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Process Engineering for Upcycling of Shell By-product

A Study in the Valorisation of Mussel Shells in the European
Union

Master's thesis in Production Engineering

MAGNUS OLANDER

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY

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A Study in the Valorisation of Mussel Shells in the European Union

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Department of Industrial and Materials Science
Division of Production Systems
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MAGNUS OLANDER

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Supervisor: Roland Örtengren, Department of Industrial and Materials Science
Examiner: Björn Johansson, Department of Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Crushed mussel shells in various sizes.

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MAGNUS OLANDER
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

The topic of blue bio-economy has been gaining a lot of interest recently. Practised responsibly, mollusc aquaculture is a highly sustainable food source that could play an essential role in securing food availability globally in the future. However, when refining molluscs and specifically mussels for their meat, a large side stream of shells is created that has to be taken care of to make this food source truly sustainable. Historically, mollusc shells have been used for several applications in many different cultures, and new research on this topic has been seeing higher volumes recently. This paper will research what these applications are, what laws and regulations apply to the use of mussel shells in the European Union, and how a valorisation process could be designed in the factory setting of Musselfeed AB.

Keywords: Mussel shells, Mollusc shells, Shell valorisation, Blue bioeconomy, Shell waste

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Magnus Olander, Gothenburg, June 2023

List of Acronyms and Abbreviations

Below is the list of acronyms and abbreviations that have been used throughout this thesis listed in alphabetical order:

1069/2009	Regulation (EC) No 1069/2009 of the European Parliament and of the Council
142/2011	Commission Regulation (EU) No 142/2011
CaCO ₃	Calcium Carbonate

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1

Introduction

1.1 Background

Musselfeed is a company within the emerging blue bio-economy market. Through an innovative process method, the meat of discarded mussels is refined into a nutritious powder ingredient with long shelf life, which can be used in food or feed applications [2].

Mussels provide an ecosystem service in the ocean, by helping to reduce the effects of eutrophication, and when using farmed mussels, a circularity of nutrients between sea and land is established [2]. Musselfeed's products contribute to a sustainability triple-win - by creating demand for cultivated mussels that benefit the oceans, reducing food waste and turning it into value, and providing an ingredient with a low environmental footprint with a high nutrient density that can replace less sustainable raw materials [2].

The mussel meat is separated from the shell in the manufacturing process, and the shells thus become a side stream in large volume. Shells have several uses, for example in agriculture, gardening, chicken production, water purification, etc [2], and Musselfeed wants to commercialise this shell fraction in 2023 which requires further processing of the shells and an expanded process line.

To make industrial mussel farming completely sustainable, all aspects of the production must be taken into account, including the by-product of mussel shells [3]. Practised responsibly, shells from mussels and other mollusc aquaculture can be valorised and turned into products, both new or as a substitute for less environmentally friendly materials in current products [3].

In this thesis, current and future applications for mussel shells will be researched, what laws and regulations are related to this in the European Union and Sweden, as well as how a valorisation process could be implemented in the factory setting of Musselfeed AB.

1.2 Aim and purpose

The aim of the master's thesis project is to design a production line adjacent to the existing meat refining line where the mussel shells would be processed and refined

into a product that Musselfeed would be able to sell. A prototype will be created in the 3D simulation software for manufacturing Visual Components to visualise a solution. It will be required to research what current and future applications and products made from mussel shells exist as well as if they are feasible for Musselfeed AB. The purpose is to create a rigid guideline grounded in current research and knowledge of laws and regulations so that in the future Musselfeed AB should be able to start valorising mussel shells by using this thesis.

1.3 Research Questions

- What current and future applications are there for mussel shells?
- What laws and regulations apply to the valorisation of mussel shells in the EU and Sweden?
- How could a valorisation process look and fit into the current factory of Musselfeed AB in Ellös?

1.4 Delimitations

- The prototype does not need to cover more than five different product groups.
- The study is limited to European Union.
- Due to time limitations, the prototype will not be able to be tested in the current factory setting.

2

Methods

In this chapter, the methods used for each of Sections 3 through 6 will be described. However, as most methods came as a direct result of the previous chapter, they will be more thoroughly described in each chapter.

2.1 Applications of mussel shell

For the literary research on current and future applications of mussel shells, information was mostly found by searching online research databases and other databases. Databases that were searched were amongst others: ResearchGate, ScienceDirect, EBSCOhost, and Google Scholar. Further, a few papers were provided by Musselfeed, where the papers had been written in collaboration with the company before. Search phrases were amongst others: mussel shells, mollusc shells, shell valorization, shell valorisation, mussel poultry, mollusc liming, etc. Articles that were about mussel or other mollusc shell valorisation or applications were then gathered, summarised, and further investigated.

2.2 Regulation (EC) No 1069/2009 of the European Parliament and of the Council

The laws and regulations from the European Union and Sweden were studied thoroughly to make sure that the solutions would be legal. To ensure that all laws and regulations were understood and would be followed correctly, a dialogue was had with an employee of Jordbruksverket.

2.3 Decision on Processing Method and Application

To decide what processing method to use and what applications to focus on, the findings from the two previous chapters were presented and discussed with Musselfeed. With the processing method decided on, a small test was run at the factory to see if the chosen method would have any impact on the aesthetic of the mussel shells.

2.4 Designing Production System

The required data for all processes were calculated and summarised to know what machines and components would be required in the prototype. The required parts were found and decided on through collaboration with the company, through search engines, as well as through guidelines and product sheets provided by companies. The parts were modelled using the CAD software CATIA V5 and imported into the virtual factory software Visual Components to create the prototypes. CATIA V5 and Visual Components were chosen as software as they were familiar and had been used for similar projects in the bachelor of the student.

3

Applications of Mussel Shell

Today there is a plethora of different use cases and applications for mussels and other mollusc shells [3]. In this section, the most common current products and applications of mussel shells will be described, as well as a few that are still in the research phase.

3.1 Calcium enrichment for poultry

Today mussel shells are used as a calcium supplement for all livestock types, especially for egg-laying poultry, and are one of the dominant markets for mollusc shell valorisation [3]. With mussel shells being rich in calcium, it is used as a supplement to increase the bone strength of livestock [3]. Calcium is further essential for egg-laying hens since it's also the main element in eggshells, and is, therefore, a staple of egg-laying hens' diet [4]. Calcium supplement for poultry has been widely used over the last decades [5] where CaCO_3 has been sourced from limestone mining [3], and oyster shells, which in almost all regards have the same chemical structure as mussel shells [6], have been used for more than 100 years [5]. Several studies have investigated the use of mollusc shell-derived CaCO_3 as a replacement for traditional limestone-enriched diet on poultry, and have found that it can not only be a cheaper source for CaCO_3 , but also that it in the right crushed mollusc shell can perform equally to limestone in a number of different parameters on the poultry [3][4][7]. Studies conducted in 1971 [3] showed that partially substituting limestone sourced CaCO_3 with crushed mollusc shells both increased egg production and the strength of the eggs laid by the hens. Another study conducted in 1990 [3] showed that substituting limestone with crushed mollusc shells had no adverse effect on the strength of the egg shells nor the production of eggs but that it did increase the weight gain of the hens, a desirable trait on egg-laying poultry [3]. A study conducted in 2003 found that there were no discernible differences between using bivalve shells, periwinkle shells, oyster shells, or limestone as calcium supplements for egg-laying poultry in terms of egg production or eggshell strength [8]. A more recent study conducted in 2012 by Çath et al.[9] showed that with more modern feed mixes, the addition of mollusc shells to traditional feed mixed with limestone supplements did significantly improve the performance of egg-laying hens.

It is further advantageous to utilise mollusc shells as an environmental enrichment and calcium source for floor-housed laying hens to prevent feather-picking, which results in impaired welfare and economic losses [10]. Feather picking is a behaviour

that can be found in egg-laying poultry which can arise as an effect of insufficient foraging or scratching material for commercial floor-housed laying hens [10]. Several studies have proved that environmental enrichments such as litter can reduce the behaviour of feather picking [10]. Moreover, enriching the environment by stimulation from foraging and pecking for mollusc shells have shown to enhance the feather condition of floor-housed laying hens [10]. Studies have also shown that calcium particles of larger sizes than limestone-sourced calcium supplements and with lower digestibility, in comparison with ground powder, yield better eggshell quality and higher bone strength for egg-laying hens. The preferred size of the crushed shell differs between 10-20 mm [10] for the best effect on reducing feather-pecking to as small as 3 mm [10] for maximising calcium retention. The effects of less feather pecking due to larger particle sizes are likely to stem from that larger particle sizes of coarse calcium will have a longer retention time in the gizzard, and therefore providing the poultry with calcium over a longer time [10].

On average a commercial egg-laying hen will lay one egg per day and will have to consume between 2.0 and 2.5 grams of pure calcium each for proper eggshell creation [3][10]. Consequently, egg farming will have a high demand for calcium in layer-feed to meet the demand for calcium intake for egg-laying hens [3][4][10]. For floor-housed laying hens the average retention rate of calcium is 50% which would equate to that an average-sized hen would require to consume between 4-5 grams of pure calcium each day [3][10]. With CaCO_3 consisting of on average 40% calcium this would mean that on average a hen would have to consume between 10 and 12.5 grams of CaCO_3 per day [3][6].

To be able to use mollusc and mussel shells as a calcium enrichment for egg-laying poultry, one would have to follow the regulation as outlined in 1069/2009 [11] which will be discussed later in the thesis. It is also important to take into consideration the distance between where the shells are farmed and valorised, and the distance between where the shells are valorised and used as a calcium supplement, where one study shows that the total for these two should not exceed 400 km [3]. This distance is calculated so that the environmental impact would be less than that of using limestone-sourced calcium, but also so that the economic impact would be less than that of traditionally sourced calcium [3].

3.2 Agricultural liming agent

The second big market for using valorised mussel- and other mollusc shells is yet again the agricultural sector, but this one involves spreading the calcium-rich shells on soil to neutralise acidification, nutritify the soil, and reduce metal contamination [3][12]. The practice, generally referred to as liming since it traditionally has utilised limestone as its calcium source, dates back to the first or second century BCE, and has been and still is prevalent in a variety of societies [3]. Today the most common source of liming agent in organic agriculture is nitrogen, with high-quality phosphorus being a close second but declining [12]. Liming has proved to have a variety of positive effects on the productivity of agricultural crop yields and some studies have

even shown that it can have a net positive effect on soil quality [13]. Since the main goal of liming is to have an alkaline effect on the acidity of the soil and neutralise the pH, other alkalies such as calcareous material, and specifically crushed mollusc shells have proved to have similar effects on the soil [3][14].

One study produced in the Republic of Korea in 2008 wanted to see the effect that applying crushed oyster shells to acidic soil instead of a traditional liming agent would have on the yield of Chinese cabbage, soil pH, and nutrient levels of the soil [15]. In the study, it was concluded that the crushed oyster shell spread over the soil significantly increased the pH of the soil, and improved the nutritional value of the soil such as levels of available phosphate and organic matter [15]. Before the study, there were concerns that the spreading of crushed oyster shells would significantly increase the levels of salt (NaCl) in the soil, but the results showed although there was a slight increase in sodium levels (Na), there were no signs of toxicity damage in the cabbage [15]. The study further showed that the soil had increased its microbial population which in turn had increased nutrient cycling [15]. All of these above-mentioned factors are likely to have contributed to the significantly higher productivity of Chinese cabbage than if crushed oyster shells were not spread over the soil according to the study [15]. In the study, the highest productivity was achieved when 8.000 kg/ha of crushed oyster shells were spread on the soil [15]. In Galicia, Spain, the leading region in Europe for utilising mollusc- and other seashells as a liming agent thanks to their proximity to large seashell processing facilities and shellfish aquaculture sites[14] a similar study was conducted in 2009; where the results showed that if applying 9.000 kg/ha of crushed mollusc shells it would have similar positive effects short-term on the pH-levels of the soil as traditional magnesium limestone liming agents would have [3]. A further study conducted in Galicia in 2013 showed that as much as 24.000 kg/ha of crushed mussel shells had both decreased the desorption and increased the absorption of arsenic in both vineyard and forest soils and in turn reduced the risk of arsenic soil pollution on these crops [3].

Acidic soils that could benefit from liming are prevalent across large regions of Europe; but are especially prevalent in northern European countries such as Sweden and Finland and in western regions such as Galicia in Spain as is visualised in Fig 3.1 [16].

Crushed mollusc shells as a liming agent/pH buffer are not only relevant or of interest in industrial agriculture, however. Although on a smaller scale, crushed or whole mollusc shells are also of interest to gardeners and landscapers where they not only can be used as a liming agent, but double as decorative topsoil, either on its own or spread together with mulch [3][17]. Added benefits of using shells as mulch are among many: improved water retention by letting the water run through the porous surface of the shells and percolating the ground underneath, preventing bugs by deterring them with the sharp edges of shells, and also restricting sunlight that weeds can receive which can prevent their growth [17]. The use of shells in landscaping and gardening is of extra interest today when the concern for using more organic products in gardens has increased [17]. As was the case for using mussels as

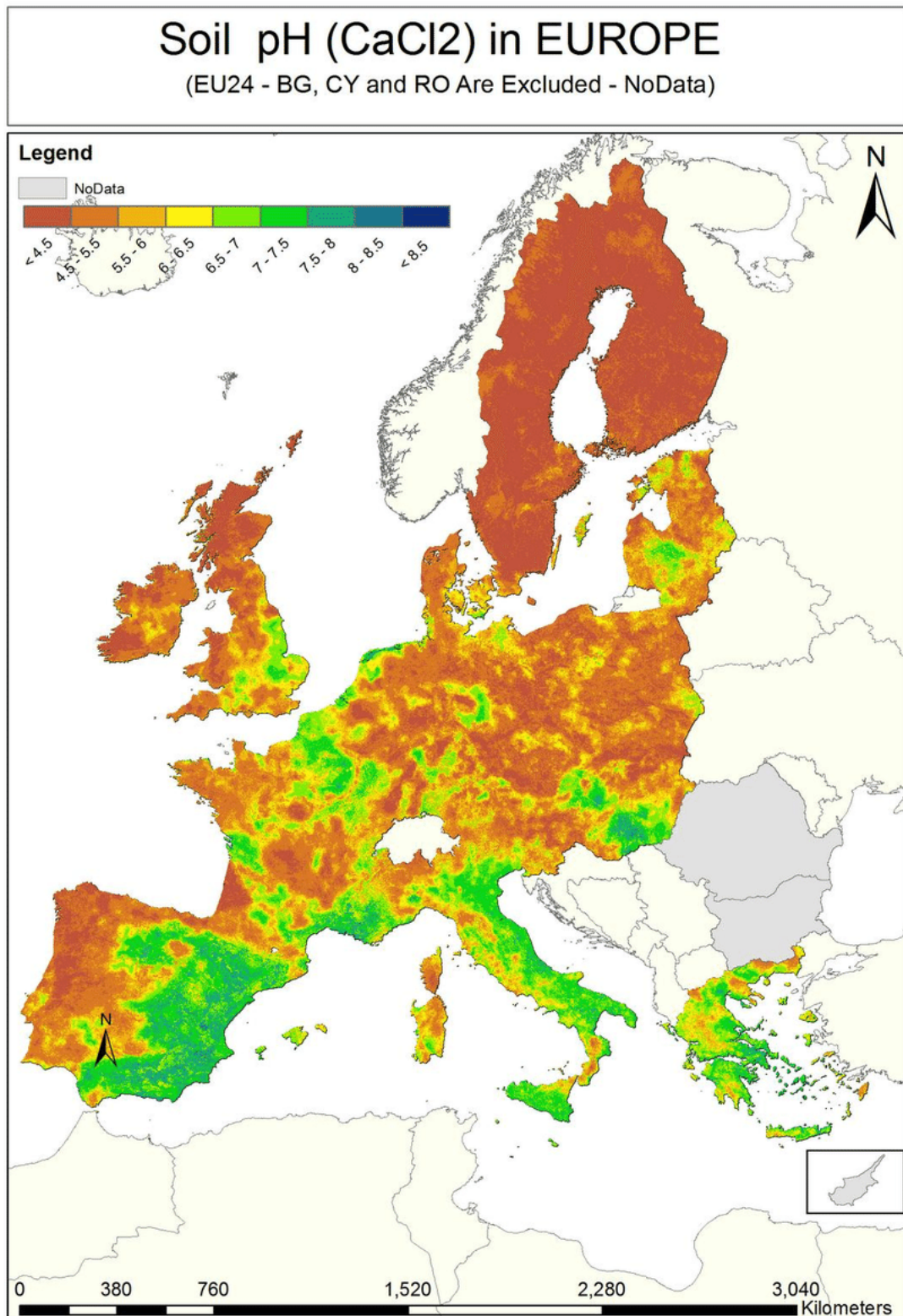


Figure 3.1: Estimated values of topsoil pH in EU-member countries in 2012

calcium enrichment for poultry, the use of mussel shells in agriculture/landscaping is too regulated by Regulation (EC) No 1069/2009 [11], if not free-from-flesh.

3.3 Construction aggregates

Shells have for a long time been utilised in construction in many a application, either on their own or as part of mixes with other materials, such as in aggregate or mortar mixes [3]. Historical examples of using mollusc shells in construction range all over the world, from Florida (USA) to seaside cities in China where oyster shells have been integrated into house walls [18]. Although many a historical case of this application can be found one should proceed with caution when considering this application today as construction materials are regulated by several stringent requirements for performance and safety as outlined in EU Regulation No. 305/2011 [3]. Today there is a project ongoing in Galicia, Spain, called *Bivalve* on the subject of "Galician bivalve shells in the field of construction", and similar research projects are likely to start in the future with the depletion of non-organic aggregate- or mortar mixes [3]. Although there likely are numerous more examples of how one could use shell aggregates in construction since it has to adhere to strict regulations and scientific scrutiny research in this subject is still in its infancy [3][18]. An example of mollusc shells in concrete can be seen in Figure 3.2.



Figure 3.2: Mollusc shells used in concrete tarmacking [1]

One such study conducted at the University of A Coruña, Galicia, Spain in 2016 showed promising results for using mussel shells as aggregates in concrete [19]. Although the results showed that there was some weight loss of the concrete over time and that the use of mussel shells reduced water permeability compared to using pure limestone or sand as aggregate, it was noted that if the mussel shells were heat-treated at 135°C for 30 min, as per 1069/2009[11], finely crushed mussel shells can be used as aggregates in plain concrete [19]. In the study, it was further argued that as long as one substituted the common aggregate with no more than 25% of shell aggregate, either as sand or gravel, or no more than 12,5% of shell aggregate if a mix of both sand and gravel was used, crushed mussel shells were suitable as aggregate for plain structural concrete [19].

3.4 Decorative

In terms of products made from valorised mussel shells the by far largest product group is mussel shells valorised in such a way that they can be used for decorative purposes [6]. An online survey conducted in 2022 by Linder[6], showed that products ranged from jewellery with integrated valorised shells to art pieces and buttons made from shells. With few shells used per product in this category, the decorative and design product group usually had the highest price per volume of shells [6]. Almost all products in this group were however sold by private vendors who had collected these shells on their own in marine environments, making the demand for selling these shells to designers uncertain [6]. Further, the shells in this category have often been through more cleaning than the other categories; such as having been soaked in chlorine or other toxic chemicals to increase the aesthetic value, on top of the regular cleaning with the one outlined in 1069/2009 [11], or being free-from-flesh [6].

3.5 Abrasive in grinding

Today the abrasives used in sandblasting usually are from raw materials from non-renewable sources. A change to waste from aquaculture, industry, or other marine sectors could severely reduce the consumption of non-renewable sources for abrasives [20]. Although no other sources for this application were found and the use of this application of mussel shells therefore still being in its infancy, one interesting article was produced where a study was conducted on the topic in 2022 [20]. The article studied whether mussel shells could be used as a replacement for traditional non-renewable abrasives in sandblasting processes [20].

In sandblasting the abrasive grits are propelled at high speeds using compressed air at the surface such that the grits will hit the surface and smooth the surface of the material. The material used as the abrasive grit is of great importance since it has to smooth the surface and remove paint, rust, or other irregularities without damaging the surface nor producing plastic deformation in the material that is being sandblasted [20]. For this reason, qualities and properties of the abrasive material used such as density, grit morphology (shape), hardness, and friability, which is the

ability for the abrasive to break down and produce new sharp edges, has to be taken into account to reach the requirements mentioned above [20]. Further, the grit's re-usability is becoming more important to increase the grit's environmental and economic feasibility of the grit [20]. Today, the usual abrasive materials for sandblasting include mineral (silicon, garnet), synthetic (glass, ceramics etc.) or metallic (steel) [11]. Although not looked into further in this study, mussel shells could prove to be feasible for other abrasive processes besides sandblasting [20].

When the mussel shells are crushed and ground, the hard sharp edges that are needed are created thanks to the high levels of calcium carbonate (CaCO_3) in the mussel shell. As the study was conducted in Spain, and the Spanish government has no own guidelines on the proper use of mollusc-production-derived by-products, it required full compliance with 1069/2009[11][20], similar to what would be needed in Sweden. In the study, three different methods for complying with 1069/2009 were tested, with one being heat treatment for 32 minutes in 135°C , and the other two being chemical treatments of Hydrogen peroxide (H_2O_2) for 25 minutes and Sodium hypochlorite (NaClO) for 25 minutes respectively [20]. The result of the study concluded that mussel shells could be utilised as a soft abrasive with medium density and hardness [20]. Further, the study showed that heat treatment for 32 minutes in 135°C proved to be the best treatment to comply with 1069/2009 since it did not damage the inner structure and therefore retained the friability of the mussel [20]. Lastly, it concluded that the (CaCO_3) crystals together with the organic matter enhanced toughness compared using to non-renewable traditional minerals as abrasive [20].

3.6 Bio-filter medium & aquarium/pond pH buffer

Much research has been done on using mollusc shells as a bio-filtration medium that would treat waste waters [3][21]. However, a lot of the research has not been conducted on using mussel shells directly as a filtration medium, but rather the use of CaO , Calcium Oxide or quicklime, which is formed through calcination [3][21]. Although it is a simple chemical process to produce CaO from CaCO_3 by heating it such that $\text{CaCO}_3 + \text{Heat} \rightarrow \text{CaO} + \text{CO}_2$, the heat requirement in the process is very high which for the purpose of this project does not lend itself well both in terms of environmental and economical feasibility [3][21]. One study has however proved that non-calcined finely ground mussel shells were able to work as a bio-filter, although not as effectively as calcined CaCO_3 , where CaCO_3 in Aragonite form rather than Calcite form was better, but a mix of both forms proved optimal [3].

The use of valorised mussel shells has also proved to be useful as a pH buffer in ponds and aquariums [3]. The principle behind this is the same as for using CaCO_3 as a liming agent in agriculture. When plants and/or animals live in an enclosed water environment, the water will inevitably over time become more and more acidic, and the alkaline effects of the CaCO_3 would help to neutralise this effect [3]. This could prove to be extra useful in outdoor ponds that can be hit by acidic rains as is shown in Fig. 3.1, and would as such become acidic even quicker if not for using a pH buffer [3]. Further, the use of mussel- or other mollusc shells could double as an aesthetic

3. Applications of Mussel Shell

feature in aquariums and ponds which in turn could give the product a higher price than non-aesthetic pH buffers [3].

Type of application	Processing required	Quantity sold	Selling price	Source
Poultry feed	Heat treated, crushed	1–25 kg/pkg	0,4€–3€ per kg	[3]
Pet bird nutrition	Heat treated, crushed	440 g–2,5 kg/pkg	0,6€–7€ per kg	[3]
Soil liming	Heat treated, powdered	22,7 kg/pkg	0.4€–0.6€ per kg	[3]
Shell aggregates	Whole shell, dried	250–1000 kg/pkg	0.3€–0.9€ per kg	[3]
	Crushed, dried	15–1000 kg/pkg	0.3€–3€ per kg	
Decorative	Whole, heat treated, chlorine-washed	Varies	Varies	[6]
Abrasive	Heat treated, crushed/ground	-	-	[20]
Bio-filter medium	Heat treated, crushed	600–1000 kg/pkg	0,4€–0,5€ per kg	[3]
Aquarium & pond pH buffer	Heat treated, crushed, chlorine-washed	5 kg/pkg	4€ per kg	[3]

Table 3.1: Summary of applications of mussel shells, processing required, as well as a collection of information on quantities sold and its respective price class

4

Regulation (EC) No 1069/2009 of the European Parliament and of the Council

Regulation (EC) No 1069/2009 is a European Union regulation and legislation that provides the rules for the handling of animal by-products that are not intended for human consumption within the European Union [11]. It is put in place to ensure that animal by-products are handled in such a way that it poses no risk to the public and animal health. Further, it provides guidelines for how the criterion mentioned in the regulation can be followed to ensure this safety [11].

The regulation describes these requirements for a wide range range of animal by-products including the shells that are a by-product of industrial mussel farming and manufacturing [11].

The main objectives of Regulation (EC) No 1069/2009 are as follows:

1. **Categorisation:** The regulation defines three different categories of animal by-products based on their potential risk to the public and animal health, and classifies them thereafter [11]. Based on the different categories it looks at several criteria and classifies the products based on the risk they pose [11].
2. **Processing requirements:** The legislation sets out strict hygiene standards and procedures for the handling, storage, and processing of animal by-products [11]. It specifies which categories can be used for certain markets and how they would have to be transported and processed to reduce the risk of harming the environment, wildlife, and human population [11]. It does however not provide any specific methods to ensure this.
3. **Traceability:** The regulations provide guidelines for how to ensure that traceability is possible throughout the whole of the production, processing, and placing on market/disposal of the product [11].
4. **Registration:** Lastly, the regulation provides the framework for the registration of organisations, companies, or other establishments that are involved in the production or processing of the animal by-products mentioned in the regulation [11]. It is in place to ensure that these establishments are complying with

the regulation and agree to regular inspections to ensure that all requirements are followed [11].

Overall, the regulation aims to ensure the safe and proper handling of animal by-products throughout the European Union to protect public and animal health, prevent the spread of diseases, and maintain environmental standards [11].

4.1 Regulation (EC) No 1069/2009 for mussels

Mussels or mussel shells are not specifically mentioned in 1069/2009, but instead fall under the category of "shells from shellfish" [11]. As almost all applications mention that one has to adhere to 1069/2009, and as 1069/2009 classifies and categorises different animal by-products into different classes and categories, it was important to know which class and category mussel shells would fall under. Shells from shellfish, and therefore mussel shells, are mentioned, classified, and categorised in 1069/2009 as following [11]:

- **p.6, (42)** - Shells from shellfish from which the soft tissue or flesh have been removed, should be excluded from the scope of the Regulation. Due to the various practices in the Community regarding the removal of such soft tissue or flesh from shells, it should be possible to use shells from which the entire soft tissue or flesh has not been removed, provided such use does not lead to a risk arising to public and animal health. National guides to good practice could assist in the dissemination of knowledge regarding proper conditions under which such use would be possible.
- **p.11 2(2)(f)** - *Article 2 - Scope:* 2. This Regulation shall not apply to the following animal by-products: (f) shells from shellfish with the soft tissue and flesh removed;
- **p.15 10(k)(i)** - *Article 10 - Category 3 material:* Category 3 material shall comprise the following animal by-products: (k) the following material originating from animals which did not show any signs of disease communicable through that material to humans or animals: (i) shells from shellfish with soft tissue or flesh;
- **p.17 14(h)** *Article 14 - Disposal and use of Category 3 material:* Category 3 material shall be: (h) in the case of shells from shellfish, other than those referred to in Article 2(2)(f), and egg shells, used under conditions determined by the competent authority which prevent risks arising to public and animal health;

Article 14(h) in 1069/2009 [11] says that the disposal of mussel shells with soft tissue or flesh should be done under conditions determined by the competent authority, which for Sweden would be Statens Jordbruksverk (colloq. Jordbruksverket, Eng. Swedish Board of Agriculture). The regulation for the disposal of animal by-products in Sweden would be Föreskrift SJVFS 2014:43 which is: *Föreskrifter om ändring i Statens jordbruksverksföreskrifter (SJVFS 2006:84) om befattning med animaliska biprodukter och införsel av andraprodukter, utom livsmedel, som kan sprida smittsamma sjukdomar till djur;* [22]. However, the only mention of mussel shells, or mollusc shells for that matter, is in paragraph 15 for *Användning av organiska*

gödningsmedel och jordförbättringsmedel (Eng. Use of organic fertilisers and soil improvement agents) that says that "15 b § *Skal från blötdjur och tagghudingar får spridas på mark. (SJVFS 2014:43).*" (Eng. 15 b § Shells from molluscs and echinoderm may be spread on land) [22].

4.1.1 Regulation (EC) No 1069/2009 in relation to Musselfeed

As there is no guarantee that the shells will be free-from-flesh after the refining process before the separation of meat and shell, and the shells would be covered in smaller volumes of meat after the separation of meat and shells in the machine, the mussels shells in the case of Musselfeed AB would fall under Category 3 in 1069/2009, and more specifically Article 10(k)(i) [11]. As Article 14(h) in 1069/2009 [11] says that the disposal of mussel shells with soft tissue or flesh should be done under conditions determined by the competent authority, and the only stated application for this category in SJVFS 2014:43 [22] is that mussel shells may be spread on land for agricultural purposes some questions arose as there clearly are other uses for it in Sweden, eg. poultry feeds [10]. Further, the founder of Musselfeed AB Odd Lindahl who have 30+ years of experience in the mussel industry, stated that mussel shells have been used in many different applications in mollusc industries in Sweden and other European countries without following the regulation. Although the use of mussel- and other mollusc shells might not be thoroughly regulated and the regulation not followed to its fullest extent in Sweden, this option was not viable for this project as the stakeholders (Musselfeed AB) wanted full compliance with all regulations. Therefore, the decision to contact Jordbruksverket with questions on how to comply with the regulation in Sweden regarding mussels was made.

4.1.2 Discussion with Jordbruksverket

Jordbruksverket was contacted through the question form that is provided on their website [23], and the whole form text can be seen in Appendix A (in Swedish). In the form, it was asked if it was possible to reach a person at Jordbruksverket who would be able to answer the questions that arose during the study of the regulation as well as literature research and discussion with the company. The form was almost immediately forwarded to a person working as an Infection Protection Manager at the Animal Health Unit of Jordbruksverket. The questions from the form were answered only with that for mussel shells that were free-from-flesh fell under category 2.2(f) and were therefore out-of-scope, and if more thorough answers were wanted that more information would have to be given. Consequently, a follow-up email was sent to the person at Jordbruksverket with more information as can be seen in Appendix B. Unfortunately, for unknown reasons, the reply to this email took a month even though multiple attempts to get in contact with the person at Jordbruksverket were made. Ultimately, the answers to the questions were made in the email and can be seen in Appendix B as well. The conversation will be summarised below in Table 4.1 with the questions asked summarised in the left column and the answers summarised in the right column.

Question	Answer
<p>In Article 14(h) mention that "in the case of shells from shellfish, other than those referred to in Article 2(2)(f), and egg shells, used under conditions determined by the competent authority which prevent risks arising to public and animal health;", however (SJVFS 2014:43) only claim that 15 b § Shells from molluscs and echinoderm may be spread on land. What is true for category 3 materials here?</p>	<p>Mussel shells free-from-flesh is out of scope according to 2(2)(f), other than that one can do everything mentioned in Article 14 for category 3 material.</p>
<p>One can presuppose that one should follow Articles 31, 32, 35, and 36 in 1069/2009 where Articles 31 and 32 specifically mention "pressure sterilisation" as the mean to comply with 1069/2009 for category 3 material, whereas Articles 35 and 36 mentions that "Safe treatment shall include application of a manufacturing process to the material used which reduces to an acceptable level risks to public and animal health arising from the material used or from other substances resulting from the manufacturing process.". What is an "acceptable level" here?</p>	<p>Article IV in Regulation 142/2011 explain most treatments for applications of mussel shells in methods 1-7. Further, the requirements for making organic soil liming can be found in Chapter II in Appendix IX in Regulation 142/2011.</p>
<p>Regulation (EU) No 142/2011 mentions that Only animal by-products referred to in Article 10(e) and (f) and Article 10(k)(ii) of Regulation (EC) No 1069/2009 may be used for the production of egg products.". Since mussel shells are an Article 10(k)(i)-material it would be out of scope for this, but the literature research proves that it is used for egg production, so this can't be true. What is true?</p>	<p>This item is only for products made from eggs, not for use in the production of eggs.</p>

Table 4.1: Summary of the second email to Jordbruksverket

The Articles 31, 32, 35, and 36 mentioned in the email are all about how one should place category 3 material-derived on the market. Further, the pressure sterilisation-method mention is the one that is used by most literature articles as the method

4. Regulation (EC) No 1069/2009 of the European Parliament and of the Council

for complying with 1069/2009, with one example being the complying of 1069/2009 in Section 3.5.

Article 31 is about animal by-products and derived products for feeding to farmed animals excluding fur animals where it claims that *"they have been collected or processed, as applicable, in accordance with the conditions for pressure sterilisation or other conditions to prevent risks arising to public and animal health in accordance with measures adopted pursuant to Article 15 and any measures which have been laid down in accordance with paragraph 2 of this Article"*. [11]

Article 32 is about placing on the market and used for organic fertilisers and soil improvements where it is said that the product has to derive from category 2- or 3 materials and that they *"they have been produced in accordance with the conditions for pressure sterilisation or with other conditions to prevent risks arising to public and animal health, in accordance with the requirements laid down pursuant to Article 15 and any measures which have been laid down in accordance with paragraph 3 of this Article;"*, same as for products destined for animal feed in Article 31 [11].

Article 35 is about placing on the market for use in pet food. It states that only category 3 materials other than materials referred to in Article 10(n), (o) and (p) may be used and that they may be placed on the market provided that *"they ensure the control of risks to public and animal health by safe treatment in accordance with Article 38, where safe sourcing in accordance with Article 37 does not ensure sufficient control."*[11].

Article 36 is about placing on the market products other than the products mentioned in Articles 31 through 35. Here it is mentioned that they ensure the control of risks to public and animal health by: (i) safe sourcing in accordance with Article 37; (ii) safe treatment in accordance with Article 38 [11].

Lastly, Article 37 says that *Safe sourcing shall include the use of material from which no unacceptable risks to public and animal health arise* [11], and Article 38 says that *Safe treatment shall include application of a manufacturing process to the material used which reduces to an acceptable level risks to public and animal health arising from the material used or from other substances resulting from the manufacturing process. and It shall be ensured that the derived product poses no unacceptable risks to public and animal health, in particular by means of testing of the end product.*[11].

Through the email conversation with the handler at Jordbruksverket it became clear that to comply with 1069/2009, the methods presented in Article IV in Commission Regulation (EU) No 142/2011 [24] would have to be studied and followed.

4.2 Commission Regulation (EU) No 142/2011

Commission Regulation (EU) No 142/2011 [24] is a European Union non-legislative act that is in place to supplement and support the implementation of Regulation

4. Regulation (EC) No 1069/2009 of the European Parliament and of the Council

(EC) No 1069/2009 [11] where it established the specific rules in terms of health and safety-requirements for animal by-products and other derived products that are not intended for human consumption.

The key provisions for 142/2011 for mussels shells are that it sets the specific requirements for the handling of the shells and specifies the conditions under which the mussel shells can be used, processed, and disposed of [24]. Further, it establishes the standards for the processing and utilisation of mussel shells (category 3 material) both in terms of use for consumption by other animals, use for agricultural soil liming, and other use cases where the product is not intended for consumption by other animals. Additionally, it provides guidance on the treatment of specified risk materials (SRMs) to prevent the spread of certain diseases [24].

The processing requirements for different variables for Category 3 materials are outlined under Chapter II Section 4 in the English version of 142/2011 [24]. The different variables that are taken into account are as follows: raw material particle size, the temperature achieved in the heat treatment process, pressure, if applied to the raw material, and duration of the heat treatment process or feed rate to a continuous system [24]. Further, it is stated that category 3 material shall be processed in accordance with any of the processing methods 1 to 5 or processing method 7, or, in the case of material originating from aquatic animals, with any of the processing methods 1 to 7, as referred to in Chapter III [24].

The processing methods 1 through 7 in Chapter III are as follows [24]:

1. Pressure Sterilisation - Particle size less than 50 mm heated to a core temperature of at least 133°C for at least 20 minutes under an absolute pressure of 3 bars
2. Reduction of particles to less than 150 mm. After reduction, the animal by-products must be heated in a manner which ensures that a core temperature greater than 100 °C is achieved for at least 125 minutes, a core temperature greater than 110 °C is achieved for at least 120 minutes and a core temperature greater than 120 °C is achieved for at least 50 minutes. This method is only applicable to batch systems.
3. Reduction of particles to less than 30 mm. After reduction, the animal by-products must be heated in a manner which ensures that a core temperature greater than 100°C is achieved for at least 95 minutes, a core temperature greater than 110°C is achieved for at least 55 minutes and a core temperature greater than 120°C is achieved for at least 13 minutes.
4. Reduction of particles to less than 30 mm. After reduction, the animal by-products must be placed in a vessel with added fat and heated in a manner which ensures that a core temperature greater than 100 °C is achieved for at least 16 minutes, a core temperature greater than 110 °C is achieved for at

least 13 minutes, a core temperature greater than 120 °C is achieved for at least eight minutes and a core temperature greater than 130 °C is achieved for at least three minutes.

5. Reduction of particles less than 30 mm. After reduction, the animal by-products must be heated until they coagulate and then pressed so that fat and water are removed from the proteinaceous material. The proteinaceous material must then be heated in a manner which ensures that a core temperature greater than 80 °C is achieved for at least 120 minutes and a core temperature greater than 100°C is achieved for at least 60 minutes.
6. Reduction of particles to less than 50 mm for (a) or 30 mm for (b). After reduction must then be mixed with formic acid to reduce and maintain a pH of 4,0 or lower. The mixture must be stored for at least 24 hours pending further treatment. After reduction, the mixture must be heated to a core temperature of at least 90 °C for at least 60 minutes for (a); or a core temperature of at least 70 °C for at least 60 minutes for (b).
7. Method 7 is specified as: *"Any processing method authorised by the competent authority where the following have been demonstrated by the operator to that authority:"*
 - (a) That relevant hazards in the starting material have been identified by the operators in terms of the origin of the material, and that the potential risk in view of the animal health status of the Member State (Sweden) has been analysed.
 - (b) The capacity of the chosen processing method so that hazardous levels identified in the previous step can be reduced to a level in which it does not pose any significant threats to public and animal health.
 - (c) The final product should be sampled daily over the span of 30 production days and contain less than:
 - i. Clostridium perfringens: 0 grams when doing a sample of 1 gram
 - ii. Salmonella: 0 grams when doing 5 samples per day and a sample size of 25 grams
 - iii. Enterobacteriaceae: less than 10 bacteria in each sample in a sample size of 5 samples per day where one sample is 1 g

If more than one temperature, as well as more than one time span, is mentioned in the method, these time spans and temperatures can be combined so that the highest of both variables are reached [24]. For example, in Method 3 the core temperature must reach 100°C for at least 95 minutes and 120°C for at least 13 minutes. These two highest values can then be combined so that the method can be that the core temperature must reach at least 120°C for at least 95 minutes [24].

Pressure sterilisation, also known as autoclaving, is a method for sterilising products and devices using high pressure and temperature in an autoclave [25]. The materials are placed inside the autoclave where they are exposed to steam under pressure

4. Regulation (EC) No 1069/2009 of the European Parliament and of the Council

and at an elevated temperature. The pressure facilitates the attainment of high temperature, which effectively kills microorganisms and bacteria in the sterilised material [25]. The moist heat from the steam causes irreversible coagulation and denaturation of enzymes and proteins, leading to the destruction of microorganisms and bacteria [25]. Once the predetermined time has elapsed, the steam is released, and the sterilised objects are retrieved [25].

5

Decision on Processing Method and Application

After having studied the current and future applications of mussel shells as well as the regulations and processing methods to fulfil the regulations, a thorough meeting was had with the company where how to move forward was discussed.

5.1 Deciding processing method

Since the processing methods presented in Section 4.2 from 142/2011 [24] decide the products that can be valorised from the mussel shells in terms of legality as well as the size of the final mussel shells, it was natural to decide on this topic first.

A few methods were discarded immediately for different reasons that made them unviable for the purposes of this project. Process method 3 was discarded because of the fact that it required the mussel shells to be reduced to a size of 30 mm in all dimensions. Although many of the shells already met this requirement it was argued that it was desirable to keep the shells as large as possible for as long as possible in the valorisation process so that as many different product categories could be met, and if needed the shell size could be reduced later in the process instead.

Method 4 and 5 were discarded for the same reason as Method 3 with the added fact that Method 4 required the mussel shells to be placed in a vessel with added fat, something that was not viable space-wise, and in Method 5 the mussel shells would have to coagulate, something that would be vastly energy-requiring.

Method number 6 was similarly discarded for the same reasons as Method 4 and 5. Although the shells should meet the requirement of being less than 50 mm in size, the additional requirement of mixing the shells with formic acid for 24 hours led to the method being scrapped. Not only would it likely be more expensive, require more space, and be more labour-intensive, but it would also add 24 hours to the throughput time of the shells; something that was not desirable.

The remaining three processing methods were therefore: Method 1, 2, and 7. Method 1, Pressure Sterilisation, seemed at face value to be an early candidate as it was used in many of the research studies that were presented in Chapter 3. Pressure Sterilisation systems are a cost-effective and technically simple [25] system that would

be easy to implement in the factory of Mussel AB and had proved to be viable in many different applications of mussel shell valorisation. However, since the pressure chamber is a closed system it meant that the processing method would have to be a batch system. Further, it would most likely require a few manual steps when loading/unloading the mussel, something that was undesirable as per the company's request. Lastly, although it wouldn't likely be a problem with today's production volume for Musselfeed, it would likely be hard to scale up this solution in the future.

This left Method 2 and 7 as possible solutions, and although Method 2 would have been an adequate processing method for complying with 1069/2009 in terms of mussel shell size and other requirements, in the end, it was decided to move forward with Method 7. The reasoning behind this was that no modification to the size of the shells would have to be done before the heating of the shells, as well as that the temperature of and the time the mussel shells would have to be in the heating chamber could be fit to whatever value was appropriate for the factory setting and production requirements as long as the requirements for Method 7 was met. Further, it was argued that since the values of Salmonella and Enterobacteriaceae were already regularly tested in the mussel meal product and met zero values, the same would most likely be the case for the shells.

5.1.1 Testing Method 7

A small test, although not very scientific, was carried out to see how different variations in time and temperature would affect the mussel shells and can be seen in Table 5.1. The test was mainly done to see what aesthetic effects the processing method would have on the mussel shells. The shells that were used had some meat left on them since they were taken immediately after the separation, as would be the case in the real application.

Trial	Weight in [g]	Time [min]	Temperature [°C]	Weight out [g]	Weight loss [%]
1	250,0	95	120	226,2	9,52
2	250,4	65	190	233,6	6,71
3	250,1	50	30-500	225,7	9,76

Table 5.1: Three different variations of time and temperature

Trial one served as the baseline, and was based on Method 3 in 142/2011 [24]. Although the method was discarded as the processing method moving forward due to not all mussel shells meeting the requirement of being less than 30 mm, most shells do meet this requirement and the method was therefore seen as an adequate baseline. In Table 5.1 it can be seen that the weight of shells together with some meat was measured to be 250 grams, and was put in a regular kitchen oven for 100 minutes set at 120°C. 5 minutes were added to the specified 95 minutes in Method 3 so that the core temperature would be able to reach 120°C after going in. Although no tests were made on the core temperature of the shells, the shells are very thin and it is therefore likely that the core temperature is the same as the surface temperature, where the surface temperature was measured and confirmed to be 120°C

with an infrared thermometer after 5 minutes. During the trial, the shells combined with the meat lost 23,8 grams of weight for a weight loss of 9,52%. Before and after pictures of the shells and meat can be seen in Figure 5.1.



(a) Mussel shells before Method 1

(b) Mussel shells after method 1

Figure 5.1: Comparison of mussel shells before and after oven in Method 1

Trial 2 was made in the same oven as Trial 1, however with a core temperature of 190°C instead of 120°C, and for a time of 65 minutes instead of 95 minutes. The time and temperature were decided on arbitrarily and do not correlate with any method in 142/2011 [24]. In the trial, the weight of the shells and meat lost 16,8 grams for a weight loss of 6,71%. It was noted in the trial that the mixture of shells and meat experienced even more charring and discolouration of the shells than the one in Trial 1 which can be seen in Figure 5.1b. Further, it was noted that the shells were more brittle and prone to breaking than the shells in Trial 1.

Trial 3 was too made with arbitrary values for time and temperature, however, this trial was made in a ceramic kiln instead of a kitchen oven with the reason for this being that the ceramic kiln could achieve higher temperatures than the kitchen oven. The shells and meat were put in the kiln when the kiln was only 30°C with the intention of letting it get to 500°C over a period of 50 minutes before taking the mussel shells out; however, the trial had to be stopped after 22 minutes when it became apparent that the shells were charring too much, and the room where the trial was made became full of smoke. At the point of cancelling the trial the temperature of the kiln had only reached 258°C, and was therefore approximately only halfway done. After removing the shells it was noted that the shells were almost completely black of char and were breaking under their own weight when moved around. The

weight loss of the mixture was recorded as being 24,3 grams or 9,76%.

The trial, although not very scientific in terms of samples, still gave some valuable information. Firstly, it is likely that temperature has a bigger impact on the aesthetic of the shells than the time the shells are in the heating chamber. However, since the values for Trials 2 and 3 were chosen arbitrarily, and longer times with lower temperatures were not tried, it is not possible to prove with any significance that this hypothesis is true in these trials. Further, the same reasoning is assumed to be the case for how brittle the shells turn out to be after processing them. Although no information is known on what stiffness is desirable in the shells for products, at least for Trial 3 when the shells break under their own pressure was assumed to be disadvantageous. In this trial, it was also noted that no correlation could be seen between temperature, time, and weight loss. It is likely that the weight loss recorded in these trials was dependent on how much organic matter from the meat was in the mixture and therefore burnt in the heating chamber.

In the end, it was decided to use Trial 1 as the baseline to optimise cycle times and therefore throughput times while also ensuring good aesthetic and deformative characteristics. The aesthetic properties were done by eye where less discolouration was deemed better. However, it must be noted that this baseline is only for the prototype and more thorough tests have to be done in the future to ensure that the bacterial requirements in Method 7 [24] are met.

5.2 Deciding product categories

The decision on what applications the mussels should be used for and therefore what products to be produced was made quite simple. One of the requests of the company was to have as few manual steps as possible in the production, and it was therefore argued that it would be advantageous to have fewer processes in the prototype to ensure that this would be met even though high automation would be striven for. Further, the only two product groups that most likely would need one more process than being heat treated and reduced in size were Decorative and Aquarium & pond pH buffer, which would additionally have to be chlorine-treated. The use of chlorine in the valorisation process was seen as undesirable due to the fact that chlorine is heavily toxic and the product should be environmentally sustainable.

As all other types of applications had the same processing requirements except varying in size it was decided to move on with all these different product categories and decide on the size of the shells at a later stage. However, since mussel shell liming agents and poultry feed are the most common and widely available products today, it is likely that these would be the first product groups to be realised for Musselfeed AB.

6

Designing Production System

In this chapter, the current production system will be very shortly described as well as how the prototype for the valorisation of the mussel shells was designed. Today the production has a capacity of refining 1.000 kg, of mussels per day, but in the future, the goal is to have a total capacity of 8.000 kg of mussels per day. Today the mussel shells are refined in batches of 500 kg twice a day, but in the future, the goal is to have a continuous process working 24 hours per day.

6.1 Prerequisites

Today, there are a few processes that the mussels go through up to and including the process where the mussel meat and mussel shells are separated. Unfortunately, these processes can't be described in any detail as they are trade secrets of Musselfeed AB. The separation of the shells and the meat will in the future be done on a platform that can be seen in Figure 6.1. The platform has a width of 220 cm and a length of 180 cm. The top of the platform where the separation of shells and meat will be done has a height of 150 cm. The placement of the platform in the current factory setting was by the company said 585 cm from the north-north-east wall and 240 cm from the east-south-east wall as can be seen in Figure 6.2. The outlet for the shells will be through the hole at the top of the platform, where a hopper will catch and centre the flow. However, since the machines for the processes that will be needed before the separation in the future are not known today, some leeway was given for the placement of the platform.

To know what flow of mass the oven has to be able to handle, the mass flow of the current and future scenarios is calculated to see which one is bigger, and therefore the minimum requirement. As the shells are approximately 50% of the weight of the shells and meat together, the required mass flow of the prototype would have to be half of that of the mass flow to the shell and meat separation. Today, as the processes before the separation of shell and meat are done in batches of 500 kg, the mass flow of the shell and meat will be determined by the last step, the separation of shells and meat. This process takes approximately 40 minutes meaning that the flow of shells out of the separation would be 6,25 kg/min which is seen in Equation 6.1. In the future scenario where new pre-processing machines will be bought to be able to handle 8.000 kg per day the capacity and time of the separation of mussels and meat is not known. However, if all processes were assumed to have cycle times lower than the required takt time, and production was done continuously and

6. Designing Production System

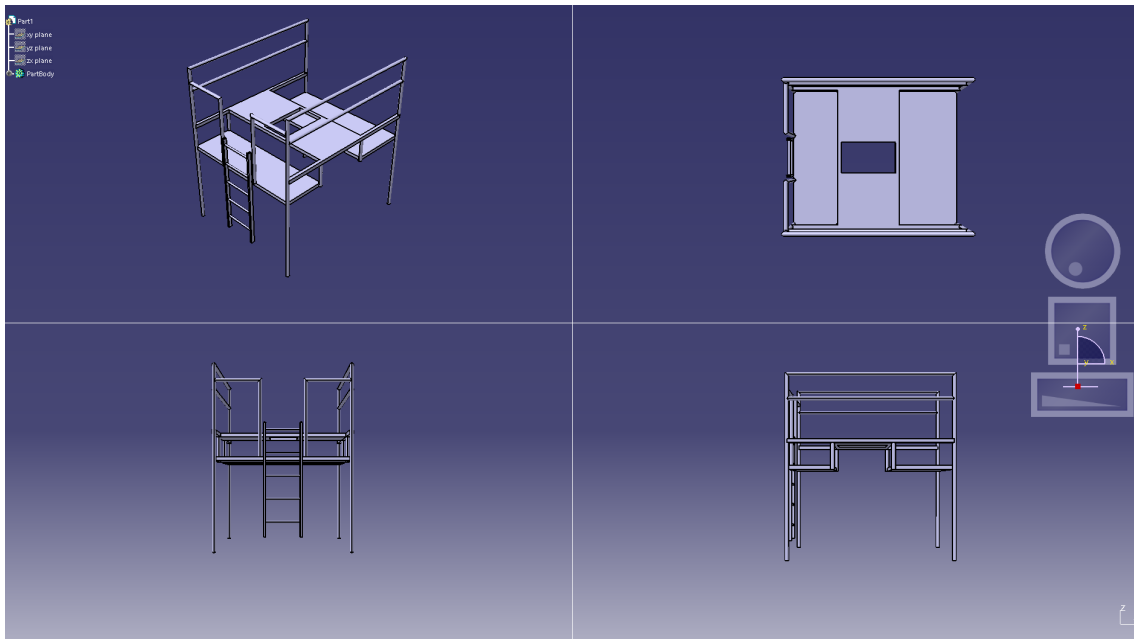


Figure 6.1: Platform where separation of meat and shell will be

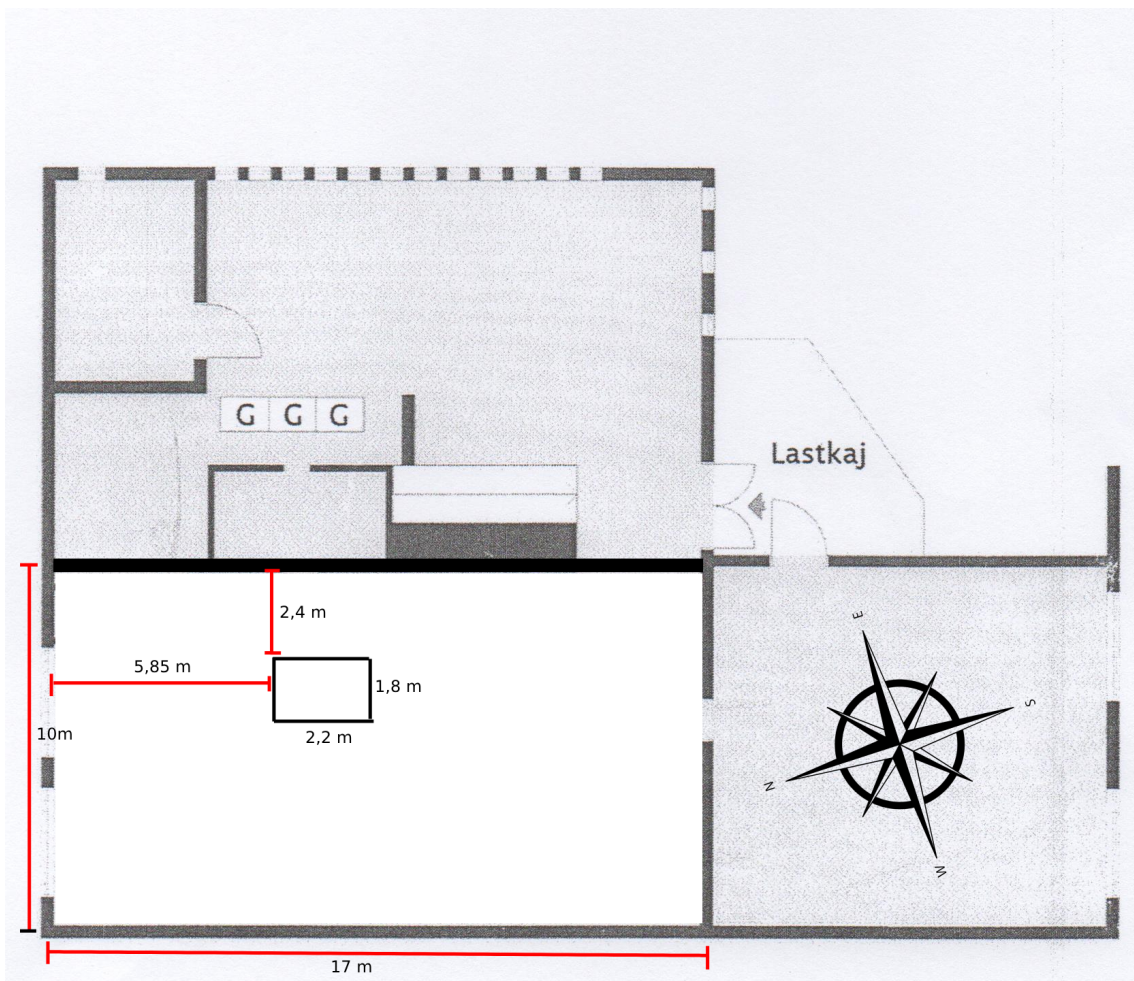


Figure 6.2: Layout of factory and placement of platform

during all hours of the day, the required mass flow would be 2,78 kg/min as seen in Equation 6.2. Nonetheless, the bottleneck in the future would likely be the conveyor elevator which will carry the shells and meat up to the platform, and according to Odd Lindahl, this conveyor has a capacity of 25 kg/min. This in turn means that if the separation process would be able to handle this, the flow of shells would be 12,5 kg/min, the highest of the three options and therefore what will be used as the baseline.

$$\dot{m}_1 = \frac{500}{40} \cdot 50\% = 6,25 \quad (6.1)$$

$$\dot{m}_2 = \frac{8000}{24 \cdot 60} \cdot 50\% = 2,78 \quad (6.2)$$

6.2 Processes in the valorisation

In an early brainstorming session together with founder Odd Lindahl, it was believed that there should be three processes in the valorisation of the mussel shells: cleaning of the shells, reduction of size to a uniform size, and of course the heating stage to ensure compliance with 1069/2009 [11][24].

6.2.1 Cleaning solution

Musselfeed AB was in possession of a drum screen from Lackeby of the model Roto-Sieve RS-11 [26]. A Roto-Sieve drum screen is a machine that pushes material through a drum with a rotating spiral while simultaneously cleaning the material by flushing water through the drum. While most use cases for drum screens are to clean fruit in food production, one use case mentioned on their website is specifically for aqua-derived products [26].

6.2.2 Crushing solution

As the shells are quite brittle, the only reasonable solution that was discussed for the crushing of the shells and reducing their size to the appropriate size for each solution was to put them in a drum that would shake and crush the shells while having a sieve at the bottom of it that would let the right sizes for the application through. The sieves would then be able to be changed to different sizes depending on what size of the shells was needed. A machine that could work like this would be a grain sieve, a product that comes in many different variations depending on the application.

An early prototype was made in Visual Components with these two machines presented in Figure 6.3. In the first prototype, the stock conveyor belts from Visual Components were used and the heating solution had arbitrary dimensions with a diameter of 1,5 m and a length of 3 m.

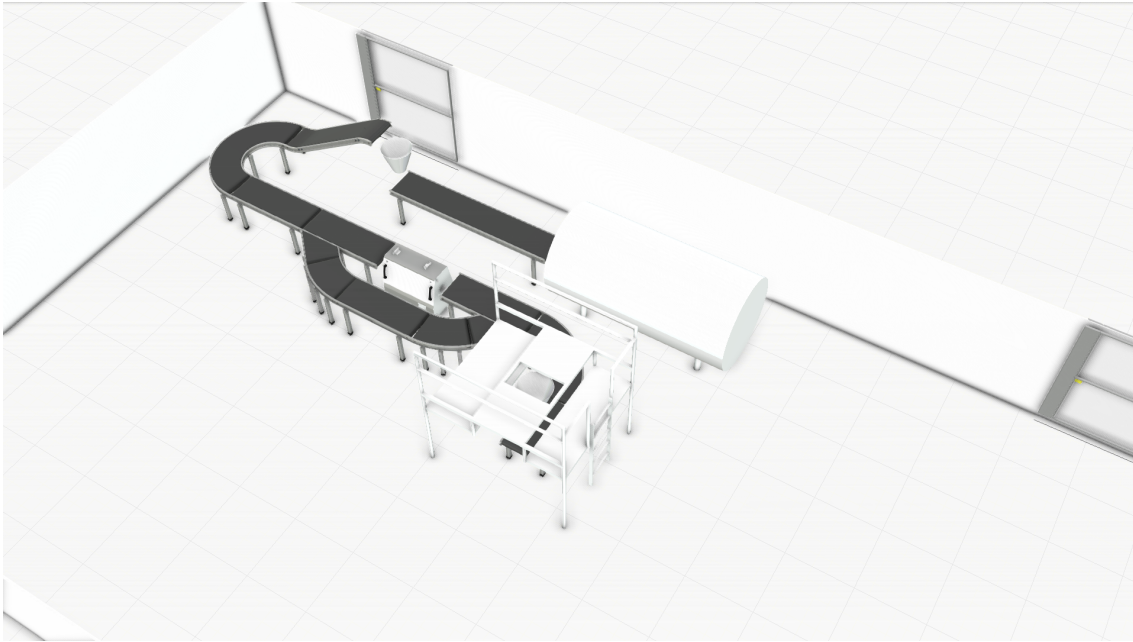


Figure 6.3: First prototype with cleaning and crushing solution

When presenting and discussing the first prototype with Musselfeed, a few things were decided. Firstly, it was decided to not include the cleaning- or crushing solutions in the prototype. The reason for this was mainly that these two processes were deemed to not essential to the valorisation of the shells, and that not enough was known about the needed machinery. The Roto-sieve had not been used in several years and never started since it was bought by Musselfeed and it was therefore not known if it was even functional. Furthermore, it was seen as disadvantageous to have conventional conveyor belts transporting the shells from the platform to the processes as they would likely block the doorways on the east-south-east wall and would be in the way of other material- and personnel flow. However, at the Nordic Food Industry fair in Gothenburg on 18-20 October 2022, Musselfeed had been introduced to a product that seemed viable for this purpose, the Schrage Conveyor Tube [27].

6.2.3 Schrage Conveyor Tube

The Schrage Conveyor Tube is a mechanical conveyor system used for conveying bulk materials that consist of two parallel tubes with a chain that runs in a loop that transports the material [27]. A cross-section of a Schrage Conveyor Tube can be seen in Figure 6.4. Although the density of the shells is not entirely known, even the volume flow of 20,8 l/min [27] of the smallest tube, the Type 115 [27], should be able to handle the flow of 12,5 kg/min of shells that was the requirement. The Schrage Conveyor Tube is advantageous to use since it is dust-proof, almost entirely self-cleaning, and has a flexible line layout (three-dimensional), making it ideal for food production [27].

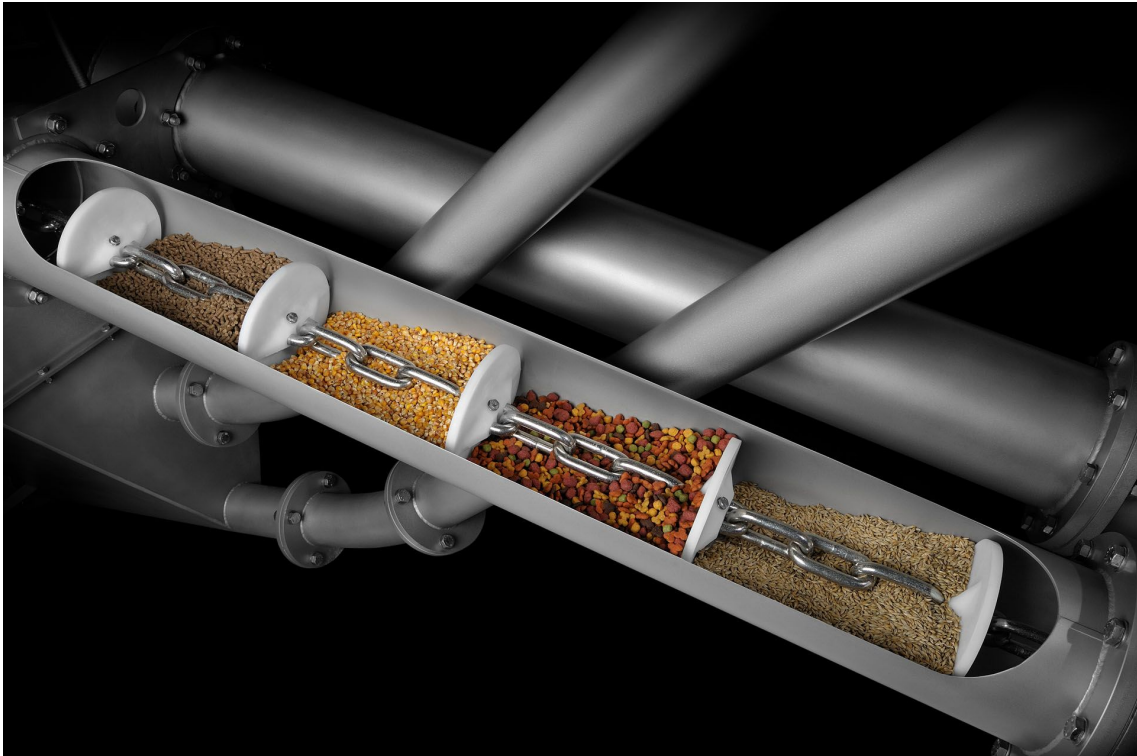


Figure 6.4: Cross-section of conveyor tube (Source: schrage.de)

6.2.4 Heating solution

To decide what oven to use for the heating solution, the International Thermal Systems (ITS) Industrial Ovens Selection Guide was used [28]. The requirements for the oven are only that it has to be able to reach a temperature of at least 120°C and that the shells should be in the oven for at least 95 minutes according to the testing done in 5.1.1. As it is assumed that there is no need for the oven to reach temperatures much higher than the 120°C required, the category of drying ovens seemed like an adequate choice, as they usually have maximum temperatures around 300°C [28]. Further, although not needed today, as the volumes handled will be high in the future, the conveyor-type oven was chosen instead of a batch-oven type to promote automation and fewer manual steps. With these two options combined, it was recommended to use a rotary drum dryer [28]. This correlated well with a tip from Odd Lindahl who had used this type of heating solution for other mussel applications before with success, and the company that produced those products was Torkapparater AB [29]. A rotary drum dryer is a type of oven that has a rotating cylindrical drum that gets heated during the process. Further, the inside of the drum is covered in slightly diagonal blades that push the material forwards during the heating process.

6.2.4.1 Choosing rotary drum dryer

An email was sent to Torkapparater AB inquiring about their products, however, this email was promptly answered that they were not interested in providing any information to a Master's Thesis. This, unfortunately, turned out to be the case for all suppliers contacted, including FEECO [30], which in the end was used as the model for the prototype as they were the only company that had any specifications available on their website.

The FEECO model that will be used for the prototype is the smallest available rotary drum dryer and has a diameter of 0,9 m, a length of 6 m, energy usage of 5,5 kW, and a capacity of 7.000 kg/h, or 116,7 kg/min [30]; which well clears the requirement of 12,5 kg/min.

The model was placed in the virtual factory to see if it would fit between the two doors so as to not obstruct the present flow of material and personnel, which it did not as can be seen in Figure 6.5.

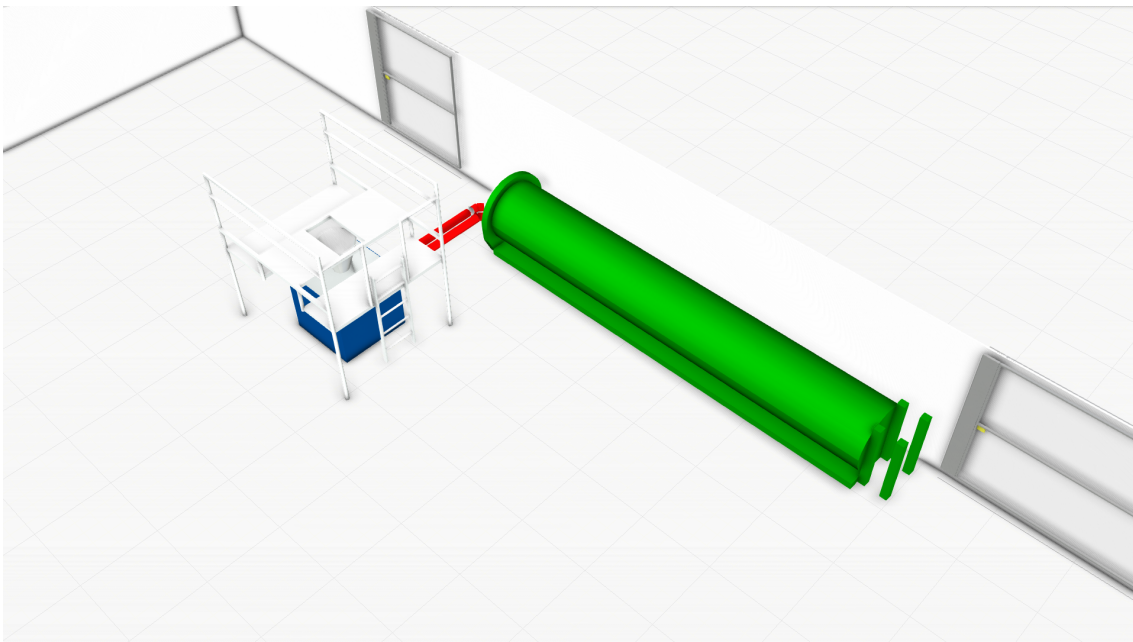


Figure 6.5: Test placement of rotary drum dryer in virtual factory

When testing the dryer in the virtual factory, the question arose as to how to store the valorised shells. Although no thought had been put into this before, it was argued that as the shells most likely would be bought in bulk in the future, they could be stored in a container just outside the factory's north-north-east wall. To facilitate this it required the dryer to be rotated 180° in the XY-plane, which will be represented in the two final prototypes. Two prototypes will be created due to the fact that it is likely that the dryer will operate differently depending on the volume of shells needed to be valorised.

6.3 Prototype for current setting

As they today only handle 1000 kg of mussels in batches of 500 kg, meaning that the shells will come in two batches of 250 kg each, it was argued that due to the high capacity of the dryer, it would be excessive to utilise a continuous system directly from the separation process. A collection vessel was therefore added just before the dryer that would collect the mussel shells so that the heating process could be run in two batches and utilise the capacity of the dryer more effectively. The prototype for how it could look in the current setting can be seen in Figure 6.6 and with the storage solution in Figure 6.7.

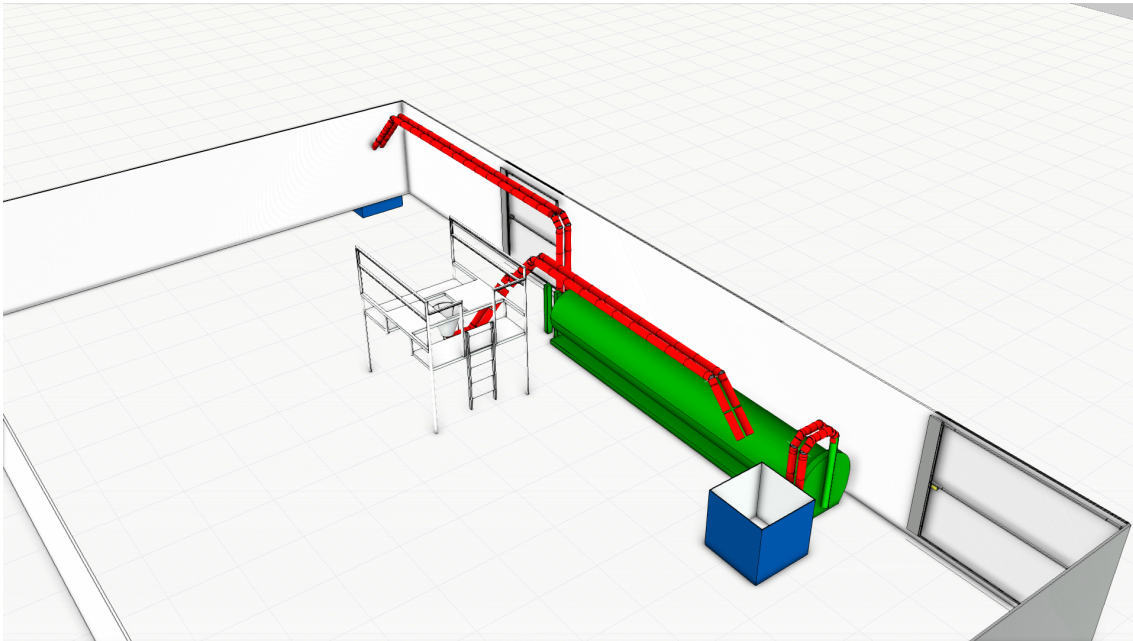


Figure 6.6: Final prototype for current production volumes

6.4 Prototype for future setting

In the future when the production volume will be 8.000 kg/day, the dryer would have to handle 4.000 kg/day of mussel shells, and it is assumed that the separation would be running at all hours of the day with a steady flow. Although the flow of 2,78 kg/min of shells is substantially lower than the capacity of 116,7 kg/min from the dryer, it was still argued that continuous production would be advantageous, and the shells could therefore go straight to the inlet of the dryer. The resulting prototype for this figuration can be seen in Figure 6.8 and with the storage solution in Figure 6.9. The same reasoning was applied to the case of if the production wasn't continuous and would have a mass flow of 12,5 kg/min of shells: the capacity of the dryer would still well clear the flow of shells.

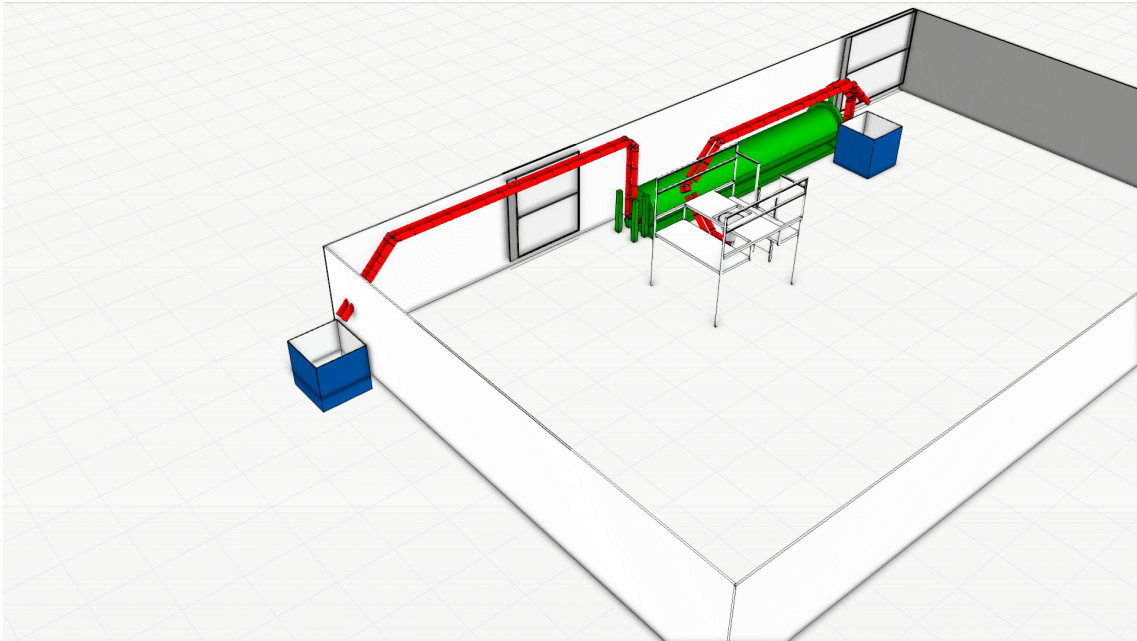


Figure 6.7: Final prototype for current production volumes with storage solution

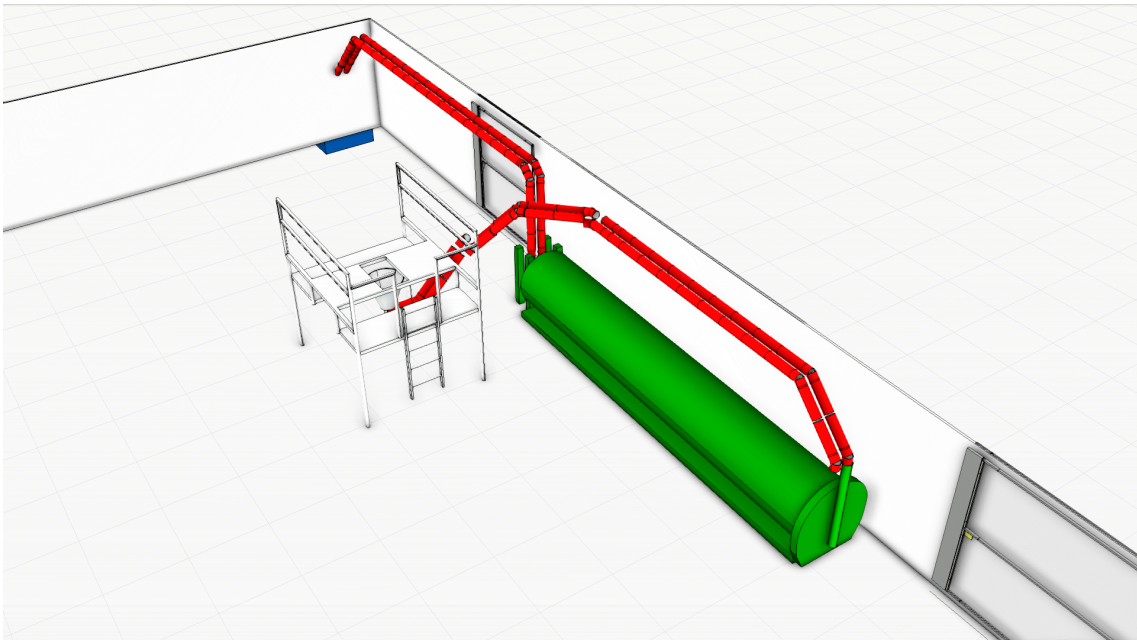


Figure 6.8: Final prototype for future production volumes

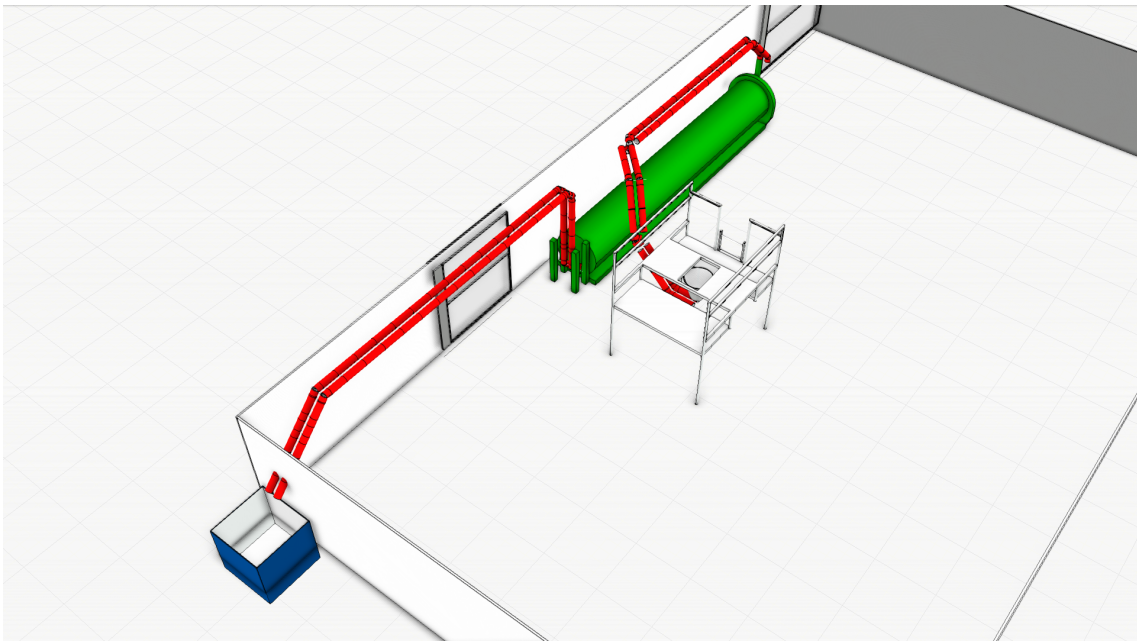


Figure 6.9: Final prototype for future production volumes with storage solution

7

Discussion and further work

In this chapter, the findings and decisions for each chapter will be discussed, as well as proposing how the work could be continued in the future.

7.1 Applications of Mussel Shell

This chapter only covered the most common current and extensively researched future applications of mussel shells. Throughout the literature study, it became apparent that mussel- and other mollusc shells can be used as a very versatile replacement in many a different application. Today, mussel shells are mainly used for poultry feed and soil liming, but it became clear that it is of great interest for Musselfeed to investigate how to reach the product categories that are sold in smaller quantities to achieve higher profit margins. Additionally, as the mussels are crushed today from the separation process, if there was a way for Musselfeed to ensure whole shells this could lead to the product being viable for even more product categories and higher profits. Further, as shortly mentioned in the literature study but excluded for this paper due to its high energy requirement, the option to refine the calcium carbonate CaCO_3 into calcium oxide CaO could make Musselfeed be able to tap into even more markets.

7.2 Regulation (EC) No 1069/2009 of the European Parliament and of the Council

This chapter is mainly filled with information and not much can be discussed. For future purposes, it could be interesting to research if there is a way to ensure that the shells could be free-from-flesh, and therefore not be needed to follow this regulation. Unfortunately, it is not likely that this would be too easy and could prove to be as big of a process as the solution presented here, and therefore not make any difference in the end. Further, I would strongly advise Musselfeed to consult with a lawyer knowledgeable in food production when and if implementing this solution as it is of utmost importance that everything in the regulation is complied with.

7.3 Decision on Processing Method and Application

The decision on choosing Method 7 processing method to comply with 142/2011 and 1069/2009 was made because it provided the most leeway in terms of adaptability. Although it is likely that the method tested as trial 1 in this chapter would suffice to meet the requirements of the regulations, extensive testing must still be done to ensure this. Furthermore, it is even likely that lower temperatures or shorter times of heating could be used as the bacteria level of the mussels is already at such a low level, which could alter how the heating process could or would have to be designed.

7.4 Designing Production System

For this chapter, there is a lot that can be discussed. Although the requirements for today's production volumes are established, not much is known about how the production before the separation is scaled up, which is indeed very relevant to how the final design will be. For the purpose of this thesis, it was assumed that the mass flow in the future would be constant; however, if this changed it is very likely that a continuous solution would not make sense in terms of the heating solution and other processes. Granting that 5,5 kW is relatively low energy consumption for the heating solution, it could prove to be better to have a batch solution in the future to optimise the capacity of the dryer and lower energy consumption. As the capacity of the dryer suggested in the prototype is more than 100 kg/min higher than the required capacity it would be very under-utilised if running for 24 hours per day. Depending on if it is more energy-consuming to have it running at all hours of the day or starting and stopping it every time a batch would, the layout of the production could change. If the dryer would be run at max capacity, rather large batches could be run, but then other problems would likely arise. For example, large volumes of unprocessed and untreated shells and meat have a tendency to release quite an odour, especially during the warmer summer months, and would therefore create a bad work environment for employees. Further, it could lead to a higher risk of bacteria growth in the organics rendering the proposed solution of heating not sufficient. Moreover, the decision to reduce manual steps was made so as to not overwork the operator and alleviate their back pain. If manual operations could be found and studied that were more efficient and designed to be highly ergonomic it could prove to be a better solution than full automation.

Lastly, although not necessarily a requirement, research should continue on how to reduce the size before or after the dryer to ensure that many of the products' required sizes can be achieved.

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A

Mail 1 to Jordbruksverket

Hej,

Jag håller på med min mastersuppsats på Chalmers där jag skall designa en produktion för olika typer av produkter gjorda av musselskal som är en typ av animalisk biprodukt i kategori 3. Detta har betytt att jag har spenderat mycket tid att tolka föreskrifterna Regulation (EC) No 1069/2009 samt SJVFS 2014:43. Då jag har upplevt att det inte alltid är helt enkelt att tolka vad som menas i dessa föreskrifter, och det även i vissa fall inte är så hantering av kategori 3-material hanteras i Sverige så som beskrivs i föreskrifterna, hade jag gärna kommit i kontakt med någon som hjälpa mig att tolka dessa lagar och ge klartext i vad som faktiskt gäller i Sverige idag.

MVH, Magnus Olander

B

Mail 2 to the handler at jordbruksverket

Hej [REDACTED],

Tack för snabbt svar! Musslorna kommer ifrån Scanfjord som då har musselodlingar, och musslorna som vi köper är de musslorna som är "för fula" för att sälja till restauranger och butiker. Kött separeras från skal i vår fabrik för att sedan göra diverse produkter av köttet, och mitt uppdrag är då att hitta användningsområden för skalen i framtiden. Processen är idag inte tillräckligt effektiv för att garantera 2.2.(f), utan lite kött och muskelfästen finns idag kvar på skalen. Jag har inte haft möjlighet att testa något sätt där man kan garantera att allt kött är borta, och har inte heller hittat någon process under min litteraturforskning. Detta leder till att jag förstår det som att man måste följa reglementena i 1069/2009 fullt ut.

Jag ser det som att det finns två tolkningar av av 1069/2009 för kategori 3-material.

1. Artikel 14(h) säger att "in the case of shells from shellfish, other than those referred to in Article 2(2)(f), and egg shells, used under conditions determined by the competent authority which prevent risks arising to public and animal health;", och att det enda jag hittar på Jordbruksverket är i sådant fall "15 b § Skal från blötdjur och tagghudingar får spridas på mark. (SJVFS 2014:43)". Detta skulle ju tyda på att det i sådant fall är det enda som man får göra med musselskal av kategori 3, men sådant är ju inte fallet.

Svar: musselskal enligt Artikel 2(")f är out of scope och kan hanteras utanför abplagstiftningen. Sen är musselskal med rester normalt ett kategori 3 material (i alla fall de musslor som du avser om jag förstått det rätt) och då kan man göra allt som står i artikel 14 med det materialet.

2. Man kan utgå ifrån Artikel 31, 32, 35, och 36 i 1069/2009 där Artikel 31 och 32 specifikt nämner trycksterilisering och 35 och 36 genom Artikel 18 nämner att "Safe treatment shall include application of a manufacturing process to the material used which reduces to an acceptable level risks to public and animal health arising from the material used or from other substances resulting from the manufacturing process.". Vad är en "acceptable level" här? Grundaren av företaget jag är på säger att vissa företag i Sverige idag hettar upp musselskalen till 80 grader celsius under 2-3 min, men det är ju inte ens i närheten av lika mycket som en trycksterilisering

som är 133 grader celsius under 20 min med ett tryck på 3 bar, där trycksterilisering verkar vara ett minimum för egentligen alla användningsområden.

Svar: Se bilaga X i förordning 1142/2011 för fiskmjölskraven. Det måste dock tillverkas i en godkänd anläggning. Fiskmjöl kan tillverkas med olika metoder (metod 1-7 som finns i bilaga IV i förordning 142/2011). Kraven för att göra ett organiskt gödningsmedel av musselskal med rester på finns i kapitel II i bilaga IX i förordning 142/2011. Sen kan man göra all möjliga saker av musselskal om man har en teknisk anläggning, tex lampskärmar, smycken eller murbruk.

Se länk: [Produkter från djur i utbildning, för konservering och som konstprojekt - Jordbruksverket.se](#)

Jag läste även i (EU) No 142/2011 att "Only animal by-products referred to in Article 10(e) and (f) and Article 10(k)(ii) of Regulation (EC) No 1069/2009 may be used for the production of egg products.". Detta kan ju omöjligt stämma då musslor räknas som Article 10(k)(i), men det finns ju samtidigt gott om mussel- och ostronskal att köpa för att föda upp fjäderfän i Europa och Sverige, där även forskning görs på det i Sverige (e.g. <http://dx.doi.org/10.3382/japr/pfw056>). Hur ska jag förhålla mig till det här, och vad för processer skulle skalen behöva då?

Svar: denna punkt rör bara fjäderfä.

Allt detta är som sagt mycket rörigt för mig som inte är en jurist utan ingenjör, och mottager gärna alla tips jag kan få för hur man skall tolka detta och vilka processer som används idag i Sverige för att uppnå alla dessa krav.

Tack för svar.

Svar: Har du tänkt att starta något ska du anmäla anläggningen/verksamheten till oss innan du startar.

DEPARTMENT OF SOME SUBJECT OR TECHNOLOGY
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