in the mesh	Stress (MPa)
1043	219
2412	202
4129	195
6231	188
8553	179
16918	172
24543	168
43229	169
64582	169

Finally, has been made a plot of the stress vs. the number of elements in the mesh of the model. At a point, the response of the system converges to a solution and adding more elements has no effect on the solution. In consequence it can be assessed the convergence and demonstrate the mesh independence.

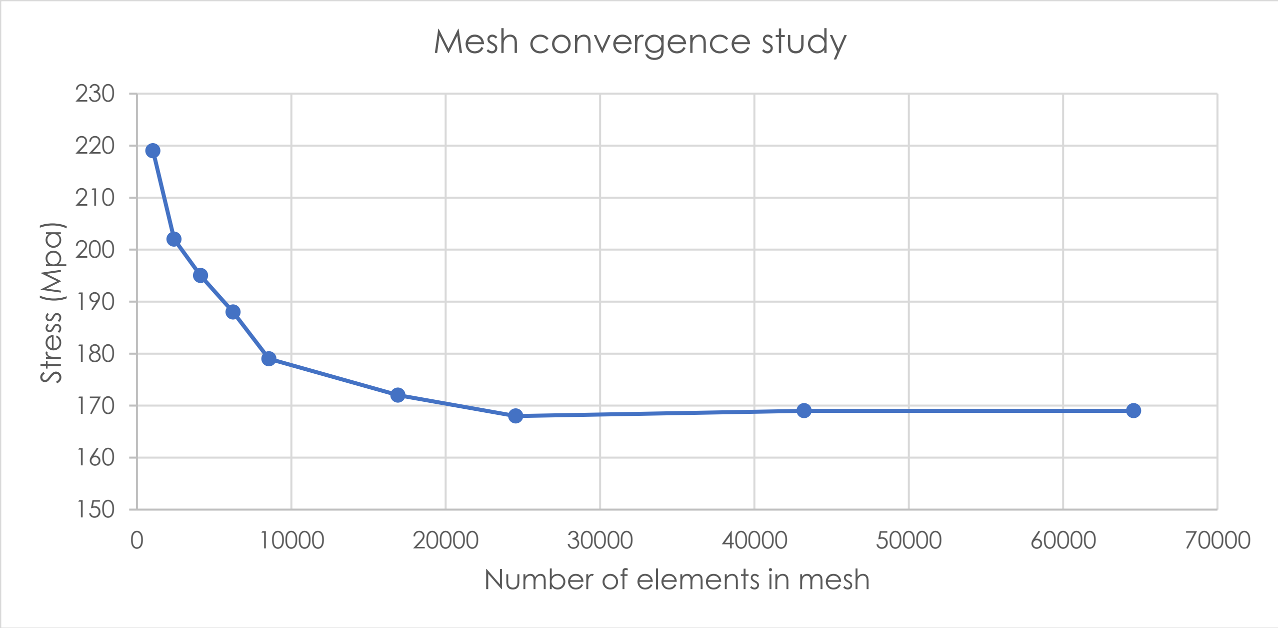


Figure 31: Graphic of the mesh convergence study

10. Discussion

This chapter includes an overall discussion about the results and knowledge obtained during all the thesis course.

Getting to know the use and functions of the SGS technology and also some literature and market analysis of the packaging commonly used in specifically the market of Norway was primordial for this thesis. It has been seen that many different types of packaging for salmon are existing these days, but all of them can be overall classified in MA-packaging or vacuum packaging according to the atmosphere inside the package. Moreover, the shape and form of the packaging is changing depending on the way they are manufactured, nevertheless, almost all the Norwegian brands of salmon are using the same machines for packaging all the packaging trays used in MAP packaging are having the same dimensions (24 x 16 x 4 cm) and a volume of 1536 cm^3 changing the amount of salmon inside. In terms of the materials used for the packaging of salmon mostly plastics are used due to its good mechanical properties, but also, aluminium for being comfortable to put the tray directly in the oven and also, it is starting to be common the cardboard coated trays for being environmentally friendly.

Using a functional criteria analysis compared with the packaging materials in terms of suitability it has been reached that the film PE, with LLDPE contributing to the highest score, is the most suitable alternative when all functional criteria in regard to film material are considered. In terms of the tray, it can be seen that the aluminium tray has contributed at the maximum score. Otherwise, the carboard coated although been the most eco-friendly option, has reached the lowest score in the functional criteria.

Moreover, with the modelling made by SolidWorks and the strength analysis has been seen that in terms of strength PA is the material that has the maximum amount of stress that can tolerate. Also, the PE with the LLDPE is the one that has less deflection when is it used as a film with a pressure of 0,1 bar inside. However, the results obtained in the strength analysis are not an accurate result because is not used the real overpressure that you have inside the packaging provided for the CO_2, just a referential value to make a comparison of all the film materials and make a selection of it.

The findings of this both studies showing that LLDPE is the most suitable material for an SGS treated salmon packaging provide valuable insights for industry professionals and researchers interested in enhancing the shelf-life of perishable food products through effective packaging solutions.

11. Conclusions

In this thesis is been addressed the problem of the waste of food specially in the food industries one of the bigger contributors of it. Extending the shelf-life of food products can reduce food loses along production and supply chains, so that's why, the main focus of this thesis is developing of a packaging to preserve a certain amount of SGS-treated food, especially salmon, for a certain time in a good quality.

To achieve the general aim of developing an optimal packaging for SGS-treated salmon a concept development study has been successfully conducted to enable an industrial implementation of the product.

So as to achieve the goals of this project that are stated at the introduction of the thesis, several procedures were done. On the first place the study of the SGS technology and the most commonly packaging used and its materials and properties were mapped thanks to literature research and also a market analysis made in the Norwegian supermarkets.

With all that knowledge has been proceeded to identify the packaging requirements using a functional analysis as the Octopus diagram which were translated into measurable assessment criteria and then were compared with the packaging materials and its properties in terms of suitability and several packaging solutions have been sketched and modelled using SolidWorks. Finally, a strength analysis has been conducted not only to determine which of the materials is better to support the contraction in the film layer due to the pressure of CO_2 inside the packaging, but also, to provide a comparison to the results obtained in the functional criteria study.

To sum up and as an overall analysis of the procedures exposed above, I consider that the goals of the thesis were reached.

11.1 Further work

This thesis is a theoretical study about how should be a packaging for containing SGS treated salmon all the experimental part could be done as a future work to provide a deeper analysis on the ideal packaging. More knowledge is needed to understand complex and physical phenomena.

There are some ideas that I would have liked to try during the development of the product that could make a huge contribution on it:

1. Making the strength analysis with the real overpressure inside the packaging will provide an accurate result about the amount of deflection that the film of the packaging will experience with it.

2. It could be interesting to prototype the packaging solutions proposed in a theoretical way in this thesis. Prototyping the packaging will provide more accurate data in terms of the strength analysis than the theoretical analysis made with the SolidWorks to distinguish in more complex problems in all the regions of the product.

3. A storage trial could be also very helpful to establish fairly accurately shelf lives of the salmon inside the packaging, which could then be expressed either as the date of minimum durability of the product and compare which material provides a larger shelf life of the salmon.

4. This thesis has been mainly focused on the packaging of SGS treated salmon leaving the study of other foods outside the scope of the thesis, so continue studying other foods treated by the SGS technology will also contribute in more knowledge and a better achievement of the perfect packaging in terms of SGS treated food.

To conclude, the data obtained in this thesis regarding to SGS treated salmon packaging are believed to be a very useful tool for further studies to improve this product and generate the most suitable one, build a physical prototype and therefore, contribute to get a step closer to reduce food waste.

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