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Design of a Mechanical Treatment Method for Salmon Lice

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PREFACE

This master thesis has been conducted as a research work at the Norwegian University of Life Sciences (NMBU), deptartment of Mathematical Science and Technology. The purpose of this thesis work has been to develop a proof of concept for the procedure described, a method for removing the salmon lice from the salmon's body.

Although treatment of salmon lice is a field far from what I am used to work with, this Master thesis has indisputably been extremely interesting and exciting to work on. It has opened up for a more widely mindset, and it has forced me to think along new lines. It has been especially stimulating to see how conventional mechanical principles can be implemented into salmon farming technology.

I would like to thank everyone who has contributed to this project. My supervisor Dr. Tor Kristian Stevik at NMBU for providing me with guidelines and supervision throughout the entire project and to Carlos Salas Bringas for helping me with 3D design drawings and flow simulations in Solidworks. I would also like to sincerely thank the staff at the Marine Harvest Norway and Aqua Farms Vartdal for their enthusiasm, for sharing their knowledge, and for letting me visit their installations. A special thanks goes to Børre Vaagan for kindly introducing me to the aquaculture industry and for sharing with me of his valuable knowledge and enthusiasm.

Ås, May 18th 2016

Sondre Myhrum Sletmoen

ABSTRACT

Salmon lice infestations represent the most significant disease problem for the salmon farmed industry. The stakeholders struggle to find an adequate solution to this problem. A search to find a more efficient and gentle mechanical delousing method has formed the backdrop for this master thesis.

A method for mechanical lice treatment in the salmon farmed industry is a term for a lice treatment with no use of medicaments, chemicals or any kind of biological involvement. These factors have otherwise been common to use in conventional treatment processes. However, several incidents have shown that the use of chemicals has constituted a major risk to the salmon welfare. This has led to a higher incentive among the stakeholders to search for new and improved treatment methods. The salmon farmed business is a growing industry, estimated by the Norwegian Government to have an annual growth of three present until 2050. As per today´s situation with the salmon lice, the salmon industry's ability to supply is restricted even though the demand is insatiable. This has led to a triggering need for finding a sustainable solution.

The main objective for this master thesis has been to identify and examine the possibilities for a mechanical treatment method to solve the salmon lice problem in the salmon farmed business. Furthermore, the purpose was to develop proposals for concepts with the aim of satisfying all the defined requirements. Ideally, it should be able to treat the lice infestations at every position on the salmon´s body. The final concept should be able to replace existing treatment methods.

This master thesis can be divided into two parts; the first part is the research part and the second is the concept development part. The research phase included an investigation of current treatment methods and an external company visit to identify the needs and demands for an improved lice treatment method. The concept development process has been conducted using the Osborne's method, where the mechanical treatment method was divided into required features and were then considered individually. Afterwards, the brainstormed concepts were combined in feasible solutions and evaluated up against a zero-concept based on the defined specifications. Pugh´s method was then used to screen all of the ideas and choose the most suitable concepts. The chosen concept was further shaped in 3D models made in SolidWorks and evaluated with a number of flow simulations.

This project is only the early phase of a product development process for designing a mechanical treatment method for salmon lice. Therefore, a final solution with selected materials and metric measurements is not developed. The underlying desire for the

development process has been to move the treatment method down into the net pens where the salmon live, instead of pumping the fish up and into the fish carrier, which traditionally have been the normal procedure. It was assessed that this could lead to a more efficient farming production for the aquaculture, like it has been for the animal husbandry in the agriculture. Production methods for the final solution has not been studied and described, since a full-scale prototype needs to be tested before this can be considered.

The final result of this project is a funnel-shaped tube with curves in the longitudinal direction. This is meant to force the salmon to change the swimming direction, since the tube changes the centre point in the longitudinal direction. This will eventually force the salmon to be at a position close enough for the treatment of lice infestation, which are being conducted. The lice treatment is conducted by four water outlets positioned along the tube, from four different angles, where high velocity water is sucked through the outlets by a pumping system. The exerted water flow is meant to extract the lice off the salmon´s body. The solution makes it possible to treat the salmon constantly and with low maintenance and operational costs. This provides a possibility for treatment with a high accuracy and efficiency, without exerting a significant stress factor to the salmon.

SAMMENDRAG

Luseinnfestninger på laks representerer i dag den største utfordringen i lakseoppdrettsnæringen. Aktørene i bransjen sliter med å finne gode nok løsninger for å bli kvitt problemet. Et ønske om å finne en mer effektiv og skånsom mekanisk avlusingsmekanisme på laks, har formet bakteppet for denne masteroppgaven.

En mekanisk avlusingsmetode er et begrep for behandling av luseinnfestninger uten bruk av medikamenter, kjemikalier eller andre biologiske virkemidler. Disse faktorene har det normalt sett blitt mye brukt i behandlingsprosessen av lakselus, men de senere årene har man ønsket å finne andre behandlingsmetoder. Dette skyldes at lusa blir mer og mer resistent mot kjemikaliene som brukes og at disse kjemikaliene har en negativ effekt på laksehelsen. Laksenæringen er en økende bransje, estimert av norske myndigheter til å øke med tre prosent frem til år 2050. Slik situasjonen med dagens nivå av lakselus er, blir næringens evne til å levere svært begrenset selv om etterspørselen nærmest er umettelig. Det er derfor et enormt behov for å finne en bærekraftig løsning på dette problemet.

Hovedmålet for denne masteroppgaven har vært å identifisere og undersøke mulighetene for en mekanisk behandlingsmetode for avlusing i oppdrettsnæringen. Videre var målet å utvikle forslag til konsepter med formål å kunne tilfredsstille kravene som ble spesifisert. Ideelt skulle behandlingsmetodene være i stand til å behandle laks med luseinnfestninger i alle posisjoner på laksen. Det endelige konseptet skulle kunne erstatte eksisterende behandlingsmetoder.

Denne masteroppgaven kan deles inn i to deler: den første delen er et førstudium og den andre er en konseptutviklingsdel. I førstudiefasen inngår en undersøkelse av dagens metoder for behandling av lakselus og et eksternt bedriftsbesøk for å identifisere behovene og kravene for en forbedret avlusing av laks. Konseptutviklingsprosessen har vært gjennomført ved hjelp av Osbornes metode, hvor den mekaniske behandlingsmetoden ble splittet opp i spesifikke funksjoner og vurdert individuelt. Konseptene fra Osbornes metode ble så kombinert til gjennomførbare løsninger og evaluert opp mot et null-konsept basert på de definerte kravene.

Dette prosjektet utgjør tidligfasen av en omfattende utviklingsprosess for å utforme en mekanisk behandlingsmetode mot lakselus. Derfor er det ikke blitt utviklet en endelig løsning med riktige materialer og metriske mål. Målet med utviklingsprosessen har vært å flytte behandlingsmetoden ned i merdene hvor laksen lever, og samtidig å redusere pumpingen opp i brønnbåt, som normalt har vært den tradisjonelle prosedyren. Det ble vurdert at dette kunne føre til en mer effektiv oppdrettsproduksjon, slik det har vært for

dyrehold i landbruket. Produksjonsmetoder for sluttløsningen er ikke blitt undersøkt og beskrevet, ettersom dette krever at det bygges en fullskala prototype som skal testes.

Det endelige resultatet av dette prosjektet er et traktformet rør, med innlagte kurver i lengderetningen. Dette er ment for å tvinge laksen til å endre svømmeretning, siden røret endrer senterpunktet i lengderetningen. Dette vil tvinge laksen nær nok til behandling av lakselus som skal skje. Behandlingen av lakselus blir gjennomført fra fire vannuttak plassert langs røret, hvor det er store mengder vann som blir sugd ut av et pumpesystem. Den utadgående vannstrømmen er ment å ekstrahere lus som sitter på utsiden av laksen. Løsningen gjør det mulig å behandle laksen kontinuerlig og ved hjelp av lite vedlikehold og arbeidstid. Det vil også kunne gi en mulighet for behandling med høy nøyaktighet og effektivitet, uten å utøve en enorm stressfaktor på laksen.

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1 INTRODUCTION

This first chapter is an introduction to the field of farmed salmon and the different treatment methods against salmon lice. The introduction includes information about the salmon farmed plants, the treatment methods and a presentation of the salmon lice's life cycle.

1.1 The report structure

This project report starts with an introduction to the field of farmed salmon and continues with a review of currently used lice treatment methods. This introduction should provide the required knowledge for the upcoming concept development process.

However, before describing the concept development phase, a review of the used methodology is presented under chapter 4. This chapter describes the procedure for the conceptual product development. The first step in the procedure is to form the concept definition that sets the specifications for the further brainstorming phase. The brainstorming procedure is then described with accompanying simple sketches to present the ideas. The most feasible ideas are then evaluated in a screening procedure in chapter 9. This evaluation is conducted on basis of the specifications formed in the concept definition, chapter 5. The most applicable concept is chosen and more fully described. The presentation involves 3D visualizations and results from a flow simulation study created in the CAD application Solid Works.

1.2 Background

The background for this master thesis is a growing problem in the salmon farmed industry, which is the salmon lice or Lepeophtherius salmonis. According to the research center Nofima, the salmon lice until today represents a cost of approximately 3 billion NOK annually in the Norwegian salmon industry and number still increases[1]. This means that the parasite is the largest obstacle for further growth for the farmed salmon companies. "As long as we have as much salmon lice as we have today, we can not increase the volume of farmed salmon", says Jon Olaf Olaussen, professor at NTNU[2].

The salmon farmed business has had an extreme growth since the beginning of the 1970s. Today the production is thousand times as much as in the early 1970s[3], and the growth is still going on. Norway produced a world-leading 1.16 billion metric tons of farmed Atlantic salmon in 2013[4]. The Norwegian Government has a vision of a fivefold of the industry by 2050, which means an annual growth of almost three percent[5]. This vision sets a high demand for the future production, and the Norwegian Fisheries Minister, Per Sandberg, states the extermination of salmon lice as the main objective to achieve the Government's vision of growth[6].

The salmon farmed industry is a huge export industry in Norway, and in 2015 it was exported salmon for 47,7 billion NOK[7]. This was a record high number, and the growth is assumed to persist. According to business executives on the west coast of Norway, the salmon farmed business will be Norway's largest business in 30 years, even greater than the petroleum industry[8]. Further improvements of the production and solving the salmon lice problematic is therefore a key point for the export of salmon to be able to replace the export of oil, which has been crucial for the prosperity of Norway.

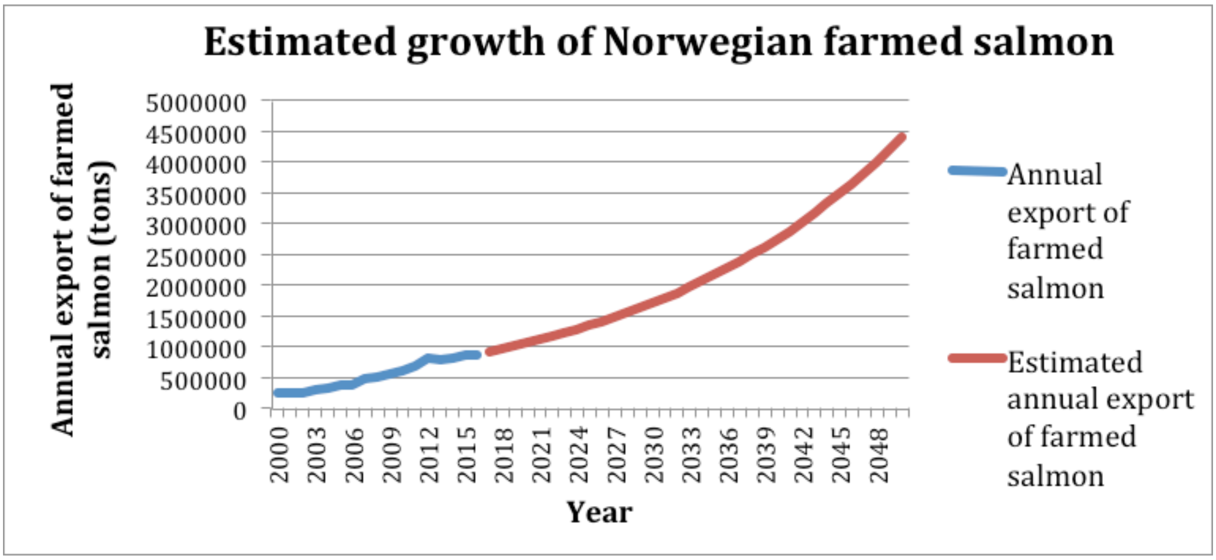


Figure 1: Historic export and estimated export of Norwegian export of farmed salmon based on the Governmental goal for 2050[9].

The rising demand of seafood worldwide sets an exceptional good basis for further growth. The shortage of production has to come from farmed fish in aquaculture, since the wild fishing cannot cover the needed supply[10].

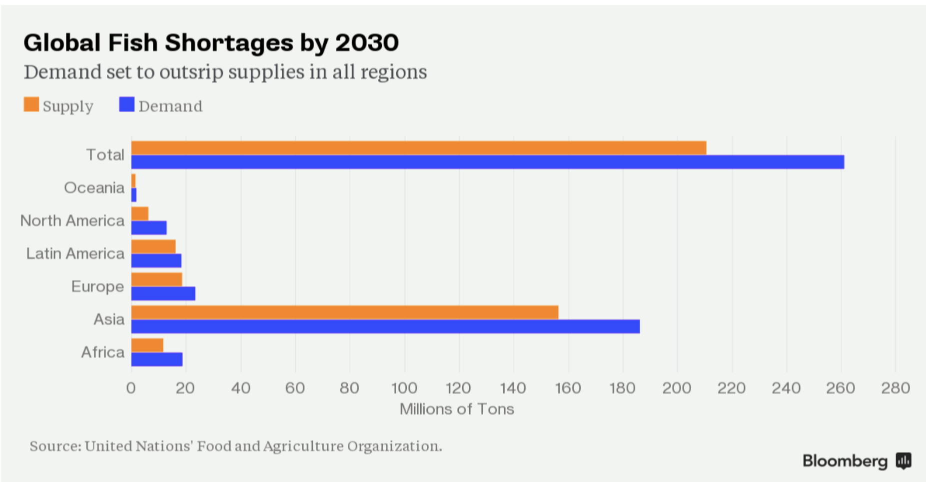


Figure 2: The forecasted demand and supply for seafood in 2030[10].

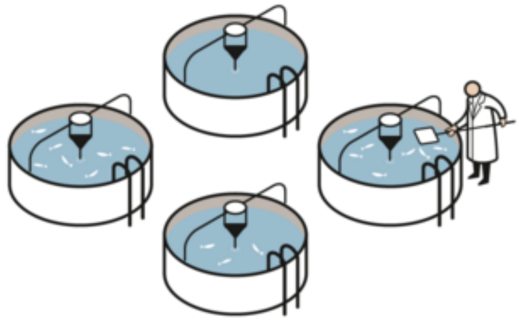
1.3 The production cycle of farmed salmon

The figure below shows the cycle of farmed salmon with the different steps that are included in the production cycle.

1

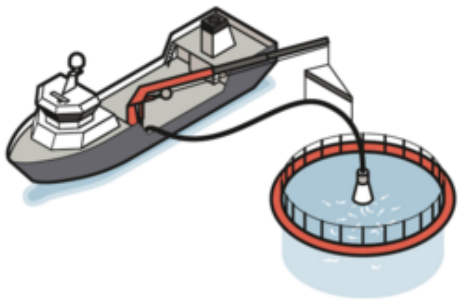
Eggs: There are about 5000 fertilised eggs per liter, which are kept in incubation tanks in fresh water. From the eggs hatch tiny fish called *alevins*.

2



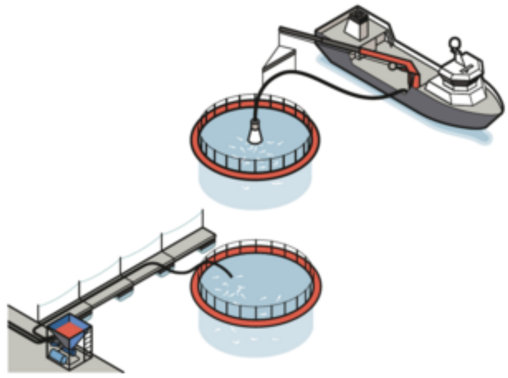
Parr: After the tiny fish weigh about 6 grams they are moved to larger freshwater tanks. They live here to they are about 60-80 grams.

3



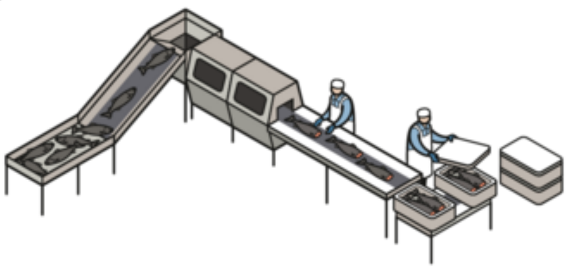
Smolt: The smolt stage is where the fish changes physiologically and can now live in seawater. The smolts are kept in net pens until they mature into adult salmon.

4



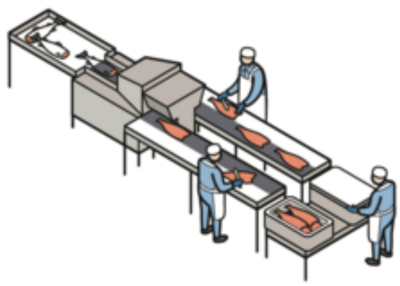
Harvest: The salmon is kept in the net pens in excess of one year when the fish has reached the market weight of 4.5-5.5 kg. The fish is then harvested.

5



Processing: After harvesting comes the processing of the fish, done on a various of specialized facilities around the world.

6



Distribution: The fish is distributed all over the world.

Figure 3: The salmon farming process for Marine Harvest can be divided into these steps[11]

1.4 The behaviour of the salmon

There are some interesting aspects about the behavior of the salmon. In this chapter these distinctive behaviors will be discussed.

- **Attracted to counter flows**

Salmon are anadromous fish, which means that they are migrating up rivers from sea to spawn. They are born in freshwater (rivers or streams) but travel to live much of their lives in salt water and return to freshwater to spawn. As a natural instinct, salmon is therefore attracted to counter flows. This instinct can also be seen for farmed salmon, even though they never have swum upstream a real river.

A concept that uses this technique for attracting salmon is the Fish Cannon by WHOOSHH Innovations, which are a transport device for salmon between lakes. The salmon feels the unnatural counter flow coming from pumps used in the Fish Cannon. The natural instinct tells the salmon to swim upstream and enters the narrow opening at the top (see Figure 4.) The fish is then pushed through a tube by a positive pressure, and finally dropped at another lake[12].

Figure 4: Showing the Fish Cannon attracting the salmon by using a waterfall.

The Figure 5 below, shows how the salmon is getting attracted to the counter flow and the narrow opening, which the salmon pushes it self through without knowing what is on the other side. The natural instinct is telling the salmon that this is the right way to swim.

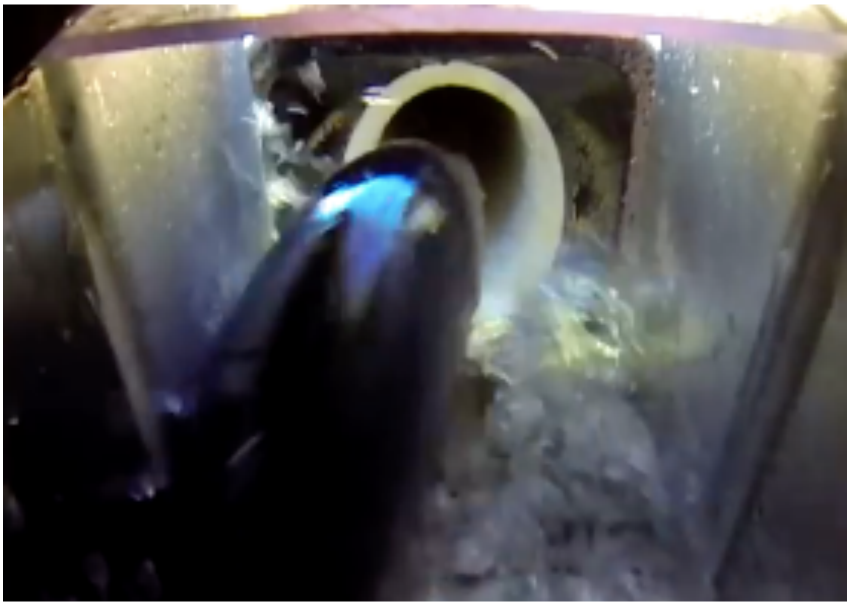


Figure 5: Image of the salmon going through the narrow opening at the Fish Cannon.

- **Luring methods**

There have been researched a lot on different methods to luring the salmon, since the salmon picks their environment. And the environment inside the net pen can differ significantly with time and depth. These environmental choices can be based on different factors like temperature, oxygen level, salinity, water current, lighting, feeding regime, appetite, chemicals and experienced fear[13].

- **High adaptability**

The salmon is very adaptable and can eat a lot in a short period of time, or little bit all day long. If many salmon are put in a net pen there will start to form a shoal pattern. The pattern means that the fish will swim close together and keep a distance from the netting. The result is that the salmon will swim in a circle on a curtain depth of the net pens. They choose to swim on large depths because of the water temperature and they try to avoid sharp lights in the daytime[14]. Frode Oppedal at the Institute of Marine Research says: "These behavior choices implies that the volume in the net pens does not get fully used, and the fish swims tighter on some depths. It is typically to observe that the actual density of salmon in the net pens are 1,5 to 5 times as high as if the salmon was evenly distributed, and in extreme cases up to 20 times."[15]

- **Ability to stand hydrostatic pressure**

Wild salmon has been recorded down to 550 meter depth, and sometimes in the winter even further down[16]. At these depths the pressure equals 56 bar or 5,6 MPa.

1.5 The life cycle of salmon lice

Figure 6: The female and male louse at their adult stage[17].

Lepeophtheirus salmonis

The salmon louse, *Lepeophtheirus salmonis*, is a sea louse, a parasite that lives mostly on salmon. The louse occurs in water on the northern hemisphere. It is an ectoparasite, which occurs on all salmonid species as salmon, trout and char[17].

The above figure shows a female louse to the left and a male louse to the right at their adult stages. The female louse has an egg string hanging as a part of the parasite body. The size for the adult female can be up to 12 mm (29 mm with egg strings), and 6 mm for the adult male louse[17].

The figure below shows how the louse is attached to the salmon´s body.

Figure 7: A female and a male louse is attached to a salmon´s body[18].

Life cycle

The life cycle of the sea lice can be divided into a free swimming and a parasitic stage[19], as shown on the figure below[20]. Altogether there are eight stages, and as the lice grow throughout these stages, it continues to molt. Between all stages the lice has a shell replacement, which allows the lice to continue to grow.

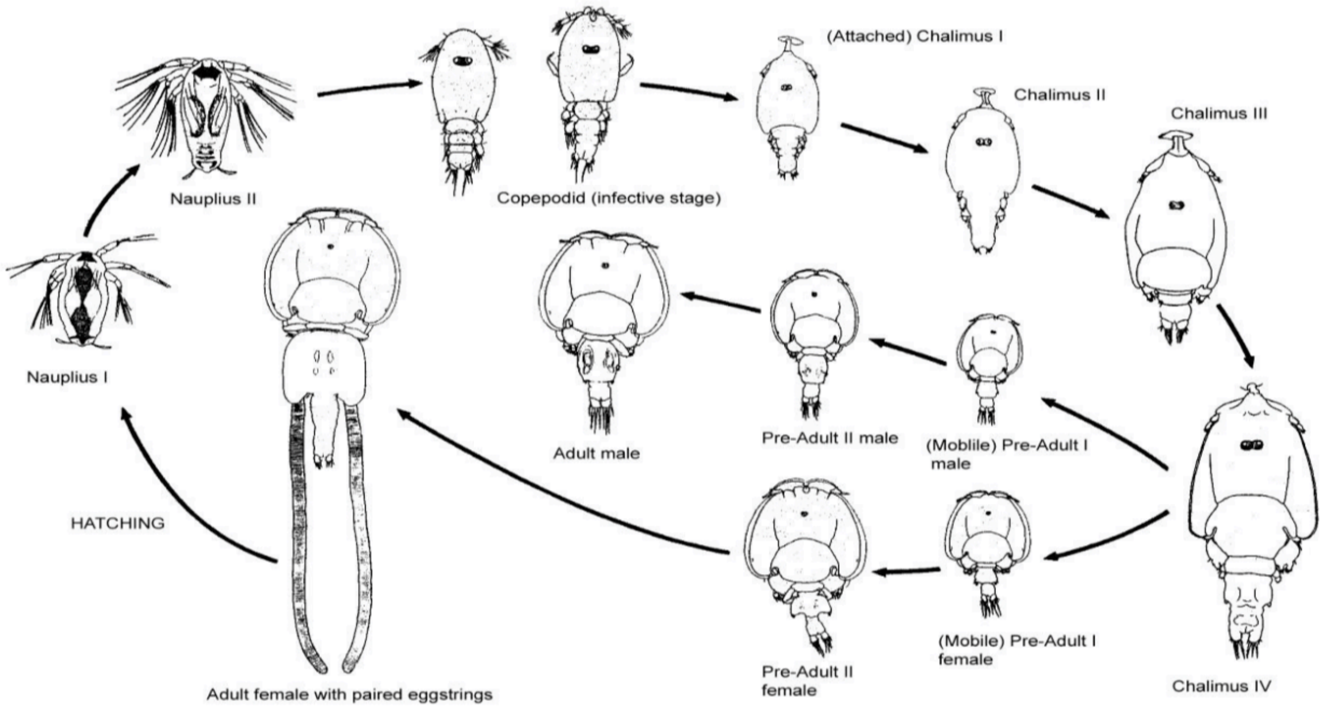


Figure 8: The stages in the life cycle of the sea louse[21].

Free-swimming stages:

- ***Napulius I and II*** are the two first stages, and they are both a free-swimming part of the life cycle. They hatch out of eggs and does not have the ability to swim directionally against the water current, but only drift passively and adjust their water depth in the vertical direction. They are almost translucent in colour and sizes vary between 0.5-0.6 mm in length.

- **Copepidid** is the next stage after Napulius II, and it is the last free-swimming stage. As they mature, the louse finds a host to live on, but the louse is not yet attached to the fish. The first attachment to the salmon usually occurs at the fins or the scales of the salmon, and the Copepodid clasps the tissue of the host. Then after settlement undergoes a moult to the first sessile stage in the life cycle. The typically measures of the Copepidid is about 0.7-0.8 mm.

Parasitic stages:

- ***Chalimus*** is a parasitic stage, and it is the stage where the lice attach themselves to the fish. Like a tether, they use their frontal filament to attach themselves to the host. The start length of the Chalimus is around 1.1 mm. The louse continues to grow and develop, and at the end of the stage is the length around 2.3 mm.

- ***Pre adult I*** is the first stage where the louse is capable of moving around on the skin of the fish. It is possible at this stage to divide the louse into sexes, where the female has a gender segment which is more triangle shaped. The male has a barrel shaped gender segment and has a length of 3.4 mm, which makes it smaller than the female that is 3.6 mm in length.

- ***Pre adult II***: In the transformation from stage I to II the louse attach itself to the fish again using the frontal filament. The difference between the sexes is now even greater, and it is now possible to see the difference of the sexes without using a loupe. During the stage is the gender segment growing in the similar shapes as before. In the pre adult stages the louse can be found all over the fish, but it is most common found on the fish's head, the gill cover and the backside. The difference in size is now even greater, due to the different growth in the gender segment. The male measures around 4.3 mm and the female is 5.2 mm.

- ***Adult female*** is easily recognized, since she often has long egg strings. The cephalothrorax is oval and the fifth segment is shorter and thinner than the gender segment. The adult female is commonly found behind the adipose fin and the anal fin. The length at the adult female can differ a lot dependent on the egg strings, but usually the length is between 8-18 mm.

- ***Adult male*** has the same cephalothrorax as the female, but it is smaller in size. The male seems to be all over the salmon, but it is typically to find at the anterior regions, such as the fish's head, the gill cover and the back area. The adult male is shorter than the female in length because of a shorter gender segment, and mean length measures about 5-6 mm.

Duration

The normal duration at the different stages at 10°C water temperature is about 10 days for Copepodid, 25 days for Chalimus, 10 days for pre-adult 1 female and 12 days for pre-adult 2 female. The duration for the two male pre-adult stages, 1 and 2, are usually about 8 and 9 days respectively[17]. If the water is colder the duration is longer, and opposite.

The infestation

A salmon can have a lot of lice attached to it. There can be found a lot of lice at different stages and at different places on the salmon. This makes it uncertain where the lice can be found and how well it will be attached to the salmon. However, it is easy to remove the lice from the salmon according to Dalvin Sussie at the Institute of Marine Research. "It is easy to take the louse off the fish with a tweezer, so there is no need for great forces", he says.

Affect on the salmon by infestations

The sea lice can travel along the water current for many kilometers before they reach suitable hosts. After they have found their host, they live off mucus, skin and blood from their host fish. This increases the probability of infections from for instance bacteria and fungus, and it also affects the osmotic salt balance to the fish[22]. Figure 9 shows how damaged a salmon can get from the salmon infestations.

Figure 9: Salmon damages due to salmon lice infestations[23].

This was a short description of the life cycle of the salmon lice. Knowledge about the life cycle can be used to design a working treatment method against salmon lice.

1.6 Traditionally Treatment Methods of Salmon Lice

This chapter describes different methods for how the salmon lice are currently being removed from the salmon´s body. Today, there exist a wide range of different ways of treating the salmon lice, and new treatment methods are being developed and tried. Therefore will the following chapter only involve the most used methods for treating salmon: medical treatment and cleaner fish.

1.6.1 Medical treatments

The use of chemicals is a very common method for getting rid of the salmon lice. There are a several options when it comes to type of chemicals and how they are applied, but the most common is Hydrogen Peroxide. The chemicals can be applied in a bath for the fish or an as an ingredient in the fish food. When using the chemicals as a bath, the net pen gets surrounded by a tarpaulin to assure that the medicaments stay inside the net pen.

There are several factors that determine the delousing process and how long the fish has to be in the bath of chemicals. Some examples of those factors can be the type of delousing agent that is used, the temperature of the sea, the amount of lice, size and amount of salmon etc. The treatment method has raised a lot of opinions on whether this is a safe treatment for the fish and for the environment around the net pens. But another problem with this this type of treatment is that the salmon lice is getting resistant, which means that more medicament has to be used and eventually this treatment has no impact on the lice. There is a huge interest in the industry to find a new chemical treatment that the louse is not resistant to, but it has not made any results yet. Another difficulty with the chemical treatment is that the salmon has to be starved 2-4 days prior the treatment[24]. The reason for the starvation is to assure the environmental conditions and to lower the amount of stress on the fish, and also to lower the oxygen consumption.

Figure 10: Atlantic salmon treated with hydrogen peroxide[25]

1.6.2 Cleaner fish

A cleaner fish is a fish that provides a service to other fish species by removing dead skin and ectoparasites[26]. The most common type of fish used as cleaner fish today is wrasse and lumpfish. There are six types of wrasse species in Norway, but only three of these are used for the removal of salmon lice in farming; Wrasse, Corkwing and Goldsinny. These wrasse species are good lice eaters, but they are not so active in the winter, when the lumpfish are used. Lumpfish is active at low temperatures, so that is a common cleaner fish when farming in northern parts of Norway.

Figure 11: A wrasse eating a louse attached on a salmon[27].

The cleaner fishes swim along with the salmon in the net pens, and eat the lice that are attached to the salmon, see the figure above. There is not an exact science on how many cleaner fish there should be in a net pen, but the Marine Harvest plant at Vigra used about five percentage of the total amount of salmon in the net pens. The use of cleaner fish has proven to be a sufficient way to reduce the increment of salmon lice and there is not too much work associated with the treatment. This has made a high demand for cleaner fish, and it is been developed an own farming business of cleaner fish. Over ten million cleaner fish is annually dropped into the salmon net pens, and their lives are often short and stressful[28]. This has raised a discussion about the cleaner fish welfare.

Figure 12: A numerous of cleaner fish eating salmon lice[29].

1.7 Future delousing methods

The following chapter is describing the treatment methods that are currently being developed. Some of them are just in the idea or concept stage but they can give an insight on how the future delousing methods may look like. Others are close to commercializing their concept and may be an essential part of delousing methods in near future.

1.7.1 Delousing oil

Figure 13: The salmon jump through the water line and can be coated with oil[30].

Delousing oil is an idea that has its origin from 1989 but after a while got shelved. Since then it was not been improved until in 2011 when it got a new interest for scientists. The idea is based on the concept that the fish should jump through a coat of oil that lay on the water´s surface. The oil film will then exterminate the lice on the salmon. The most challenging problem related to this idea is that the fish does not tend to jump enough, but now the scientists might have found a solution to this problem. Some scientists figured that if the salmon does not have the ability to jump over the water surface for one to two days they would be more motivated to jump if they get the chance. Therefore a barrier between the salmon and the water surface is a way to get the fish to jump after the barrier is opened again[30].

1.7.2 Optical delousing

Optical delousing[31] is a concept that uses camera vision to identify the lice attached to the fish and a laser to remove the individual sea louse from the fish. The technology used is developed by a Norwegian company called *Stingray Marine Solutions AS*. The method should be gentle to the fish, and the lice are being killed so they are not a threat to the environment.

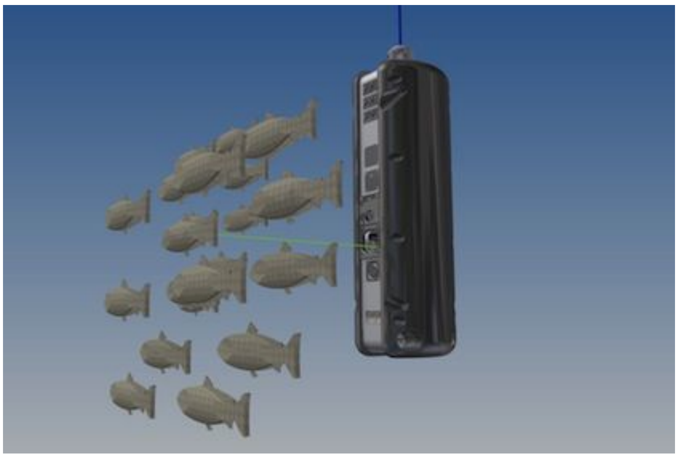


Figure 14: Illustration of the optical delousing from Stingray, using a laser to delouse.[32].

1.7.3 Water spray machine

There are basically two different types of delousing methods with a water-spraying machine, used by the two companies Flatsetsund Engineering AS and SkaMik AS. They are a bit different but the main concept is the same. Both companies conduct the following procedure: the fish are pumped up from the net pens and then get flushed by seawater. In addition, SkaMik also brush the fish to remove lice. After the removal of lice the fish are pumped back to a net pen. One good aspect of this method is that they collect the lice and destruct them, but it is heavily debated if these methods improve fish welfare or not.

Figure 15: Large vacuum pumps are used to pump up the salmon for treatment[33].

1.7.4 Fresh water treatment

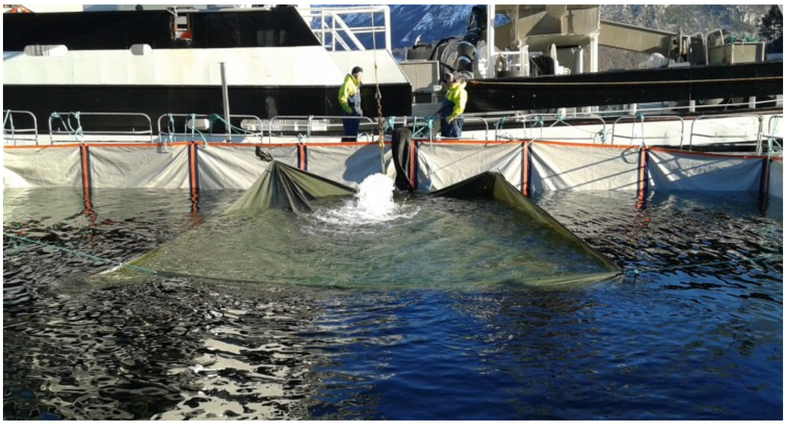


Figure 16: Fresh water is pumped out in a limited area, where some salmon are being treated[35].

The process of this treatment starts with the pumping of salmon up in a fish carrier that has a chamber full of fresh water. Then the salmon is held in the fresh water for about 2-3 hours before the fish is released back to the net pens. During this process there has to be added oxygen to the fresh water and carbon dioxide must be removed. The director of Research and Development in Gifas, Ronald Jørgensen, says that with enough time in the fresh water it is possible to exterminate up to 90 percent of the lice[34].

1.7.5 Thermal delousing

The concept is pretty similar to the water-spaying machine. The only difference is that the fish are flushed with warm water at a temperature around 30-35 degrees Celsius, before they are moved to a warm water bath where they are kept in 20-25 seconds. Then the fish are flushed back into a new net pen, and filters in the process collect the dead lice caused by the warm water. Thermolicer designed by Steinviks AS is a product that uses this method, and Anne-Gerd Gjerve from the Veterinary Institute states regarding Thermolicer that: "It is an absolute potential, but for the further I think it will be wise to have focus on a system that is adapted to the fish in a best manner, and not the other way around. Fish welfare has to be ensured"[36]. She is referring to the vacuum pumps that are pumping up the loads of fish, and this process might hurt and stress the fish.

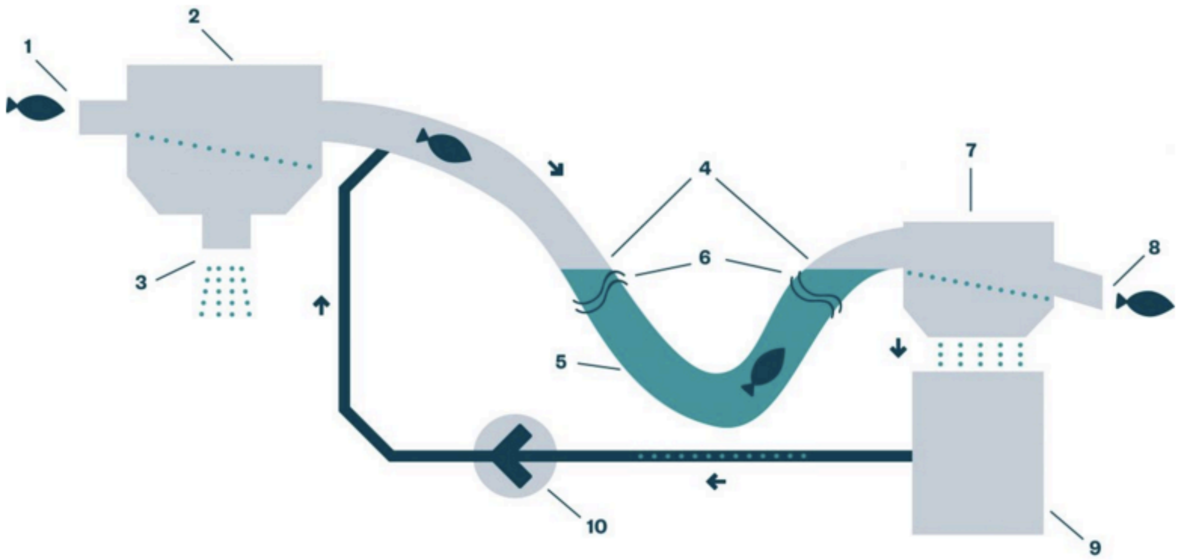


Figure 17: The figure shows the process of the Thermolicer[37].

Table 1: The list below explains the stages in the Thermolicer process.

No.	Activity
1	Fish enters Thermolicer after pumping.
2	Water separation.
3	Seawater is filtered and released.
4	The fish is exposed to lukewarm water.
5	Treatment loop.
6	Water surface.
7	Water separator for treatment water.
8	Fish exits the system.
9	Heated water is circulated to water tank for filtration, aeration and reheating.
10	Treatment water is pumped back to the treatment loop.

1.8 Future preventive mechanical delousing methods

Instead of delousing the lice from the salmon´s body, another way to avoid lice infestations can be to prevent the lice from entering the net pens where the salmon live. There are several ways for how this can be done and there are several concepts currently under development, which may be an important part of the lice treatment in the future. These future concepts will be discussed and shortly reviewed in this chapter.

1.8.1 Seafarm Pulse Guard (SPG)

The Seafarm Pulse Guard is a concept, which prevents the lice from entering the net pens by using a form of electronic netting or electronic fence[38]. The netting around the net pens uses electronic pulses to stun the lice, which are in the free-swimming stage (Copepidid), and the lice is then drifted through the net pen without attaching to any salmon. The method is quite new, but it has been proven to be over 90 percent effective in laboratory studies[39].

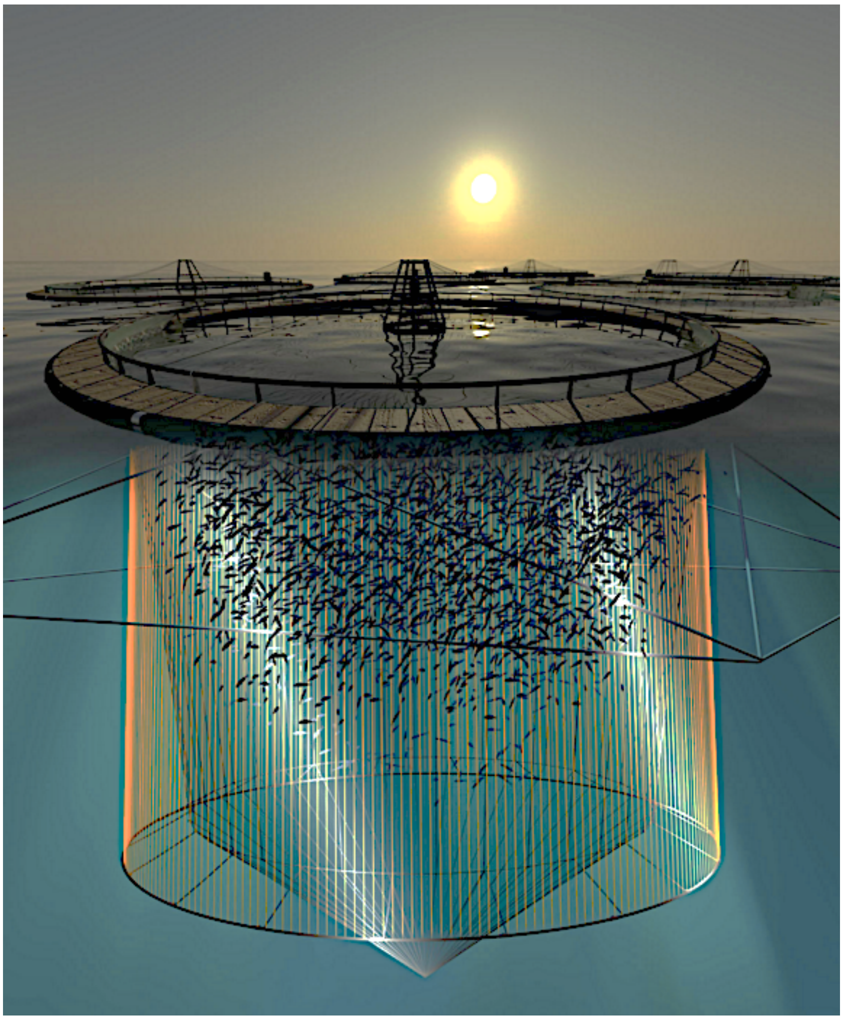


Figure 18: Illustration of the Seafarm Pulse Guard installed at a net pen[40].

1.8.2 Snorkel net pens

This is a concept developed by the Institute of Marine Research, and the main idea is to keep the fish at a certain depth where the salmon lice do not live. The solution is to have netting at a depth of 3-5 meters over the area the fish live in the net pen to prevent them from swimming over this depth. Then there is placed a tube or a snorkel from the water surface and down to the netting. This allows the fish to fill up their swim bladders when that is needed. This method has been proven to be very effective, and results have shown up to 84 percent reduction of lice infected salmon[41].

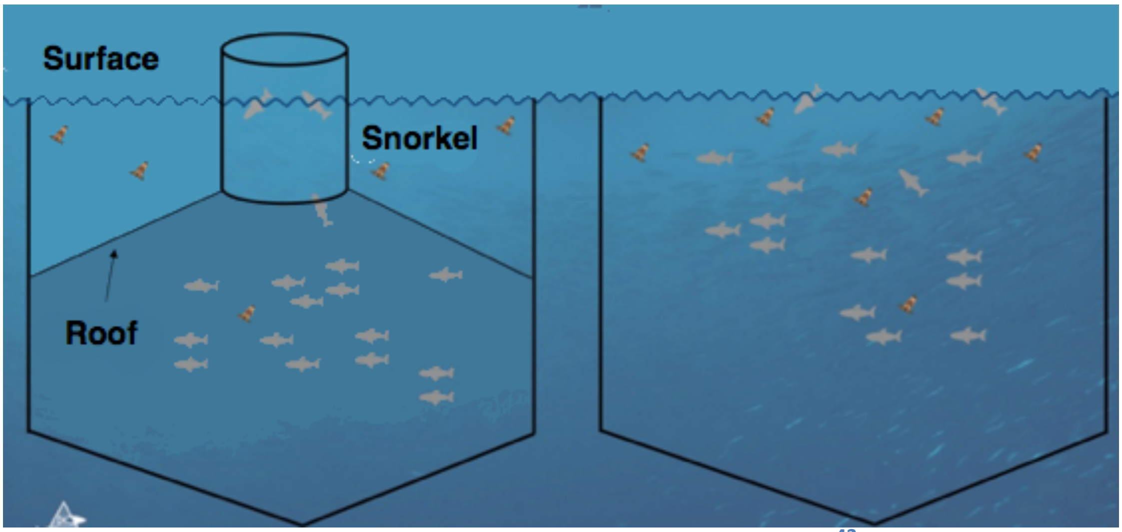


Figure 19: Shows the concept of the snorkel[42].

1.8.3 Closed plant

Closed plant is a collective term for plants that are based on the idea that the net pen should be closed and nothing should go in or out of the plant. One way to do it is to use a big bag, and in the bottom of the bag it is a hose that is a output of rests from fish food, sludge, fish waste and dead fish. It is also an input of seawater, which is pumped up from 25 meters depth because the water is less likely to consist of salmon lice at huge depths. Another concept is the new concept developed by Hauge Aqua, and is now being tested by Marine Harvest. These are totally closed net pens, which are placed in the ocean.

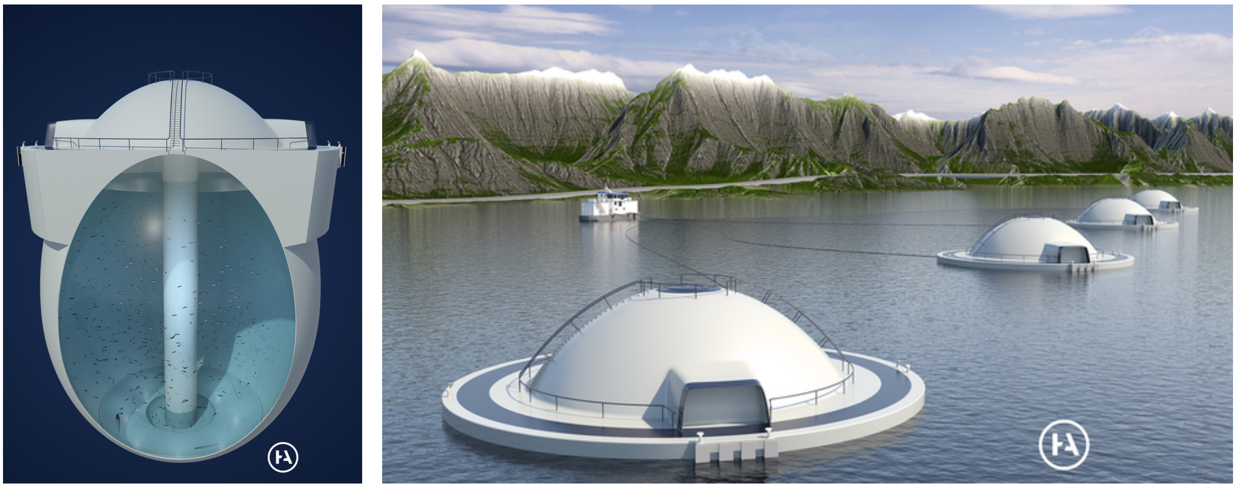


Figure 20: New concept of closed plant known as "The egg" from Hauge Aqua[43].

1.9 Summary and comparison of the different treatment methods

In the previous chapters, the currently used and the future treatment methods have been reviewed. The following table is a recap of all of these methods with pros and cons.

Table 2: Pros and cons for the different treatment methods.

Treatment method	Pros	Cons
Medical treatment (Hydrogen Peroxide)	Effective way to extinct every lice in the plant.	The lice get resistant, which means an increasing of the dose. This harms the fish as well.
Cleaner Fish	The best way today to reduce the increment of lice in the plant.	Needs to be regulated, and entails a dependency of sub suppliers of cleaner fish.
Delousing oil	Harmless for the salmon.	There are questions how effective the oil is.
Optical delousing	Low investment and can treat the salmon in the net pens.	Been incidents when the lacer have injured eyes of the salmon.
Water spraying	Effective way to treat many salmon as an assembly line.	Can be to rough and harm the salmon's mucous membrane.
Brushing	Effective way to treat many salmon as an assembly line.	Can be to rough and harm the salmon's mucous membrane.
Fresh water treatment	Harmless treatment for the salmon.	Not so efficient results of treatment, and the lice are getting more tolerant against fresh water.
Thermal delousing	High dead ratio of the lice.	High-energy consumption by heating water. Cleaning reuse of heated water necessary with
Sea-farm Pulse Guard	Prevents the lice to enter the net pen, which reduces the increment significantly.	Needs a relative high expertise to operate, energy consumption and can be a safety issue.
Snorkel net pens	Can reduce increment of lice.	Does not secure that there will be no lice, and the increment after the first lice will likely to be high.
Closed plant	Secures no lice or predators in the plant.	High operating and investment cost.

1.10 Challenges linked to current methods

There are many treatment methods on the market and even more under development. The salmon farmers are desperate to find new sustainable solutions, and this desperate quest for a more efficient production have at some occasions led to rough treatment methods on the expense of the fish's welfare. For instance when Marine Harvest in 2015 used hydrogen peroxide to delouse a net pen with 190 000 salmon, and almost 9 percent of the fish died. This makes the total of 70 ton of salmon. The Norwegian Food Safety Authority said it was a violation of laws, and that it was a very serious incident[44]. But this is not the first time, and it is most likely not going to be the last since the resistance of the lice to hydrogen peroxide makes it necessary to use larger doses to exterminate the lice, and larger doses means a larger death rate of fish.

Another tragedy happened in November 2015 when Salmar was going to cleanse the net pens for salmon lice. During the process the salmon got overexposed of hydrogen peroxide, and in 26 minutes all of the fish died, which was almost 130.000 salmon[45]. This use of medicament is not used without risk, and according to Susanna Lybæk, biologist at the Norwegian Animal Protection Alliance, the high dose of hydrogen peroxide can inflict serious burns on the fish's gills, which eventually kills the salmon[46].

Susanna Lybæk, scientific advisor in the Animal Welfare Alliance, is very active in the protection of the salmon and she has the belief that the future's treatment methods have to look at the salmon's welfare as the highest priority. "*Generally, it is stress that is the main problem with every lice treatment. All maneuvering of the salmon (pumping, crowding etc.) causes an increased stress level, and at many circumstances the salmon are already weakened by sickness, lice, hunger, damages or something else. Increased stress could then be "the last drop", which triggers sickness or any other negative consequences*", she says.

In addition to raise the stress level, some treatment methods harm the salmon physically. Susanna Lybæk points to the use of brushes and flushing of water. "The salmon has a mucous membrane on their shells, which is a critical part of the salmon's immune system. Everything that harms the mucous membrane is potentially very damaging for the salmon's health and welfare".

Many people criticize the way the breeders operate, and the increment of lice has increased the criticism. Some have the opinion that the only solution is the closed plant solution, and either put them on-shore which has been the traditionally way, or has the new concept, The Egg by Hauge Aqua. The challenge with both solutions is the amount of water needed to farm salmon at today's rate, and it demands a huge investment cost.

1.11 Agriculture versus Aquaculture

The farming of salmon is a relative young business compared to the farming in the agriculture. The farming in the agriculture as changed a lot since the origins, and today's farms has a lot advanced technology that is monitoring, feeding and harvesting etc. The new advancement has made the agriculture more efficient.

One part of the agriculture that has had a tremendous transformation the last century is the farming of cows and milk production. There has the farming and milking process transformed from manual labor to a totally automatic production.

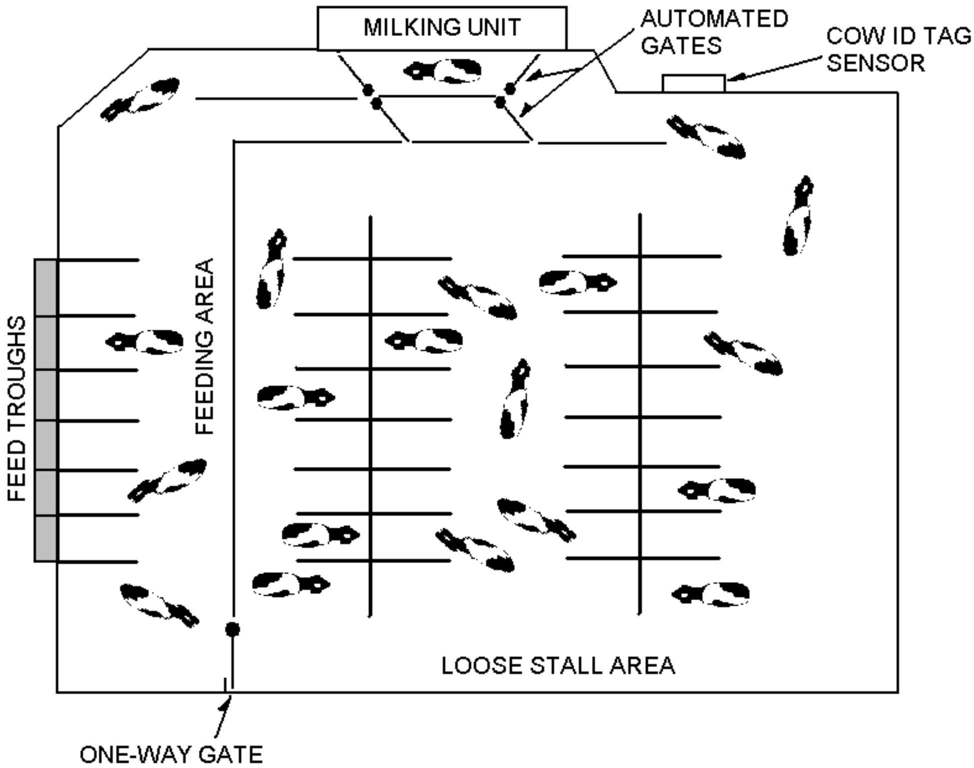


Figure 21: Cow farm layout of a voluntary milking system[47].

The layout is divided into sections where the cows are stationed (see Figure 21). The main station is the loose stall area where the cows are sleeping and living. The cows are wearing an identification tag, which makes it possible for the gates to identify that exact cow and regulate the milking and feeding area to the cows that have not eaten or needs to be milked. The milking and feeding process are also automated before the cows are let back into the loose stall area.

This farming process has been developed through years of research and testing. And it may be possible to adapt some ideas and the mindset over to the aquaculture. It is possible that the farming process could be designed in a similar way, even though the amount of individuals is a lot more.

1.12 Key Issues

The key issues for the conventional delousing methods are listed below. These issues form the background for the project objective and the project plan, which are described in the next chapter.

- For conventional lice treatment, the fish has to be pulled up from the water to conduct the treatment. This makes the treatment a complex procedure, which could be easier if the treatment was conducted inside the net pen where the salmon live.

- Medical treatment, which is a very common delousing method constitute a major risk for the salmon´s welfare.

- For currently used treatment methods, the lice treatment is not constantly active, but initiated when the level of lice is at a critical level. Instead, a constantly working lice treatment would keep the lice infestations at a low level at all times, and it would stabilize the amount of lice in the net pens at a sufficient level.

- The adult female louse is the critical factor for the rapid increment of salmon lice in the net pens. The currently used lice treatments are not specifically designed for exterminating the adult female louse, which potentially would reduce this increment.

1.13 Quality Assurance

The development of the device(s) in this project report has been reviewed and commented regularly by supervisors at the Norwegian University of Life Sciences and has been subject to modifications and further development.

2 PROJECT PLAN

This chapter gives an overview of the project objective, which describes the main objective and the corresponding secondary objectives for this master thesis. The project schedule with all the project activities and corresponding milestones are also listed in this chapter, among with the project limitations.

2.1 Project Objective

The main objective is to identify and examine the possibilities for a mechanical treatment method to solve the salmon lice problem in the salmon farmed business. Furthermore there will be developed proposals for concepts with the aim of satisfying all the requirements that are defined, and finally contribute to resolve the problem of salmon lice in the industry. The product development process will be reported, and the concept-generating phase will be systematically described in detail, and finally a result will be presented.

Secondary Objectives

To fulfil the main objective, there is a list of secondary objectives that are listed below.

1. Hold a kick-off meeting.
2. Define the project specifications.
3. Identify the existing treatment methods of salmon lice and their challenges.
4. Develop the system and functional analysis.
5. Brainstorm and identify possible ideas.
6. Develop and conduct the concept screening.
7. Conduct an external company visit.
8. Choose a final solution or a concept to develop further.
9. Visualize the concept in CAD drawings.
10. Conduct a flow analysis.
11. Complete the report and hand in.
12. Make a presentation of the chosen concept.

2.2 Project Schedule

The following time and work schedule includes all the project´s main activities and is developed to assure the project progression. The amount of time spent (weeks) on each activity can be read from the schedule.

Table 3: The project schedule with the main project activities.

Activities	January				February				March				April				May			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Kick-off meeting	1																			
Define specifications		2																		
Research of existing methods						3														
System/function analysis							4													
Brainstorming											5									
Concept screening												6								
Company visit									7											
Choose final concept/solution														8						
Visualize in CAD																	9			
Flow analysis																	10			
Report writing																				11
Presentation																				12

Milestones

The milestones listed below are derived from the secondary objectives.

Table 4: The list of milestones with deadlines.

Number	Milestone	Deadline
1	Held the kick-off meeting with Dr. Stevik	5.January.2016
2	Defined the project specifications	15.January.2016
3	Identify the existing treatment methods	12.February.2016
4	Developed the system and functional analysis	19.February.2016
5	Brainstormed and identified possible ideas	18.March.2016
6	Finished the concept screening	25.March.2016
7	Done an external company visit	4.March.2016
8	Chosen final solution	8.April.2016
9	Finalized the CAD drawings	29.April.2016
10	Finalized the flow analysis	27.April.2016
11	Finalized the project report	18. May 2016
12	Made a presentation.	20. May 2016

2.3 Project Limitations

Due to restrictions, the following limitations are set for the project. These limitations state the aspects of the project that not will be considered or conducted during the project phase.

- There will only be conducted a concept development phase, and hopefully result in one concept that fulfill the demands as best as possible.

- There will only be modeled one concept in SolidWorks, due to time restrictions. This can affect the screening process with uncertainty, because with more time would a closer investigation of every concept be conducted.

- The final concept will just involve the process from when the salmon is swimming freely in the net pen to when it is treated from salmon lice. There will not be developed a concept for killing the lice or collecting the lice, but the concepts will be evaluated feasibility for developing these additional features.

- The final solution needs to be docked in the net pen in some way, but this will not be considered in this project.

- Cost evaluations for manufacturing and the final operating will not be considered during this project.

- Precise measurement and manufacturing will not be specified.

- The concept will not be practically tested.

3 TERMINOLOGY

This chapter is an overview of the terminology that used in this master thesis, including definitions, symbols and other terminology that is essential to understanding the thesis.

3.1 Definitions

Table 5: List of definitions.

Definition	Explanation
Alevins	A newly spawned salmon or trout still carrying the yolk.
Anadroumous	Migrating up rivers from the sea to spawn.
Biocompatibility	Properties of materials that are not harmful or toxic to living tissue.
Cephalothrorax	Tagma of various arthropods, comprising the head and the thorax fused together.
Delousing	Removing the louse.
Hydrogen Peroxide	Chemicals used in treatment of salmon lice.
Northern Hemisphere	The half part of Earth that is north of equator.
Smolt	A young salmon (or trout) after the parr stage.
Tagma	Specialized grouping of multiple segments into a coherently functional morphological unit.

3.2 Symbols

The symbols used in this master thesis are listed in the table below.

Table 6: List of symbols.

Symbol	Definition	Unit
ρ	Density	kg/m^3
g	Acceleration due to gravity	m/s^2
p	Pressure	Pa
v	Velocity	m/s

4 METHODOLOGY

This chapter describes the theoretical basis for the conceptual product development. It discusses the early phase of a product development process and gives an overview of different definitions regarding the early phase. In addition, all of the methodology used in this master thesis is described and stated in this chapter.

4.1 Definition of the term "early phase"

The early phase in a project is critical and a crucial factor for the final success of the project. The early phase starts from the first initiative for a project concept, and the phase ends with the final decision to finance the concept[49]. A normal early phase will involve evaluations of different alternative concepts that satisfy a certain identified list of needs, goals and demands, where the decision-making situation often is characterized with a high complexity and uncertainty[48].

The figure below shows a simple product development process, with the early phase, decision-making stages, product development and finally the commercialization of the chosen product:

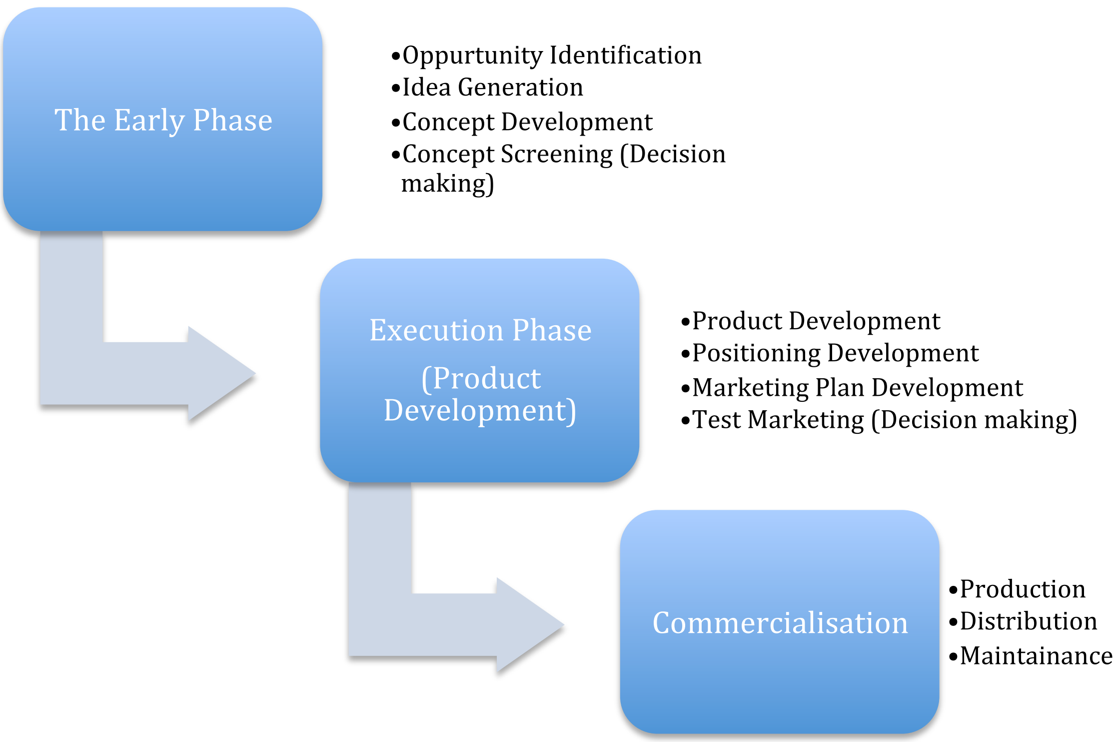


Figure 22: General project model.

Knut Samset is a Professor of Project Management at the Faculty of Engineering Science and Technology at the Norwegian University of Science and Technology. He is the director of the Concept Research Programme and he decribes the early phase of a project as the stage where the project only exist conceptually, and the early phase involves all the activities from the idea of a project is born to the final decision about the execution of a project is enacted[49]. This vision of the early phase is supported by Kjell J. Sunnevåg, who defines the project's early phase as the time from the needs triggering state, to when a decision of which concept that assures the best satisfaction of the needs and this concept is chosen to bring further in the project phase[50].

4.1.1 The cost of information and utility

As earlier mentioned it is important to pay attention to the early phase, and one of the reasons for this is that experience shows that the basis for information is most limited at the beginning of a project. But the uncertainty and possibilities of influence of the project is at it's highest at the early phase. Simultaneous is the cost of a change relative low in comparison to a change in the execution phase of the project. In other words, the chance of increasing the value of the project with relative few resources is highest at early phase[49].

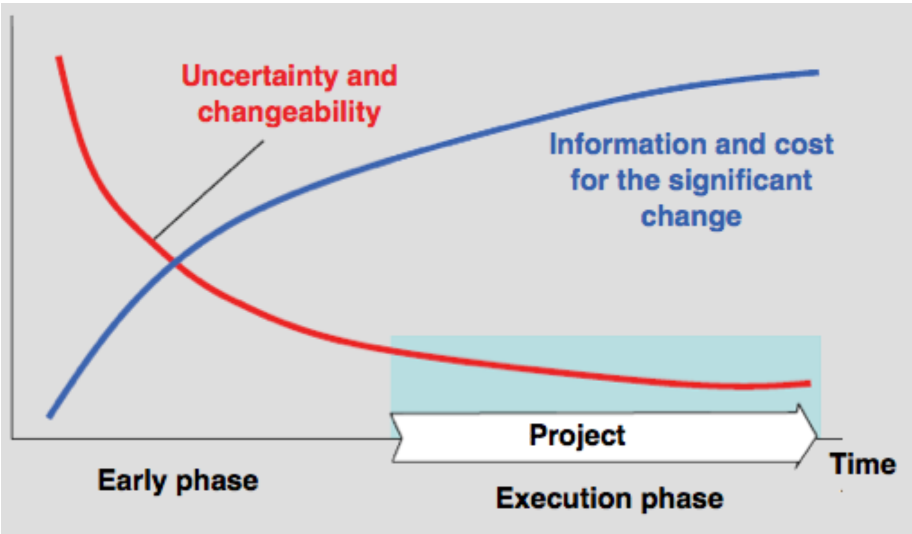


Figure 23: The importance of the early phase [52].

The uncertainty in the project associated with decisions over time is shown in the Figure 23, where it is assumed that the uncertainty is greatest at the beginning when the idea is being born. With time new information is obtained and as an affect the uncertainty decreases as a response. The obtaining of information is an ongoing activity all through the process, and the need of information increases with time throughout the process[49]. The reason is that initially in the process it's going to be most valuable to think comprehensive on the context of the problem the project is meant to solve, where creativity, imagination and intuition are more important than seeking the exact information[50].

The utility of obtaining new information is at is highest when the known information is at it's lowest, which is at the beginning of the development process. The cost of obtaining the information will increase approximated exponential, because the demand on precision, reliability and validity will increase as an affect from the decreasing of availability of information[51]. From the two measures, utility of information and the cost of information, it can be determined a relationship. The relationship is shown in the Figure 24 below.

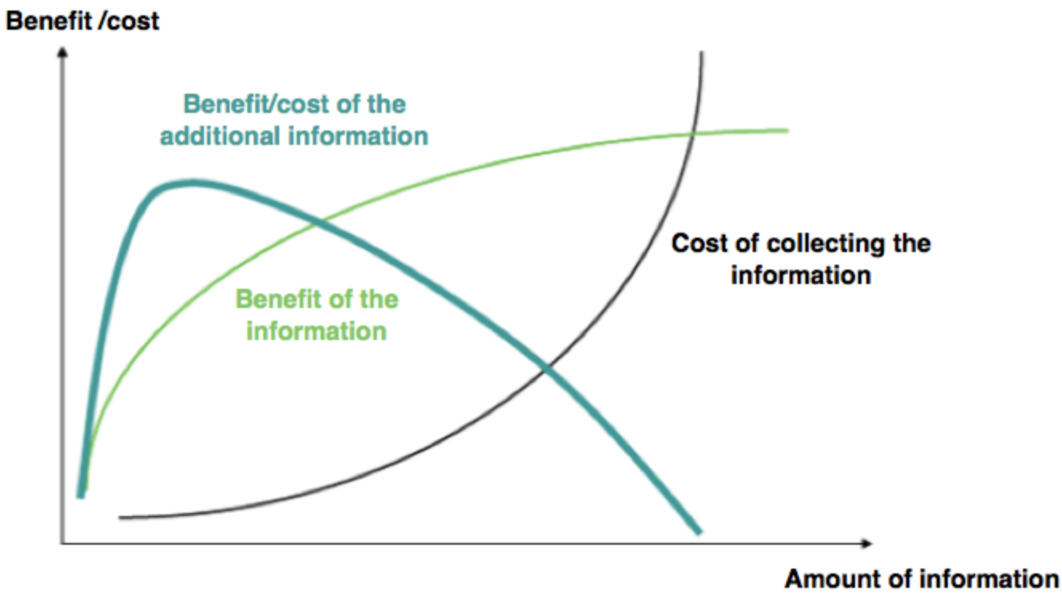


Figure 24: Costs and utility of extra information[51].

The graph for the relationship between the utility and the cost shows that the apex is at the beginning and afterward it is rapidly decreasing. This should be a high incentive to gather the best possible information basis at the early phase of any project process. The lack of information, which makes the decision-maker not capable to predict all outcomes from the decisions, comes from the sources of uncertainty in the project. The resources put into the early phase will be an investment to assure the project's success strategically and tactically[52].

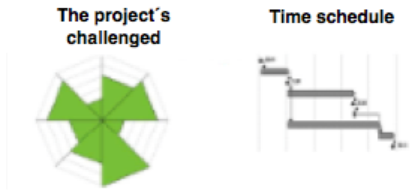
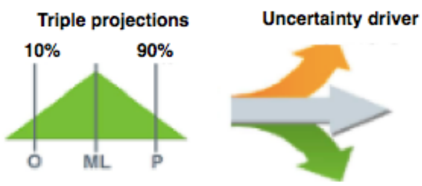
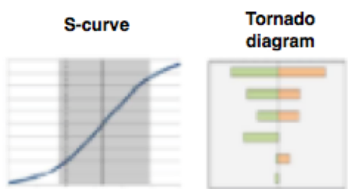
4.2 Conceptual product development

Indications imply that the final choice of concept is as important as the project management in the execution phase[48]. That is why this study will pay a lot of attention to the conceptual phase of a product development process. The process model for the conceptual product development process has the purpose to communicate what the product development should involve to assure that right basis for making a decision.

The conceptual product development process used in this study is presented in Knut Samset's book, "Prosjekt i tidligfasen – valg av konsept", where the focuses are the project's early phase and the choosing of different concepts. The process can be divided into four steps: (i) concept definition, (ii) concept development, (iii) concept evaluation and (iv) concept recommendation.

The Table 7 illustrates the conceptual product development, and it is meant to give an insight on how the process model is organized. The early phase of the process is divided into four stages with sub activities in every stage. This is done to assure the best possible process to fulfill the needs of input to the product development.

Table 7: An overview of the concept development process.

CONCEPTUAL PRODUCT DEVELOPMENT	
1 **CONCEPT DEFINITION**  a. System analysis - System definition - Analysis of demands - Define the objective - Define the specifications b. Concept alternatives c. Rough screening of the concept	2 **CONCEPT DEVELOPMENT**  a. Identify elements of uncertainty - Actions to meet uncertainty b. Hierarchy of goals and plan of iterations c. Concept testing
3 **EVALUATION OF CONCEPT**  a. Evaluation based on utility function - Established evaluation model - Feasible analysis - Robustness in the recommendations	4 **CONCEPT RECOMMENDATIONS**  a. Summarized evaluation and priorities b. Recommendations c. Guidelines for further work

This process describes needs, goals and requirements before different concepts or decision alternatives are procured[48]. The purpose is to focus on needs and goals for measures, before it is discussed actual solutions to meet the needs or achieve the goals. The outcome is a focus on value as opposed to a focus on solutions, and this reduces the risk of a narrow creative process. Therefore it is more likely to see new ways to realize wanted values and goals[48]. The creative process is iterative, which means that it's normal to be crossing the same steps in the product development on a gradually higher cognitive level[49].

4.2.1 Step 1: Concept definition

The preliminary phase of the conceptual product development is the concept definition, and it is preceded by a system analysis, where it is important to have an open perspective and no preconceived idea of the optimal concept. The concept definition is an iterative process, and the purpose is to convert needs to realizable concepts. The final combination of different concepts will first go through a screening process, where only the identified concepts which satisfies the defined needs, goals and requirements will pass to the next step.

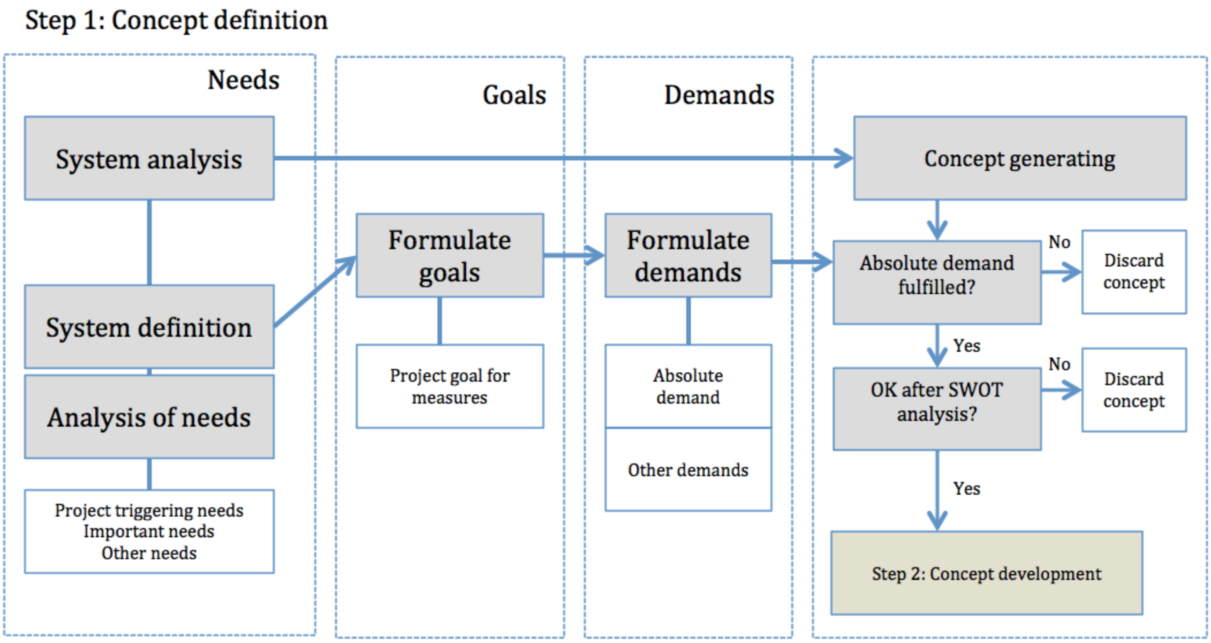


Figure 25: The different stages in the concept definition step.

4.2.1.1 System analysis

The system analysis can be a collective term for different methodological approaches and systematics to identify the most satisfying solution to the critical need, which started the whole process of product development[49]. The analysis starts with looking at the complex problem as a system, instead of using the assumed best solution as a starting point. The analysis finds the conditions that have to be satisfied in order to fulfill the system's function[51]. This way of thinking allows it to be developed concepts that satisfy the boundaries of the system rather than the system adapts the assumed optimal solution. The result is a system analysis well suited for the initiating activity in the concept definition.

The system analysis involves the following parts:

System definition
To get an overview over the complex problem it will be appropriate to build a form for system definition with clear system boundaries involving economical, resources, environmental limitations etc.[49]. Identifying necessary input and wanted effect from the system focuses the complex problem, and at the same time it is identified unwanted input and the consequences of these. This activity should make the decision-maker aware of the structure of the system, and introduce him to the problem-complex[49].

Analysis of needs
The analysis of needs reviews the different stakeholders and their preferences and needs. Then the needs are evaluated against each other to determine which of the needs that are most critical[53]. The analysis should find relevant needs on a superior level. The purpose of the analysis is to increase the value for the producer, and to increase the utility value for the consumer by satisfying the project triggering demand. The project triggering demand is based on the determined demands in the analysis, and it represents the main reason for measures[54].

The analysis of needs should explain the project triggering need based on:

1. Describing the situation today as basis for the definition of needs, goals, demands and conceptual solutions[54].

2. Describing needs from stakeholders with different needs, preferences and views in terms of choice of concept. From the analysis can the most important needs be obtained[54].

3. Evaluation of the needs sums up the obtained needs and sets it in context[53], and it is the obtained needs that make the basis of the project triggering need[54].

The needs analysis should give an insight in the decision-making situation, but the result should be supplemented with a market analysis to get a more complete overview of the situation.

Market analysis

The market analysis is coinciding with the needs analysis, but it has a larger focus on the market and the two analyses will complement each other. The purpose of the market analysis is to obtain information about the situation and evaluate possibilities and threats in the market, in due to reduce the uncertainty in the market aspect in the decision-making[55].

The main question before any product development process is to make sure there is someone that is interested to buy what we are going to develop. It is important to have close contact with the market during the whole development process, and pick up any change in the needs from the market. The analysis should investigate the needs in the market and estimate the willingness to pay to satisfy the need[55]. The market analysis should involve these elements:

1. Investigation of today's market
2. Description of domestic and international trends
3. Analysis of challenges and competition
4. Market potential and possibilities
5. Market channels

After the actual needs have been obtained and the market analysis is complete will the next step in the process be to formulate goals and demands on the basis of the obtained needs.

Formulate the goals

The goals are something that is achievable, and it is important to make them measureable either qualitatively or quantitatively. The project initiates because of a problem or a curtain need that has to be fulfilled. Therefore will the result of a project be expected to have a determined effect on the user or on the market, and this connects the needs, the goal and the effect together[56].

The needs analysis sets the basis for the definition on the goal of the project. The main challenge is to establish realistic goals, which the project can be reconciled against during the realization phase[56]. These factors should be used in the formulation of goals to achieve this at the best way[49]:

- Describe finally condition – not the process
- Specific – not a general goal linked to the strategy or policy
- Unambiguously – interpreted equally for all
- Verifiable or measureable
- SMART-approach: **S**pecific, **M**easurable, **A**ccepted, **R**ealistic and **T**imed

Formulate the demands

The formulation of demands should be based on the needs analysis and the formulated goals, and also technical, economical and functional requirements[54]. The demands can be divided into three categories:

1. *Demands formulated from goals* – Demands that are obtained from the goals in the project. The demands can be absolute, which means they have to be fulfilled for the concept to be feasible. Other demands will be used to evaluate the different concept in a screening process based on a evaluation criteria[54].
2. *Demands formulated from important needs* – The demands are showing the direction of the project defined by the important needs[54].
3. *Technical, economical and other demands* – Limits the basis for the room of maneuver of the development of different concepts. The common limitations are costs, technical specifications or government laws[54].

The identified demands are then ranked and categorized by absolute demands and other demands. When needs, market, goals and demands are defined can the generating of different concepts start.

4.2.1.2 Concept alternatives

A concept, according to Knut Samset, is an idea or a mind construction, which is a solution that satisfies the determined needs, goals and effects[49]. The concept is fundamental in the sense that different concepts can be alternative solutions to the same problem. The concept has to be expressed in goals and expected effects and derived from the actual needs, problems or possible technical solutions[49].

Concept generation

The idea behind "brainstorming" was first described by Alex Faickney Osborne, and he popularized the expression of "using the brain to storm a creative idea". The creative technique is used to solve a problem by spontaneously and uncritically list all possible solutions of the problem. The absence of criticism and negative feedback in the creative process is very important. The aim is not to have quality in the ideas, but to have quantity. All ideas should be listed.

The identified concepts should then be evaluated against a zero-concept, which is an actual solution today and is used as a reference concept or a benchmark.

4.2.1.3 Rough screening of the concepts

The screening process is an important part of the conceptual product development, since it makes the basis of the decision-making of which concept to chose. The first step in the screening process of the concepts will be to investigate if they satisfy the absolute demands. The absolute demands are the demand that have to be fulfilled, for instance government laws. Thereafter will the different alternative concepts be rated on how they satisfy the different needs, goals and demands[57].

Based on this method the results should be a selection of concepts that fulfills the absolute demands and can be brought further in the development process.

4.2.2 Step 2: Concept development

The concepts that have passed the rough screening process have to be further analyzed and further developed in the concept development phase. The analysis should be focused on the elements of uncertainty in the concepts, and the elements with the highest priority should be focused on[49].

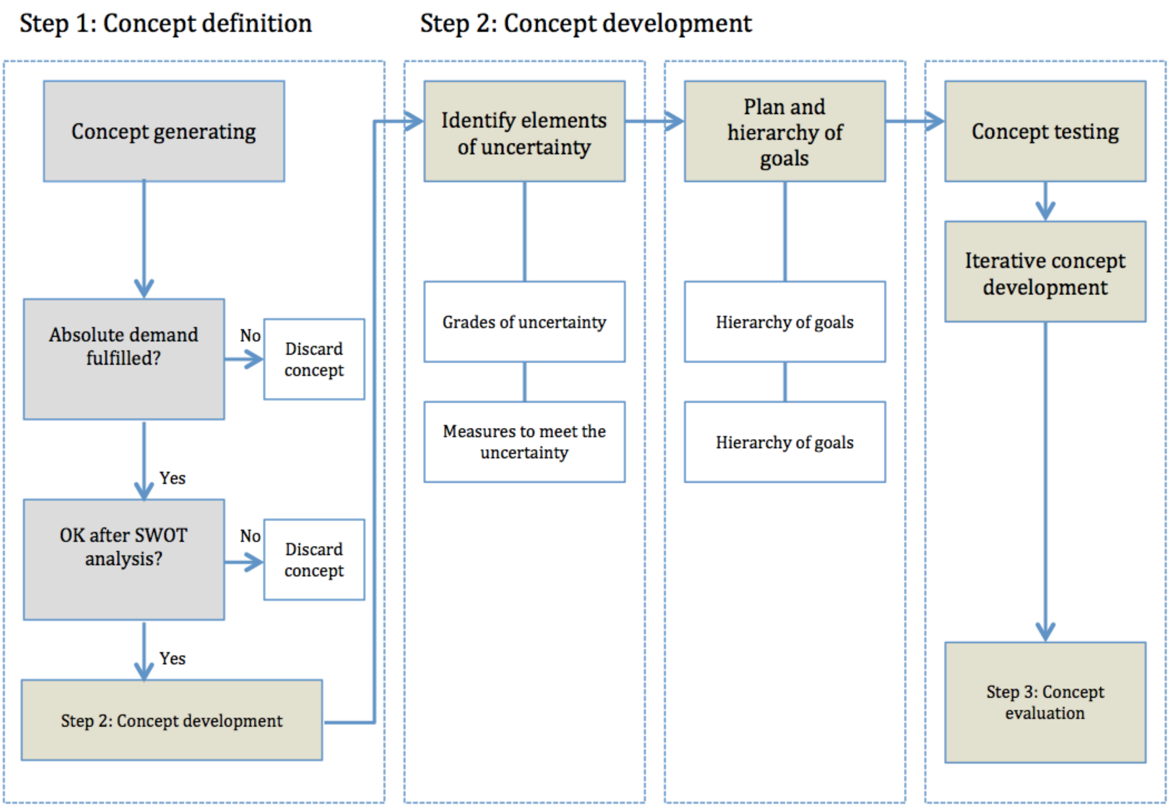


Figure 26: Step 1 - Concept definition and Step 2 - Concept development.

4.2.2.1 Identify the elements of uncertainty

The uncertainty is the difference of actual information and the necessary information to assure of a decision at the decision time. There are many reasons for uncertainty, and they can result in a positive or negative effect on the operating profit. The purpose of the identifying of uncertainty is to systematically determined potential and real elements of uncertainty, and at a best way increase the possibility of creating increased value by affecting the elements of uncertainty[58].

The decision-maker should choose a action that reduces the probability for unwanted events, and at the same time reduces the consequences of the unwanted events if they should occur. The objective is to affect the total uncertainty by making the risk as low as possible.

4.2.2.2 Goal hierarchy and iteration plan

The development projects are often complex, and goal management is used to assure the implementation of the project. The goal management is often used with several objectives that are mutual dependent of various degrees[56]. The process involves development and organizing of main goals, sub-goals and criteria, where the criteria equal the tasks that have to be done to fulfill the sub-goals.

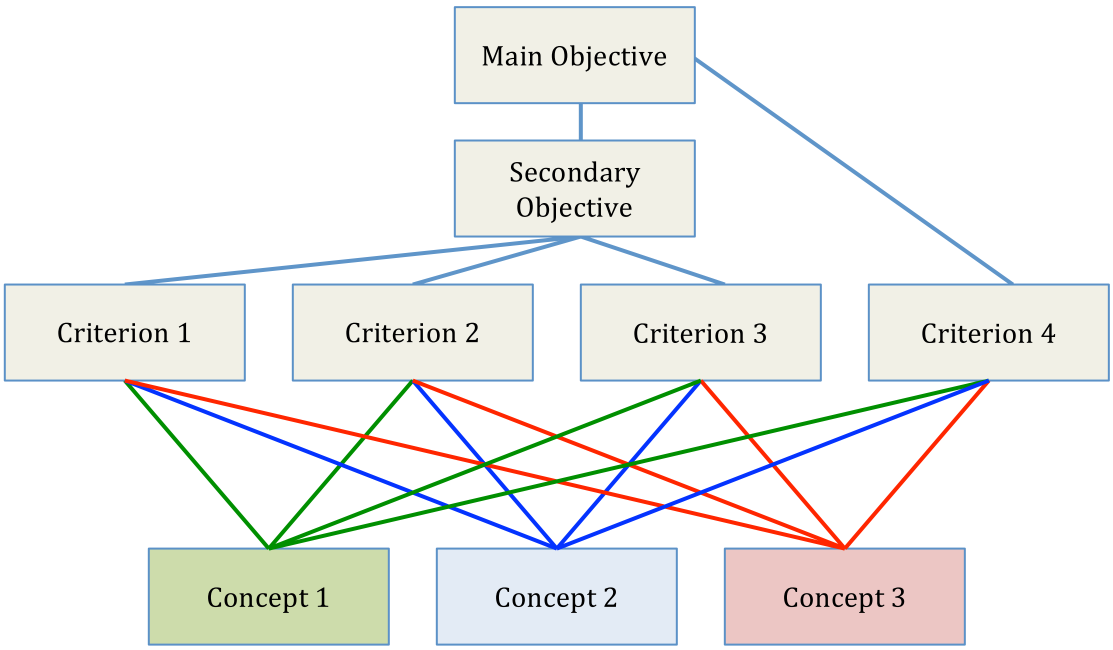


Figure 27: Hierarchy of objectives[48].

It is common to organize the goals in different levels by a hierarchically structure to clarify the goals' relationship and dependency, to simplify the complex reality[59]. When the concept definition is final included the ranked goals it is enough to move forward to planning the sub-activities and milestones in the early phase.

4.2.2.3 Concept testing

The concepts, which pass the rough screening process, will be tested towards the users to receive feedback, and a modeling of the different concepts as early as possible is important to gain as much information and knowledge as possible. The modeling can be simulation, sketching, or Computer-Aided Design (CAD), where an iterative testing and prototyping can be possible with limited time and resources consumption.

The model construction provides the possibility to test and show own ideas, and as a result get feedback from the users. The modeling makes the communication between users and developers easier and better, and it increases the possibility of an acceptance in the market. The process of modeling provides often answers to questions, and it is a fine support for the decision-maker to chose between different concepts in the screening process.

4.2.3 Step 3: Concept screening

The process of evaluating the concepts consists of defining and ranking the evaluation criteria, and then evaluates the concepts based on these evaluation criteria.

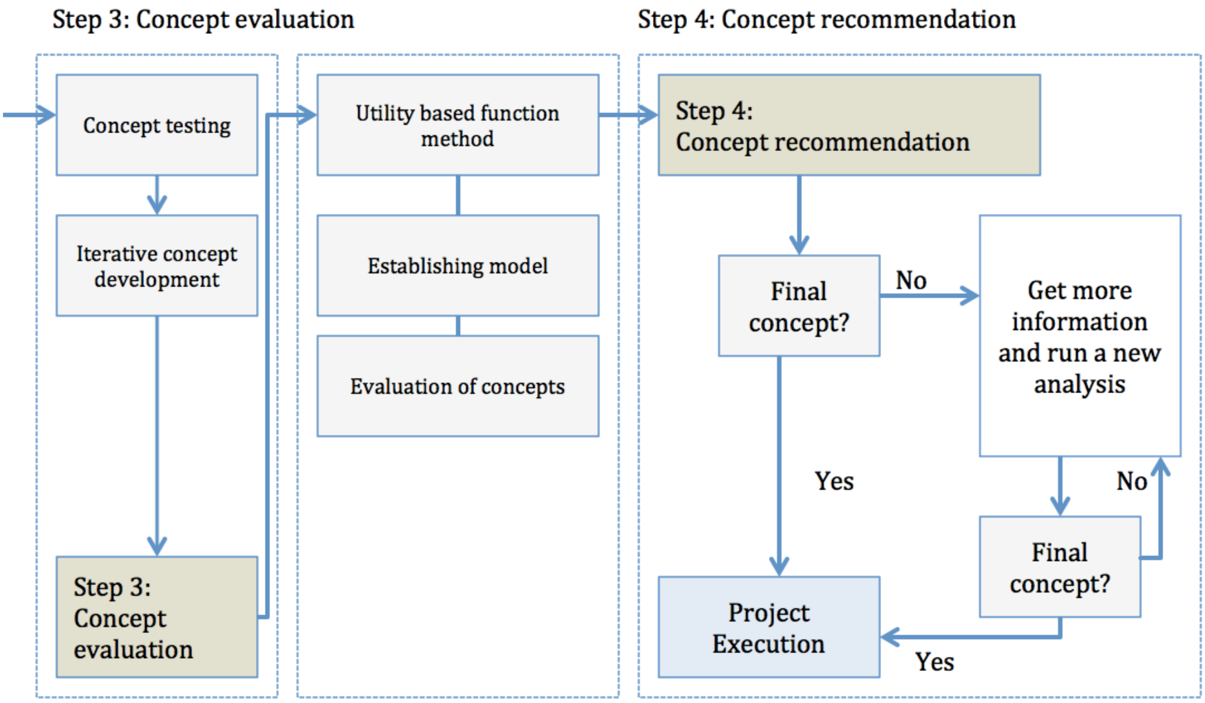


Figure 28: Step 3 - Concept evaluation and Step 4 - Concept recommendation.

4.2.3.1 *Establishing the screening model and calibration*

The screening process can be done in many ways, and one method is the *utility function based evaluation method*, which is when the most important criteria are weighted the most in the evaluation of concepts. There are four steps in this method:

1. Determine the evaluation criteria that should be a part of the model. It is often divided into quantitative and qualitative criteria.
2. Determine the initial weight the different criteria should have in the evaluation. The purpose is to accentuate how the decision-maker and stakeholders evaluate the meaning of the different criteria that is included in the screening process. The weighting between the criteria are presented as a relative value as a percentage, where the sum of all criteria values should equal to one hundred percent[48].

3. Calibration of quantitative and qualitative criteria in the evaluation model. The calibration method is a sensitivity report, which connects the quantitative and qualitative criteria[48], and at the same time will the economical aspect be apart of the scores of the criteria. The purpose of the calibration is to validate and to verify the model. To achieve this the decision-maker and other stakeholders has to be involved in the process, to make sure the model is relevant and complete. And by using this method there is a higher chance for the model to represent the stakeholders' preferences[48].
4. Allocation of the criteria score that reflects the value of a concept's performance in relation to the given criteria, and it is the most challenging and important step in the process[48]. The allocation should be based on a process, where all the central stakeholders are involved. The Pugh's method is used to allocate the different concepts in this development process. The Pugh's method is described in the chapter 4.3.

4.2.3.2 Execution of the analysis and evaluating the concept

After the weighting it is time for screening of the individual concepts, and the process can be divided into four steps:

1. Evaluate the concepts by estimating the consequences, which gives a score on how well the different concepts satisfies the different evaluation criteria[60]. The concepts are then evaluated relative to each other, and given a score between 1-6, where 6 is the best and 1 is the worst.

Criteria	Weight	Value area	
		Min	Max
Quality criterion 1	30 %	1	6
Quality criterion 2	20 %	1	6
Quality criterion 3	15 %	1	6
Quality criterion 4	35 %	1	6

Alternatives	Quality criterion 1		Quality criterion 2		Quality criterion 3		Quality criterion 4	
	Score	Norm. Score	Score	Norm. score	Score	Norm. score	Score	Norm. score
Concept 1	4,50	3,60	5,00	3,50	6,00	4,67	5,00	4,38
Concept 2	4,60	3,68	5,00	3,50	4,00	3,11	4,00	3,50
Concept 3	4,20	3,36	6,00	4,20	3,00	2,33	3,00	2,63
Concept 4	4,20	3,36	4,00	2,80	5,00	3,89	4,00	3,50

Figure 29: The definition of different criteria and process of giving scores to the different concepts, and also normalization of the given score.

2. The uncertainty in the analysis is then evaluated. It is looked at the possibility that the actual result will differ from the expected result, and this makes the basis of the uncertainty. The uncertainty is divided into quantitative (priced criteria) and qualitative (non-priced criteria) uncertainty. The quantitative

uncertainty in the priced criteria can occur when the general conditions, future pricing of labor and materials etc. is uncertain. This will affect the net present value of the project, and should be brought into the calculations when choosing a concept. The qualitative uncertainty in the non-priced criteria can occur through registration, evaluation of value, evaluation of score, evaluation of connected or individual consequences.

Alternatives	Quality criterion 1				Quality criterion 2				Quality criterion 3				Quality criterion 4			
	Min	Prob.	Max	Sim	Min	Prob.	Max	Sim	Min	Prob.	Max	Sim	Min	Prob.	Max	Sim
Concept 1	1,5	2,0	3,0	2,2	1,5	2,0	3,0	2,2	1,5	2,0	3,0	2,2	1,5	2,0	3,0	2,2
Concept 2	5,0	5,5	6,0	5,5	3,0	5,0	6,0	4,7	5,0	5,5	6,0	5,5	4,5	5,5	6,0	5,3
Concept 3	4,2	5,0	5,5	4,9	4,0	5,0	5,5	4,8	4,2	5,0	5,5	4,9	4,2	5,0	5,5	4,9
Concept 4	1,0	2,0	4,0	2,3	1,0	3,0	4,0	2,7	1,0	3,0	4,0	2,7	1,0	2,0	4,0	2,3

Figure 30: The process of scoring the different concepts based on the consequences in the worst, best and the most probable case, and additionally a simulated value based on the given values.

3. Transforming the consequences to utility by the utility function method. The score the different concepts have gotten on the different criteria based on the estimated consequences will be multiplied with the initial weighting for each respective criterion. The result will be a weighted utility score for each criterion for every concept, and the sum of the weighted scores for each concept will give the sum of utility for every concept, where the highest score is the best.

Alternatives	Quality criterion 1		Quality criterion 2		Quality criterion 3		Quality criterion 4		SUM Weigthed scores
	Score	W. Score	Score	W. Score	Score	W. Score	Score	W. Score	
Concept 1	3,60	1,08	3,50	0,70	4,67	0,70	4,38	1,53	4,01
Concept 2	3,68	1,10	3,50	0,70	3,11	0,47	3,50	1,23	3,50
Concept 3	3,36	1,01	4,20	0,84	2,33	0,35	2,63	0,92	3,12
Concept 4	3,36	1,01	2,80	0,56	3,89	0,58	3,50	1,23	3,38

Figure 31: The scores given to the concepts are being weighted in the utility function, and the sum of all weighted scores gives the total utility from each concept.

4. Collective evaluation of the weighted scores for all of the different concepts. It can be done by ranking the concepts by the highest to lowest score, or by ranking them based on a price per unit utility. In the example would the ranking be from best to worst; Concept 1, 2, 4 and 3.

4.2.4 Step 4: Concept recommendation

The utility function based evaluation process should provide a recommended concept together with the assumptions and argumentation for the choice of the concept. When it is small differences between the concepts it can be hard to tell from the screening if one concept is better than the others[48]. If this is the case, should it be conducted a further analysis of the optimal concept. The final basis for decision-making should involve an evaluation of the uncertainty involved both quantitative and qualitative criteria, which implies how robust the concept recommendation is[48]. In the recommendation is it important that the process gets explained in details and that the traceability is good. This can be assured through well documentation of the screening process, choice and weighting of each of criteria and an explanation of the given score for each criterion to all of the concepts.

4.3 Pugh's Method

Stuart Pugh developed a tool for choosing the best option from a variety of solutions linked to solving a common problem. The method uses a list of alternative solutions and a set of criteria that is used to evaluate the different solutions. The criteria will be weighted on how important the criteria are for the solution, and the evaluation of solutions generates a scoring matrix, also known as the Pugh matrix. The product of the solution's score on a criteria and the weight of the criteria gives a weighted criteria score. The sum of all criteria scores for a solution gives the total weighted score for a solution, and the solution with the highest score will be the best solution according to the method.

Table 8: The different scores in a Pugh matrix

Scoring	Description
6	Meets criterion extremely good
5	Meets criterion very good
4	Meets criterion good
3	Meets criterion as well as datum
2	Meets criterion not as well as datum
1	Meets criterion worse than datum

4.4 Software

The CAD drawings, 3D models and Flow Simulations are conducted in SolidWorks version 2015, assisted by SnagIt from TechSmith for illustration photos.

4.5 References

The references are referred to in head notes in the text and listed in chapter 15. References. The citation style used is the Harvard style.

5 CONCEPT DEFINITION

The concept definition includes a System definition, Analysis of needs, Market needs and product potential, Goals and Demands.

5.1 System definition

The salmon farmed business has in many years struggled with salmon lice in their production. The annual cost of the salmon lice problem is estimated to be around 5 billion NOK in the whole business in 2016[61]. It is therefore a high incentive in the business to solve the problem, and it is almost no limitation with respect to costs or resources available. The environment consideration, by government laws, on the other hand sets a lot of limitations on how the salmon farmed business is legally allowed to operate.

5.2 Analysis of needs

The need for a solution to the problem of salmon lice infestations is critical for all stakeholders involved in the business, from breeders to consumers. The breeders usually concentrate on the profit and how to reduce costs in the production, and now have the lice infestations become such huge expense. The Government is interested in the growth in the industry, which can provide new jobs. And they want to secure the natural salmon, which are being affected by the lice coming from the farming plants. The consumers want to have a healthy production of salmon without use of medicaments. These needs have made it a triggering need to solve the problem.

5.3 Market needs and product potential

Norway is at the moment the largest producer of farmed Atlantic salmon, and the annually production is about 1.3 billion tons of salmon, which is divided on about 1100 breeders across the Norwegian coastline[62], and the number are increasing rapidly. It comes from this that the demand for a solution for the biggest problem in the industry is critical for a further growth, and the demand from the breeders and the government is at it's highest ever.

The consumers of salmon are all over the world, and Norway is exporting fish to over 100 countries worldwide. The demand for seafood is rising, especially by consumers in Asia (see Figure 2 at page 4). The reason for the rising demand is an increased focus on a healthy substitute for meat, and the consumers are often interested in the quality of the salmon. Exposing the salmon for a chemical treatment might weaken the healthy credibility. It is important for the breeders to keep a reputation as a healthy food producer, and the news of quantities of salmon died in the production is bad commercial for the companies. This makes it a demand for the breeders as well to focus on the welfare of the salmon.

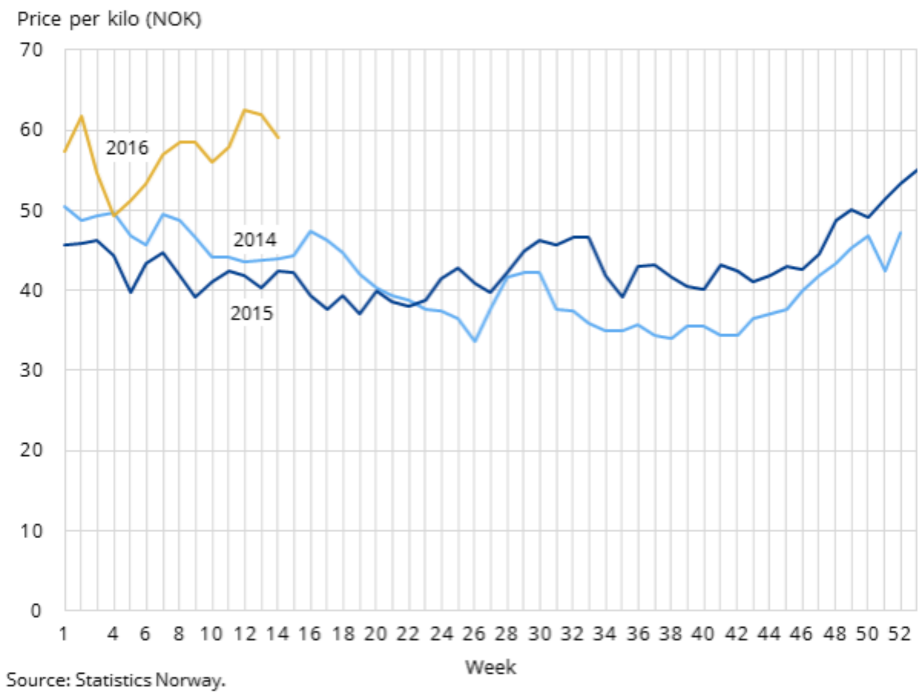


Figure 32: The weekly price per kilo fresh salmon from 2014 to present[9].

In the beginning of 2016 it has been record high revenue in the Norwegian salmon industry, but this has nothing to do with higher sales in tons. It is due to the great prices on salmon at the moment, which have been increased because of the high demand in the market. The sale per week on the other hand is actually lower than last year, but the record high salmon prices makes up for the lack of production. And this has been the trend since 2012, where the production in tons has stagnated and the prices have increased (see Figure 33). The reason for the stagnation has been blamed on the salmon lice, which reduces the production rate and precludes expansion of the production.

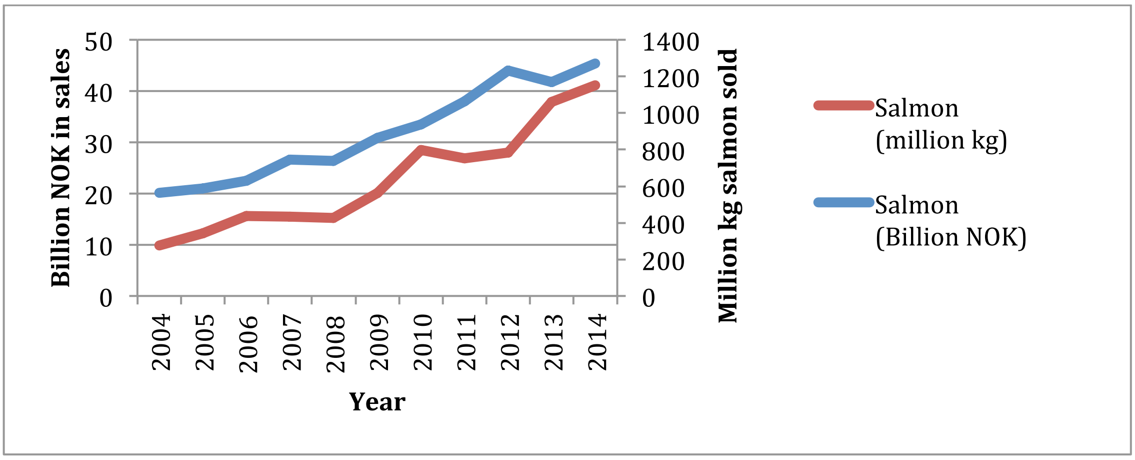


Figure 33: Historic sales of salmon in tons and revenue[63].

There is a great market potential for a treatment method of lice infestations, and it is assessed that a well functional solution for the lice infestations will have a tremendous success when commercialized. The potential sales price of the treatment can go skyhigh because of the evaluated demand for it. There are many other competitors in the market (presented at pages 10-19), but there are a lot of weaknesses regarding these methods, which is presented in chapter 1.10 Challenges linked to current methods. A treatment method with these challenges resolved will be an absolute success.

5.4 Goals

The main objective of the concept is to remove the amount of salmon lice on the salmon. Other objectives are to increase salmon welfare and making a solution that reduces working hours used on salmon lice.

5.5 Demands

The system requirements are listed under, and they are based on the demand analysis and the formulated objectives, and also some technical, economical and functional requirements:

5.5.1 Absolute demands

The demands are divided into absolute demands and qualitative demands. The absolute demands are mainly based on safety issues. The main factors are the safety of the labor and the environment that has strict Government regulations.

Solid construction
The climate and weather conditions are rough, even though the plants often are positioned near the coast. This should be considered when designing a solution. It has to be able to handle a corrosive environment and extreme weather.

Escaping of salmon
The Norwegian government has strict regulations when it comes to escaping of farmed salmon. The regulations make it necessary to minimize the amount of escaped salmon to a minimum, and the aquaculture industry has a non-escape vision for their industry. In order to reach that goal must every product used in the aquaculture been certified before use. For instance is the risk of tearing up the nets a risk that has to be minimizes.

Capturing of salmon lice
The salmon lice are a parasite that exposes the ecosystem for a great danger. The environmentalist are afraid that the salmon farmed plants are in danger of exterminating the wild salmon species, because of the high degree of salmon lice in the plants. The limitation of spreading salmon lice is therefore an important issue to assure a possibility of further growth in the industry.

5.5.2 Qualitative demands

The qualitative demands are based on factors that will increase the productivity, lower the costs and make the treatment method of salmon lice more efficient.

Treatment efficiency
The net pen's contains of a great number of fish, and they live in relative small environments with a high danger for proliferation of salmon lice. This risk has to be limited by assuring that the salmon lice does not reach the adult stage, the duration of this is explained in chapter 1.5. The treatment solution should therefore ensure efficiency in the treatment that all infected salmon gets the treatment they need before their hosting lice reaches the stage of reproduction.

Implementation
There are a large number of salmon plants, and it will cause a lot of money to change all the existing plants. It would therefore simplify the implementation of a new solution if it could be installed at the existing salmon plants.

Salmon welfare
The treatment method has to take into account the welfare of the salmon, which means that the treatment should not harm the fish in any way, for instance the salmon's fins, eyes or mucous membrane.

Access to oxygen
The fish has a high need for oxygen, and it is an absolute requirement to have it in the plant.

Stress factors
The wellbeing of the salmon has a high correlation with lack of stress factors. This means that a high degree of disruptions in the salmon's daily life will impact the salmon's health and can lead to diseases and death. It is therefore a wish to reduce these disruptions to a minimum.

Space
The net pens have different sizes, but they are usually quite large to achieve scale advantages.

5.5.3 Property evaluation

The following table is an evaluation of properties for the treatment method that will be developed in this master thesis.

Property	Description	Score	Explanation
Treating	The ability to treat the salmon with salmon lice.	6	The main objective of the project is to develop an improved treatment method against salmon lice; therefore, this has the highest possible priority.
Visual design	The product's appearance.	2	The visual design and esthetic are not of any importance, and has therefore a low priority.
Retail Price	The price per unit.	2	The cost of the problem is high in the industry. The price will therefore not play a significant role in the concept development. But some limitations there are of course.
Safety	How safe the treatment is in terms of risks of damage of the fish.	5	Safety is important when the treatment can harm the fish.
Cleaning	How easy the device is to keep clean.	3	The solution should be able to clean, especially because it consists in a corrosive environment.
Implementation	How easy is it to install the solution in today's design of the net pens.	5	This factor is important to assure that the business does not have to change their layout too much to install the new solution.
Secure	Describes how well the solution secures that no salmon or salmon lice escape.	6	The pressure to assure no spreading of salmon and salmon lice is high. This will be an absolute demand from the government to minimize.
Operating costs	Cost in terms of using the solution.	4	The same argument as for the retail price. But the operating cost should be lower than the costs regarding salmon lice per kilo today.

6 EXTERNAL COMPANY VISITS

Two external company visits have been conducted to identify the required features for the treatment method of salmon lice. This chapter includes the objectives of the visits and the feedback received from the industry.

6.1 Objectives of the visits

The purpose of the visits was to be able to identify the challenges that are associated with the daily operation of the fish farms.

The objectives of the visits was to identify the following:

- How much experience and staff is needed to operate the fish farms.
- What are the challenges linked to today's solution for treating salmon for salmon lice.
- What features are the most critical when designing a solution for a treatment method.
- Which additional features would make the daily operation of the fish farms easier and more efficient.

6.2 Selection of fish farm companies

The breeders who have experience with operating the fish farms are chosen as the expertise when it comes to answering the objectives and giving the wanted feedback. They are chosen because they are the daily users of the solutions associated with the operation of the fish farms, and they can explain and classify the challenges or possible improvements of different treatment methods.

The breeders contributing to this report are Marine Harvest Norway sea location at Røysa (Valderøy/Vigra) and Aqua Farms Vartdal sea location at Kvangardsnes (Dalsfjord/Volda). The two different locations have a bit different sizes, and this was conscious choice in order to get feedback from two different types of breeders.

6.3 Interpretation of the feedback

The most relevant feedback from the breeders listed and considered in this chapter. The most important factor for a successful treatment method is given in a short review, along with related interpretations.

The daily operation

The daily activities conducted by both companies were to make sure the salmon were fed at the right level. The whole process were automatic with blowers that blew the pellets from the silos and out to the net pens. At the Marine Harvest facility was the daily pellet consumption of 10 tons, which were blown out during daylight (approximately between 8 am to 17 pm at the time of the visit). The reason why the feeding only was conducting during daylight was because the salmon need to see the food. During the day the breeders drove a boat from the different net pens to observe if the salmon got enough food and for abnormalities. The activities regarding salmon lice were mostly just control of the lice increment in the plant. This was done weekly, and the process was to control a number of 20 salmon in each net pen if they had any lice. The lice attached to the salmon were divided into three groups: *sessile (chalimus), movable (pre adult) and sexually mature (adult).*

Figure 34: The pipes from the blowers to the net pens, where food is transported.

The group they watched especially close was the adult lice, since it is a government law, which sets a restriction on 0.5 adult lice per salmon. And it has to be counted an average amount of lice per salmon every week when the sea temperature is over 4 °C[64]. The reason for the law is because the increment of lice is highly exponential after the first of the lice is getting to the adult stage. The time period before reached this state could measures be initiated. For instance was a measure to increase the numbers of wrasse and lumpfish, which used to reduce the increment depending on the temperature of the sea. But often this is not enough and the state of 0.5 adult lice per salmon is unavoidable.

Both facilities had released their smolts in the autumn of 2015, and they had not yet needed any delousing of the net pens on this generation. The breeder at Marine Harvest meant that the reason for this was that they had found a good combination of salmon, wrasse and lumpfish, and the fact that there were not so many other fish farms nearby, which would increase the increment of lice. Even though there were many positive factors they had to delouse about 10 times the last generation (approximately 1.5 years).

Low maintenance requirements

The daily operation involves a lot of tasks, and there have been many examples of devices that should make the activities easier. For instance a ROV (Remote Operated Vehicle) using a video camera to observe and control inside the net pens. There are some fish farms that still uses this technology, but not of the fish farmers involved in this report. Their opinion was that there was to much work to maintain the robot, and the profit of using it was to little. Even though the Aqua Farms Vartdal had used it before, so technology on fleet was ready, they liked to physically move between the net pens to observe.

The demand for maintenance had to be as low as possible to not lose focus on what the business is all about, which is farming fish. Therefore it is important to keep in mind that all things that stay in the ocean will it eventually start growing on. And this combined with the constantly stresses provided by the waves will cause a risk for damage and fracture. There are many ways to secure that fracture does not occur, but it is no way to absolutely curtain. Therefore it is important to also design for when the product is damaged. In means of designs in a net pen is it important to take into account that the product will not cut up the nets. For instance if the product are surging in contact will the net.

Figure 35: Showing the boat used to observe the net pens on the Marine Harvest plant.

Figure 36: Observing the net pens at Marine Harvest

7 ANALYSING THE TREATMENT FUNCTIONS AND STRUCTURE

In this chapter, the functional analysis is presented among with reflection related to material science and shape considerations. A zero-concept is also being introduced.

7.1 Functional Analysis

There are different components required for developing the treatment device. A functional analysis has therefore been developed to identify the required components and to see how they are linked to each other. The functional analysis is shown in the figure below, and an explanation of the analysis is given on the next page.

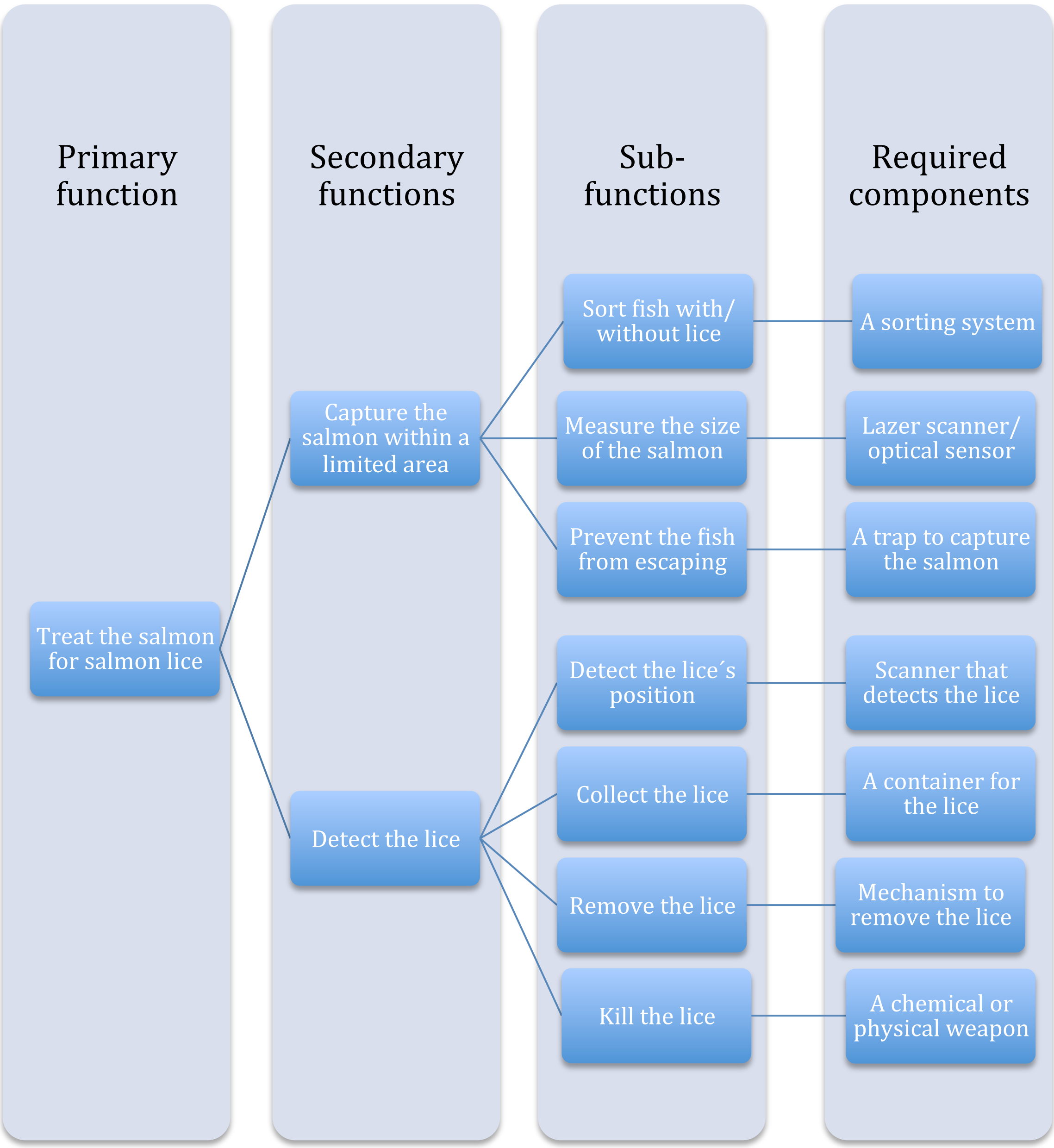


Figure 37: The functional analysis for the treating method.

Explanation of the functional analysis
The functional analysis is divided into four categories; primary function, secondary functions, sub-functions and required components. The primary function is the overall objective of this project, to find a treatment method for removing salmon lice from the salmon. From this main function a list of secondary function are listed. These functions are necessary to fulfill the primary function, and they are again split into sub-functions and at last a required component that will be taken into consideration in the following concept development. The list of required components will therefore become the background for the development phase, where the most relevant components will be investigated further.

7.2 Material Science

The aquaculture sets high standards when it comes to materials, and it is therefore important to pay attention to material science when designing something at sea. During the last decades there has been a lot of focus on the materials used at the plant, and some of the important properties are listed below.

Material in aquaculture; Material Strength and Corrosion Resistance
Selecting the right material when designing constructions at sea is very important. The material has to be able to stand extreme weather conditions, because fatigue and fracture are common problems at sea. There is also important to take into account the corrosive environment at sea, and the constantly growing of algae and such.

Biocompatible Materials
When designing a product that should be apart of food production it is important to be aware the effects the materials implies when interacting with the fish. There should not be used material that harms the mucous membrane to the salmon. Another aspect that has to be considered is that many materials will pollute the ocean, like some hideouts for wrasse has done in the past. There was it used plastics, which disintegrated and the results was a lot of small plastic parts floating around at sea.

7.3 Zero-concept

The chosen zero-concept is the Stingray solution describes in chapter 1.7.2. This solution is chosen because it is a constantly working solution against the lice. That means that it is always working to reduce the increment of lice, as opposed to other solutions that just are being initiated after a curtain level of lice has occurred in the plant.

8 CONCEPT DEVELOPMENT PROCESS

This chapter describes the brainstorming process of the project. The process starts with the functional analysis, which divided the treatment method into two parts; trapping the salmon for treatment and the removing of the lice. These two features are being evaluated individually, and the ideas for each of them are listed in tables below. In addition, there are evaluated if there are any elements of uncertainty, which can affect the concepts. These elements are considered in the first sub-chapter.

8.1 Elements of uncertainty

There are a lot of uncertainties involving this process of removing salmon lice attached to the salmon. For instance no salmon is the same size or shape, and the production is at sea so that makes it a lot of uncertainty because of weather conditions and other impacts from the environment.

List of elements of uncertainty:

- The shape of the salmon is not identical for every salmon.
- The size of the salmon.
- The position of the salmon when the solution is removing lice can be variable.
- Position of the attached lice can be at several locations on the salmon.
- Waves and weather.
- The reaction from the salmon, caused by the treatment, can differ.
- The strength needed to remove the lice can differ.
- The size of the lice can differ regarding how long in the life cycle it has come.

The elements of uncertainty are brought further in the development process, and are used to evaluate the possible consequences regarding different criteria for the different concepts. The best conceivable consequence will make the basis of the maximum score, and reverse for the worst conceivable consequence. The higher the uncertainty a concept has on a criterion, the higher will the spread of the concept’s score on that criterion be.

8.2 Alternatives for trapping the salmon

To facilitate where the fish can receive a treatment against salmon lice, is it necessary to consider the entire treatment process. From where the salmon with lice is in the net pen to when it is back in the net pen without the lice. This process is therefore divided into two parts: *the trapping sequence* that catches or lures into the other part, which is the *process of treatment*. Or in other words, does the treatment process seek out the salmon or is it the other way around. In the convectional mechanical treatment methods that is used today are all *catching* the salmon, except for the *Stingrays* solution, which uses lacer on fishes that are swimming by the lacer source.

To have an open mind are both trapping sequences evaluated, and it is not being thought of any concepts of the treatment method, which comes later. There are many combinations of trapping methods and treatment methods that would be hard to fit together, but that has not limited this concept generating process. The two different concepts are evaluated separately.

Table 9: Concept alternatives for the trapping function

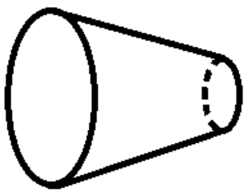
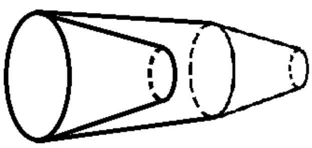
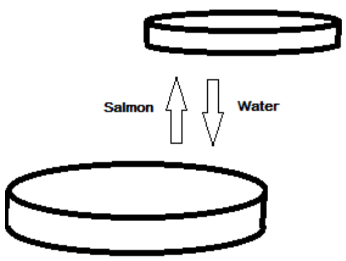
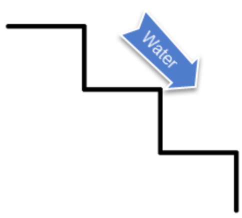
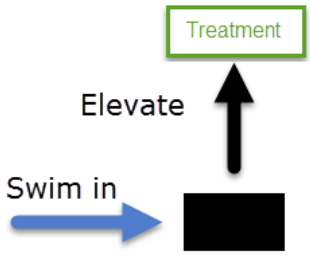
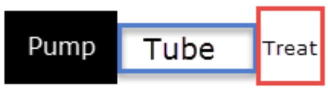
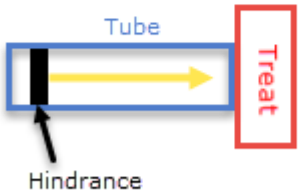
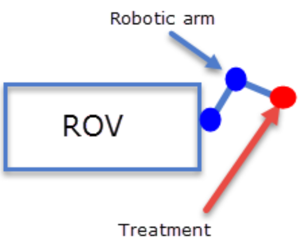
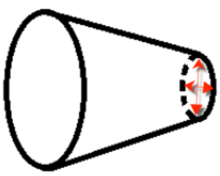
Illustration	Description	Pros	Cons
A – Funnel 	A trap where the salmon can swim into but not can swim out of.	Possible to treat the salmon individual-ly.	Difficult to ensure that each of the salmon gets treated.
B – Fish trap 	A trap with two for more funnels.	Possible to treat the salmon individual-ly or to wait for the treatment until sev-eral salmon are captured inside the trap. This can be more efficient for treatment that has a high startup time.	A bit more complex than the single fun-nel, and it is difficult to ensure that all of the salmons will swim into the trap.
C – Salmon stairs 	An installation that makes it possible for the salmon to jump up in heights, because the water flow will attract the salmon.	Uses the salmon´s natural instinct to jump upwards. Will not inflict any harm or stress on the salmon.	It might be difficult to attract all of the salmon and the salmon that is af-fected of the lice is often weakened and might not be as at-tracted to jump.
D – Counter flow stairs 	Using countercur-rent water flow to attract the fish’s natural instincts.	Easy solution to attract the fish, and Will not inflict any harm or stress on the salmon.	Requires a constant current. Risks that not all fishes will pass through, at least not the ones weakened by lice, which is the ones we are trying to get to.

Table 9 continues.

Illustration	Description	Pros	Cons
E – Fish elevator 	Traps the fish and brings it up via an elevator to a higher level. The idea is to bring the fish up and slide it down through the treatment method. The goal is to use gravity as driving force for the fish into the treatment.	Makes it possible to transport the fish into a treatment reservoir. For instance a warm water bath.	The process it quite complex, and slow. There is a possibility for increased stress also in the elevator if it takes to long time.
F – Flush the salmon through 	The idea is to trap the fish inside a limited area and then force it through a treatment method by using water flow from a pump or like flushing a toilet.	It is an opportunity to treat several salmon at once. If several salmon get into a reservoir and then are being flushed down.	Might be a huge process, and can be a very high amount of water needed to be pumped.
G – Force the salmon through mechanically 	Can be applied in combination with some of the traps above. The idea is to trap the fish and then force it through the treatment by using some mechanical device.	Can be an efficient way to get the salmon through the treatment. Makes it possible to make processes like an assembly line.	The salmon welfare could be at risk. The mechanical forcing is looked on as a method that increases the stress level for the salmon. It has to be found a gentle way.
H – Robotic arms mounted on a ROV 	When the fish is close will some robotic arms "shot out" to a position near the fish, where the treatment is conducted.	Can be very effective and operative with very low stress factor on the salmon.	Sets a very high demand on precision and rapidity, and it has also have to be observed the exact position of the lice on the salmon.
I – Moveable trap 	A tube that the salmon swims into. But when it is inside the shape starts to change.	Allows the fish to get near the treatment and makes it more likely to swim into the trap.	More complex, and it takes a bit more time to treat.

8.3 Alternative treatment concepts

Table 10: Concept alternatives for the treatment function

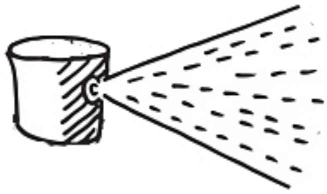
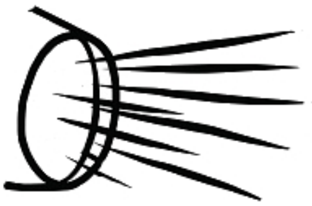
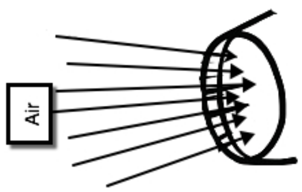
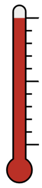
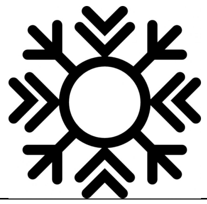
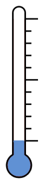
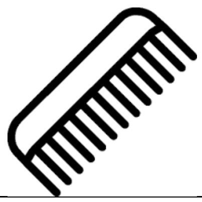
Illustration	Description	Pros	Cons
A – Flushing with clear water 	Using high-pressure water to flush of the attached salmon lice on the salmon.	Efficient way that has given good results of removing the lice.	Can be a risk for fish welfare, and can harm the fish. The lice also can be spread in different directions.
B – Blowing off the lice 	Blowing the lice off with high-pressure air.	Might be as effective as the flushing with water and not as harmful for the salmon's mucous membrane.	Not clear if it will provide enough force to rip lice of the salmon. It might be necessary to be conducted over the water surface. Collect the lice might be a problem.
C – Brush off the lice 	Using brushes to brush off the attached lice.	An efficient way to remove the lice, but is can be difficult	Harms the salmon mucous membrane and provides an increased stress level for the salmon. It can also be hard to collect the lice.
D – Vacuum compressor. 	Using suction from the vacuum compressor to remove the lice.	Easy to collect the lice. Should not provide any harm to the fish.	It is unclear how great force that is demanded to remove the lice. Can be hard to standardize suitable for every fish size.
E – Vacuum pump 	The same as concept D, but it is using water	Same pros as concept D, but is also an advantage that it is used in water.	Same as for concept D.

Table 10 continues.

Illustration	Description	Pros	Cons
F – Warm water 	The use of heated water to about 30 degrees Celsius.	Possible to treat plural of fish simultaneously.	Demands a lot of equipment like a chamber, cleaning of water, water heater etc.
G – Freezing the lice 	By the use of cold air to exterminate the lice on the fish.	Can be a very efficient way to kill the lice.	Some uncertainties regarding if the lice can be killed by coldness without harming/stressing the fish.
H – Cold water treatment 	Having the fish in a chamber of cold water for a certain time to exterminate the lice.	The temperature difference between the needed low-temperature might be smaller than for the warm water treatment.	If the needed low-temperature is below freezing point must the water be in a constant flow to prevent it from freezing.
I – Some sort of lice comb 	A comb of some sort that picks up the lice.	Can be an easy solution with few parts.	Unclear if it is possible to remove the lice without harming the fish and especially the fins.
J – Electricity 	An electricity lead trough the water. It has been proven to paralyze the lice.	Can be an efficient way to exterminate all the lice regardless of where they are sitting on the salmon.	Can be a safety issue with the electricity, because it possible can harm the fish. It also sets a demand on skills to the staff operating.
K – Picking the lice of with robotic arms 	An automatic tweezers device that picks the lice off of the salmon.	Can be very effective and operative with very low stress factor on the salmon.	Sets a very high demand on precision and rapidity, and it has also have to be observed the exact position of the lice on the salmon.

8.4 The combinations of concepts

This concept development process has been divided into two sub-concepts, which together forms multiple combinations of main concepts. In theory it is altogether 10 times 11 total concepts, which is 110 possible concepts. However, there are many of the combinations that will not be feasible or realistic, so the combinations, which are viewed on as the ones that may be most viable are shown in the table below.

Table 11: Feasible combination of concepts

Trapping Concept	Treatment Concept	Description
A – Funnel	A – Flushing with clear water C – Brush off the lice E – Vacuum water I – Lice comb	All the combinations are based on the thought that the salmon will swim through a funnel, and at the narrow ending will the treatment be conducted.
B – Fish trap	A – Flushing with clear water C – Brush off the lice E – Vacuum water I – Lice comb	Based on the same idea as for the Funnel, however it has also the ability to trap the fish inside the trap. This makes it possible to wait for the treatment process until there is several salmon inside. This can be appropriate with treatment methods that can take some time to get started, as for the treatments using a pumping system.
C – Salmon stairs	F – Warm water H – Cold water	This combination is based on some closed reservoir of water with an appropriate temperature, and the salmon swimming in and out. The reason for the reservoir needs to be closed is that it a high energy consumption change the temperature of water.
D – Counter flow stairs	B – Blowing off the lice C – Brush off the lice	The counter flow stairs have the purpose to get the salmon on a higher vertical level over the waterline, and as a result give the salmon an increased potential energy. This energy is then transformed into a kinetic energy when the salmon is dropped down to the waterline again. On the way down it is viewed as a possibility to treat the salmon using either a blowing of air or a brush.

Table 11 continues.

Trapping Concept	Treatment Concept	Description
E – Fish elevator	B – Blowing off the lice F – Warm water H – Cold water	The fish elevator has the same purpose as the counter flow stairs, which is to transport the salmon over the water-line. But it has also the ability to drop the salmon up into a reservoir of water.
F – Flush the salmon through	A – Flushing with clear water C – Brush off the lice E – Vacuum water	This combination starts with trapping the salmon in a limited area and then it pushes it through a tube by water flow. During the tube is the treatment being conducted before the salmon is re-leased back into the net pen.
G – Force mechani-cally	A – Flushing with clear water C – Brush off the lice E – Vacuum water	This combination starts with trapping the salmon in a limited area and then it pushes it through a tube by using a longitudinal hindrance. During the tube is the treatment being conducted before the salmon is released back into the net pen.
H – Robotic arms (ROV)	J – Electricity K – Picking off the lice	A ROV closing up on the salmon, and uses some sort of robotic arms that has some sort of current placed on the end or a picking device like a tweezer.
I – Moveable trap	A – Flushing with clear water C – Brush off the lice E – Vacuum water	The idea is mainly like the funnel, only it will have the ability to change shapes according to the salmon. Dur-ing the time the salmon spends in the trap is the treatment being conducted, and then released back into the net pen.

These are the combinations of trapping and treatment concepts that have been looked at as feasible combinations. However, they have not been evaluated with the defined absolute demands. This rough screening will be the first step in the next chapter.

9 CONCEPT SCREENING

The alternative concepts listed in the previous chapter are during this chapter being evaluated and rated in a screening process. The process is introduced with a rough screening of the concept with focus on the absolute demands defined in chapter 5.5.1. Then follows the development of the decision-matrix and a final utility evaluation of the concepts that is also showing the chosen concept.

9.1 Rough screening

The absolute demands are basically restricting the concepts in terms of safety based on the construction is solid and feasible. Additionally is there two demands that restricts the concepts based on environmental demands, which is no escaping of farmed salmon and no releasing of lice, at least not alive lice. The rough screening process can be view in Table 12 below.

Table 12: Rough screening based on the absolute demands.

Combinated alternatives		Construction	Escaping	Capturing lice
A – Funnel	A – Flushing with clear water	Yes	Yes	No
	C – Brush off the lice	Yes	Yes	No
	E – Vacuum water	Yes	Yes	Yes
	I – Lice comb	Yes	Yes	No
B – Fish trap	A – Flushing with clear water	Yes	Yes	No
	C – Brush off the lice	Yes	Yes	No
	E – Vacuum water	Yes	Yes	Yes
	I – Lice comb	Yes	Yes	No
C – Salmon stairs	F – Warm water	Yes	Yes	Yes
	H – Cold water	Yes	Yes	Yes
D – Counter flow stairs	B – Blowing off the lice	Yes	Yes	Yes
	C – Brush off the lice	Yes	Yes	Yes
E – Fish elevator	B – Blowing off the lice	Yes	Yes	Yes
	F – Warm water	Yes	Yes	Yes
	H – Cold water	Yes	Yes	Yes
F – Flush salmon through	A – Flushing with clear water	Yes	Yes	No
	C – Brush off the lice	Yes	Yes	No
	E – Vacuum water	Yes	Yes	Yes
G – Force mechanically	A – Flushing with clear water	Yes	Yes	Yes
	C – Brush off the lice	Yes	Yes	No
	E – Vacuum water	Yes	Yes	Yes
H – Robotic arms (ROV)	J – Electricity	Yes	Yes	Yes
	K – Picking off the lice	Yes	Yes	Yes
I – Moveable trap	A – Flushing with clear water	Yes	Yes	Yes
	C – Brush off the lice	Yes	Yes	Yes
	E – Vacuum water	Yes	Yes	Yes

9.2 Development of the decision-matrix

The screening of concepts is done by using the Pugh's method, which screens the concepts based on a weighted score for each alternative concept. By using a standard benchmark it is possible to compare the different concepts. A certain number of benchmarks or criteria are chosen in advance of the screening phase, and the benchmarks are also given a weight which tells how critical the criteria is to the final solution.

The screening process of concepts contains of the following steps:

1. Prepare the selection matrix (choose different criteria and weight them)
2. Then give each concepts a score for each criteria
3. Sum all the weighted scores for each concept
4. The concepts with the best scores are selected
5. Evaluate the results of the screening process

Point scale

The concepts are given a score between 1 to 6, where 6 is when the concept meets the criteria at a best manner and 1 is the worst. The method consists of putting the options up against each other, and then compare them in each criteria chosen in advance of the screening process.

Criteria

The alternative concepts are evaluated based on these four criteria: complexity, efficiency, accuracy, and salmon welfare.

- **Complexity – weighted 15 %**

  The criteria describe how complex the structure of the respective alternative is. The factors that impact the value of the criteria can be; number of parts needed in solution, how the solution is build etc. The higher degree of complexity gives a lower score and opposite.
- **Efficiency – 20 %**

  There is a high demand on efficiency since the net pens are full of fish and the salmon lice proliferate quickly. A low treating time of a salmon means a high score of efficiency and opposite.
- **Accuracy – 30 %**

  The accuracy gives a score on how well the treatment will removes all the lice on the salmon. A high accuracy is the better.
- **Salmon welfare - 25 %**

  The salmon's welfare is getting more and more important, and the breeders are feeling a higher pressure from the government and from the consumers to sort this out.

9.3 Screening of concepts

The screening process starts with the trapping concepts, where the process is described in the tables below. Their have the different concepts received a score in each criteria based on the evaluated outcomes (worst, best and the most probable), and based on the weighting of the criteria are the final weighted sum of utility being described. The concept with the highest score wins the screening process and is being brought further.

Table 13: Given criteria score to the different concepts

Combinated alternatives		Complexity				Efficiency				Accuracy				Welfare			
		Min	Prob.	Max	Sim	Min	Prob.	Max	Sim	Min	Prob.	Max	Sim	Min	Prob.	Max	Sim
A – Funnel	E – Vacuum water	2,5	4,0	5,0	3,8	2,5	4,0	5,5	4,0	2,0	3,0	4,0	3,0	4,0	5,0	5,5	4,8
B – Fish trap	E – Vacuum water	1,5	3,5	4,5	3,2	2,5	3,5	5,5	3,8	2,0	3,0	4,0	3,0	3,5	5,0	5,0	4,5
C – Salmon stairs	F – Warm water	1,0	2,5	4,0	2,5	2,0	3,0	5,0	3,3	2,5	3,5	5,5	3,8	4,5	5,0	5,5	5,0
	H – Cold water	1,0	2,5	4,0	2,5	2,0	3,0	4,5	3,2	1,0	2,5	5,0	2,8	4,5	5,0	5,5	5,0
D – Counter flow stairs	B – Blowing off lice	1,0	3,0	4,5	2,8	2,0	3,0	5,0	3,3	1,5	3,0	4,0	2,8	3,5	4,5	5,5	4,5
	C – Brushing	1,5	3,0	4,5	3,0	2,5	3,0	5,0	3,5	2,5	3,5	4,5	3,5	2,0	5,0	5,5	4,2
E – Fish elevator	B – Blowing off lice	2,0	3,0	5,0	3,3	1,0	2,5	3,5	2,3	2,5	3,5	4,5	3,5	3,5	4,0	4,5	4,0
	F – Warm water	1,5	2,5	4,0	2,7	1,0	2,5	3,5	2,3	2,5	3,5	4,5	3,5	3,5	4,0	4,5	4,0
	H – Cold water	1,5	2,5	4,0	2,7	1,0	2,5	3,5	2,3	2,5	3,5	4,5	3,5	3,5	4,0	4,5	4,0
F – Flush through salmon	E – Vacuum water	1,0	2,5	4,0	2,5	2,0	3,0	5,0	3,3	2,0	4,0	4,5	3,5	2,5	4,0	5,0	3,8
G – Force mechanically	A – Flushing water	1,5	3,0	4,5	3,0	2,0	3,0	4,0	3,0	2,5	4,5	5,0	4,0	1,0	3,0	5,0	3,0
	E – Vacuum water	1,5	3,0	4,5	3,0	1,5	3,0	4,0	2,8	2,0	4,5	5,0	3,8	3,0	3,0	5,0	3,7
H – Robotic arms (ROV)	J – Electricity	1,0	2,0	3,5	2,2	1,0	2,0	5,0	2,7	3,5	4,5	6,0	4,7	1,5	3,0	5,5	3,3
	K – Picking off lice	1,0	2,0	3,5	2,2	1,5	2,0	5,5	3,0	3,5	4,5	6,0	4,7	3,0	4,0	5,0	4,0
I – Moveable trap	A – Flushing water	1,0	3,0	4,5	2,8	2,0	3,0	4,0	3,0	3,5	4,5	6,0	4,7	2,0	5,0	4,5	3,8
	C – Brush off lice	1,0	2,5	3,5	2,3	2,0	4,0	4,5	3,5	3,5	3,5	6,0	4,3	3,0	5,0	5,0	4,3
	E – Vacuum water	1,0	3,0	4,5	2,8	2,5	3,0	5,0	3,5	2,0	4,0	6,0	4,0	4,0	5,0	5,5	4,8

Table 14: The simulated scores are normalized to each concept.

Alternatives		Complexity		Efficiency		Accuracy		Welfare	
		Score	Norm. Score	Score	Norm. score	Score	Norm. score	Score	Norm. score
A – Funnel	E – Vacuum water	3,8	4,82	4,0	5,03	3,0	3,77	4,8	6,08
B – Fish trap	E – Vacuum water	3,2	3,98	3,8	4,82	3,0	3,77	4,5	5,66
C – Salmon stairs	F – Warm water	2,5	3,14	3,3	4,19	3,8	4,82	5,0	6,29
	H – Cold water	2,5	3,14	3,2	3,98	2,8	3,56	5,0	6,29
D – Counter flow stairs	B – Blowing off lice	2,8	3,56	3,3	4,19	2,8	3,56	4,5	5,66
	C – Brushing	3,0	3,77	3,5	4,40	3,5	4,40	4,2	5,24

Table 14 continues.

Alternatives		Complexity		Efficiency		Accuracy		Welfare	
		Score	Norm. Score	Score	Norm. score	Score	Norm. score	Score	Norm. score
E – Fish elevator	B – Blowing off lice	3,3	4,19	2,3	2,93	3,5	4,40	4,0	5,03
	F – Warm water	2,7	3,35	2,3	2,93	3,5	4,40	4,0	5,03
	H – Cold water	2,7	3,35	2,3	2,93	3,5	4,40	4,0	5,03
F – Flush through salmon	E – Vacuum water	2,5	3,14	3,3	4,19	3,5	4,40	3,8	4,82
G – Force mechanically	A – Flushing water	3,0	3,77	3,0	3,77	4,0	5,03	3,0	3,77
	E – Vacuum water	3,0	3,77	2,8	3,56	3,8	4,82	3,7	4,61
H – Robotic arms (ROV)	J – Electricity	2,2	2,72	2,7	3,35	4,7	5,87	3,3	4,19
	K – Picking off lice	2,2	2,72	3,0	3,77	4,7	5,87	4,0	5,03
I – Moveable trap	A – Flushing water	2,8	3,56	3,0	3,77	4,7	5,87	3,8	4,82
	C – Brush off lice	2,3	2,93	3,5	4,40	4,3	5,45	4,3	5,45
	E – Vacuum water	2,8	3,56	3,5	4,40	4,0	5,03	4,8	6,08

The given scores are being normalized to get the same mean value as the point scale, and the normalized score are then transformed to the utility function based on the weighting of criteria (see Table 15).

Table 15: Consequences transformed to utility

Combined alternatives		Complexity		Efficiency		Accuracy		Welfare		SUM
		Score	W. Score	Sco-re	W. Score	Score	W. Score	Score	W. Score	Weigthed scores
A – Funnel	E – Vacuum water	4,82	1,45	5,03	1,51	3,77	1,13	6,08	1,82	5,91
B – Fish trap	E – Vacuum water	3,98	1,19	4,82	1,45	3,77	1,13	5,66	1,70	5,47
C – Salmon stairs	F – Warm water	3,14	0,94	4,19	1,26	4,82	1,45	6,29	1,89	5,53
	H – Cold water	3,14	0,94	3,98	1,19	3,56	1,07	6,29	1,89	5,09
D – Counter flow stairs	B – Blowing off lice	3,56	1,07	4,19	1,26	3,56	1,07	5,66	1,70	5,09
	C – Brushing	3,77	1,13	4,40	1,32	4,40	1,32	5,24	1,57	5,34
E – Fish eleva-tor	B – Blowing off lice	4,19	1,26	2,93	0,88	4,40	1,32	5,03	1,51	4,97
	F – Warm water	3,35	1,01	2,93	0,88	4,40	1,32	5,03	1,51	4,71
	H – Cold water	3,35	1,01	2,93	0,88	4,40	1,32	5,03	1,51	4,71
F – Flush through	E – Vacuum water	3,14	0,94	4,19	1,26	4,40	1,32	4,82	1,45	4,97
G – Force mechanically	A – Flushing water	3,77	1,13	3,77	1,13	5,03	1,51	3,77	1,13	4,90
	E – Vacuum water	3,77	1,13	3,56	1,07	4,82	1,45	4,61	1,38	5,03
H – Robotic arms (ROV)	J – Electricity	2,72	0,82	3,35	1,01	5,87	1,76	4,19	1,26	4,84
	K – Picking off	2,72	0,82	3,77	1,13	5,87	1,76	5,03	1,51	5,22
I – Moveable trap	A – Flushing water	3,56	1,07	3,77	1,13	5,87	1,76	4,82	1,45	5,41
	C – Brush off lice	2,93	0,88	4,40	1,32	5,45	1,63	5,45	1,63	5,47
	E – Vacuum water	3,56	1,07	4,40	1,32	5,03	1,51	6,08	1,82	5,72

From Table 15 can the result of the screening be seen, and the chosen concept is the Funnel and the Vacuum water with the sum utility score marked in red. This combination of concepts is brought further in the report and is described in the next chapter.

10 CONCRETIZATION OF SOLUTION

This chapter explains how the concept development were done after the concept screening was conducted, and two concepts from the screening were chosen. This phase involves a testing and evaluation of the two concepts through 3D modelling in Solid Works, and a discussion of possible combinations of the solutions.

10.1 The chosen concepts

The selected concepts from the screening process are the concepts, which are estimated to be the way to get to the salmon and the best treatment method for removing salmon lice off the salmon.

The Funnel

The first concept chosen is the Funnel, which is meant to attract the salmon into a funnel where the treatment can take place. The funnel has the purpose to narrow the cap between the salmon and the surroundings without stressing the salmon. This was first designed to be a straight trap like a funnel, but after a while was it made in a special shape. The purpose was to achieve a tighter gap between the salmon and trap. The final part, “the Tube”, can be viewed in chapter 11.

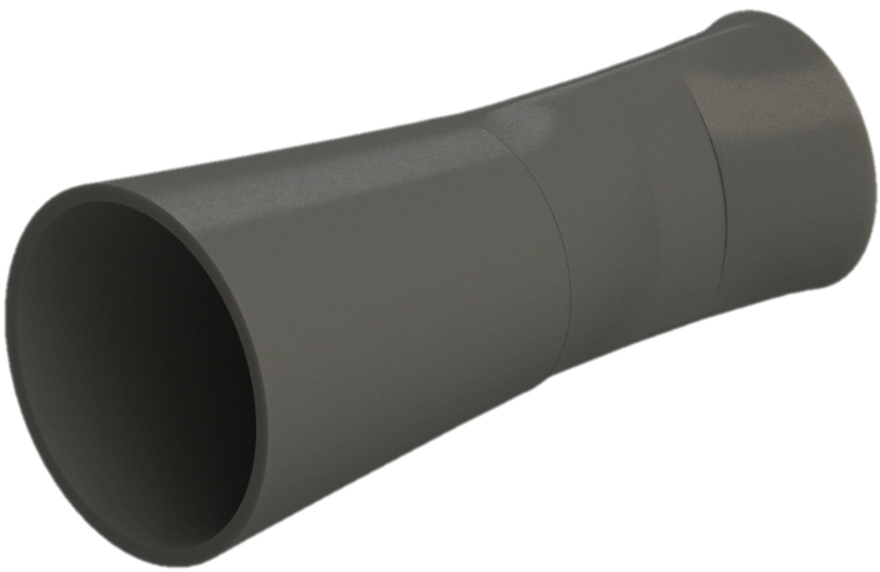


Figure 38: Shows the simple idea with the Funnel concept

This concept is viewed to be a realistic way to attract the fish into the treatment. The concept is a simple construction and there is no increases stress level for the fish due to this concept.

Vacuum pumping of water

The second concepts are the treatment method using vacuum pumping of water. The solution should use suction from a pump to extract water nearby the fish, and in the same process pull the lice off the salmon. This allows the system to loosen the lice, and simultaneously collect it in the system, which is a demand of the treatment methods. This is not a mechanism that is going to be considered in this concept development, but there should be a good possibility to develop a system for collecting the lice and it could as an additional function also count the lice levels in the net pens.

Figure 39: Showing only the concept of the vacuum water concept.

10.2 The combined concepts

The combination of the two concepts would create the final solution of the screening process. Both concepts need to be adapted into each other. The first change had to be done based on the pumping system that needed to have outlets 360 degrees around the salmon swimming through. This created the need for four water outlets through the funnel, which later has been called the tube.

Through modeling and simulations was it raised a higher demand for getting the salmon closer to the water outlets, because the simulated forces acting on the louse was highly dependent on the salmon's distance from the water outlets. The tube was therefore designed in a way that would make the salmon swim closer to the outlets without using external force or increasing the stress level for the salmon. The final shape of the tube is built in a way that forces the salmon to adjust the swimming path both horizontally and vertically. The idea is almost like a slalom course, where the thought is that the salmon will cut corners. It is at these corners the water outlet will be placed, and the result will be that the gap between the tube and the salmon will be shorter. However, the shape of the tube has not been tested in an actual scenario, but it is believed that it will be possible to swim through for the salmon. Because it is compared to the narrow opening at the Fish Cannon (see Figure 5) where the salmon are swimming through easily. From this comparison comes the assumption that the salmon will not have any problems swimming through the tube, although some modifications may be necessary.

The crucial factor to make this concept work is to position the concept in a way that attracts the salmon to swim through. There is no way to know how to do this for sure, but one recommendation is to exploit the swimming behavior for the salmon shoal. As described in chapter 1.4 by Frode Oppedal, the salmon is swimming in circles and very close to each other. This should be taken advantage of, by positioning the treatment in the swimming path of the shoal. As and additionally effect could the treatment device be moved around horizontally and vertically to reach the different parts of the shoal.

Figure 40: The complete trapping and treating system

The final result of the combined solution will be more comprehensive described in chapter 11.

11 PROJECT RESULTS AND EVALUATIONS

This chapter will present the projects results and describe all of the different parts of the concept. In addition, the results from flow simulations are described. Finally, there will be described an evaluation of possible challenges linked to the chosen concept.

11.1 Chosen Concept

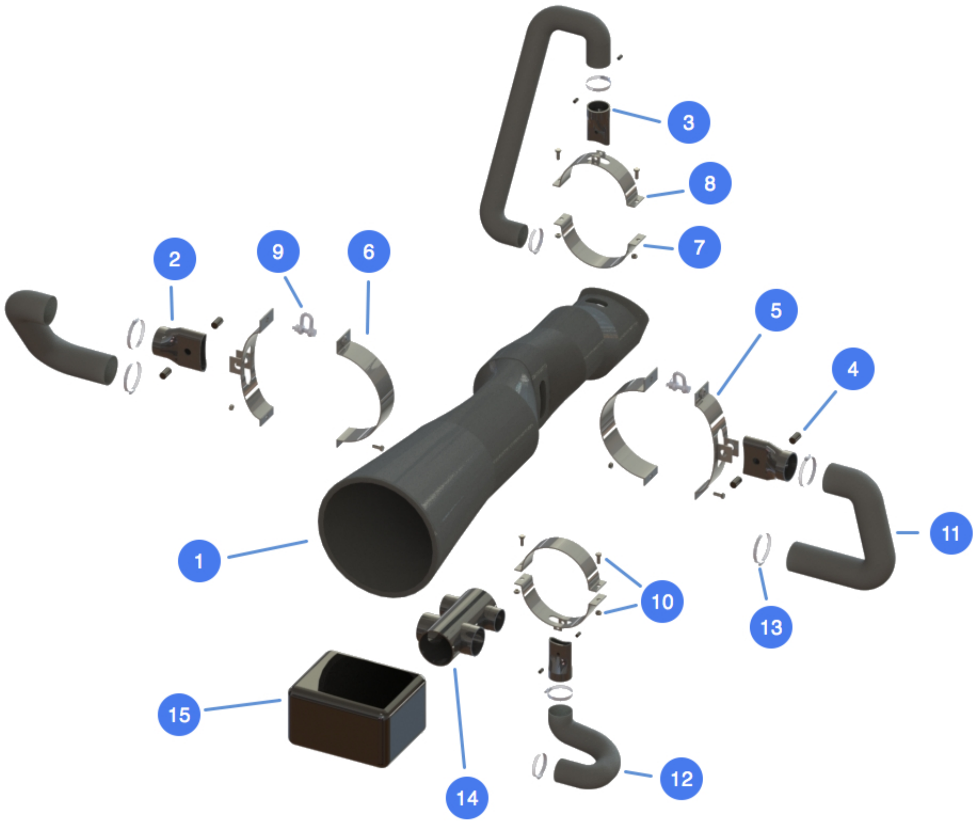


Figure 41: Exploded view of the whole system.

Table 16: A list of part numbers and part names.

Part number	Part name	Comment
1	Tube	Developed part
2	Side nozzle	Developed part
3	Top/bottom nozzle	Developed part
4	Pressure valve	Black box
5	Bracket 1	Developed part
6	Bracket 2	Developed part
7	Bracket 3	Developed part
8	Bracket 4	Developed part
9	Shackle	Imported part
10	Bracket screw	Imported part
11	Pipe 100 mm	Developed part
12	Pipe 80 mm	Developed part
13	Hose clamp	Imported part
14	Water distributer	Developed part
15	Vacuum pump	Black box

Table 17: Description of the included parts in the system.

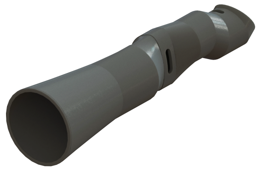
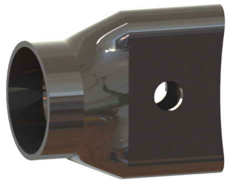
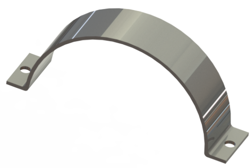
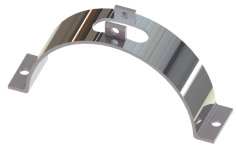
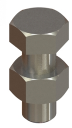
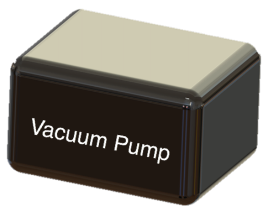
Description of parts	Drawing
1 – Tube The tube is designed to assure that the salmon can swim through it without getting stuck. The shape of the tube is specifically designed to make it possible to narrow the gap between the salmon and the nozzle, where the water is sucked in.	
2 – Side nozzle The side nozzle is designed to increase the velocity of the water and lead it into a pipe.	
3 – Top/bottom nozzle These nozzles at the top and bottom are designed in the same way as the side nozzle, only scaled down.	
4 – Pressure valve The valves are installed at both sides of every nozzle, in order to assure the safety of the salmon so it will not get stuck. It also has the function to lock the nozzle to the tube in the axial direction.	
5 – Bracket 1 The bracket 1 is used as a fastening point combined with Bracket 2. Two valves are also attached to Bracket 1 in the two holes in the middle.	
6 – Bracket 2 Used as a fastening point combined with the Bracket 1.	
7 – Bracket 3 Used as a fastening point combined with the Bracket 4.	

Table 17 continues.

Description of parts	Drawing
8 – Bracket 4 Used as a fastening point combined with Bracket 3. The pressure valves are also attached to Bracket 3.	
9 – Shackle The shackles holds the tube stable in the water and can be used to pull up the tube using a wire.	
10 – Bracket screw Attaches the brackets below the tube using a M14 screw and nut.	
11 – Pipe 100 mm Pipes used to transport the water from the side outlets. The outside diameter is 100 mm and the thickness is 3 mm.	
12 – Pipe 80 mm Pipes used to transport the water from the top and bottom outlets. The outside diameter is 80 mm and the thickness is 3 mm.	
13 - Hose clamp Attaches the pipes to the nozzles and to the water distributer.	
14 – Water distributer Connects the pipes and the vacuum pump.	
15 – Vacuum pump The pump creates the water flow.	

Further, the main components of the, which is the area around the nozzles are more detailed described.

The suction area with the pressure valves

The nozzle device works in a way that pushes the water through a narrow opening. This will make the velocity rise drastically and this will lead to a pressure drop. The suction is meant to rip the lice off the salmon without harming the fish. However there is likely that the salmon could get stuck at the nozzle as a result of the suction. Using pressure valves, which will open if the pressure gets too low, solves this problem. The pressure valves are installed to assure the safety of the salmon, but it has also the function to lock the nozzle to the trap in axial direction.

The figures below the suction areas with pressure valves.

Figure 42: Showing the inside of the tube with the right side water outlet.

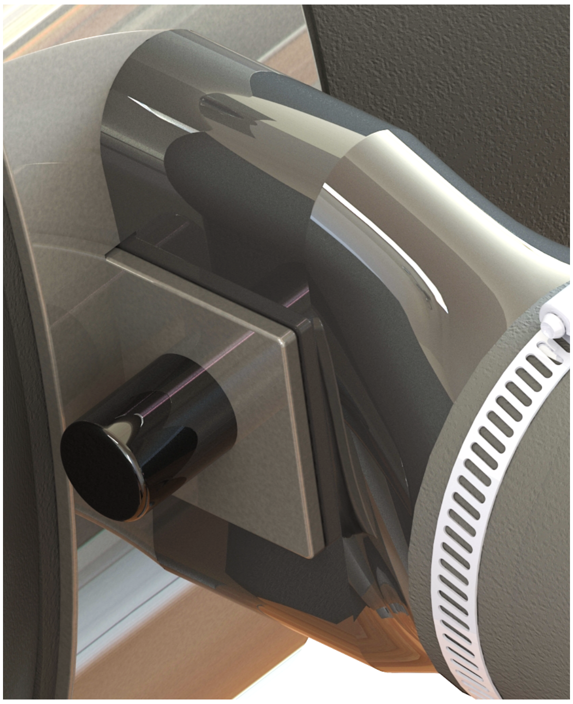


Figure 43: Showing the assembled side nozzle and pressure valve to the bracket.

11.2 Flow Simulations

The chosen concept is designed to suck in the attached salmon louse on the salmon passing through. There are many aspect with this situation that differs, many of the factors are listed in the elements of uncertainty in chapter 8.1. However, it is interesting to model an example and run a flow simulation to see how the water flow affects the salmon louse. The concept is therefore been tested with a modeled salmon with an attached salmon louse. The situation that has been studied is the specific situation where the pumping system works on a salmon louse attached to one side of the salmon (the left side in this simulation). The salmon louse is modeled at the size of an adult female louse, which approximately is 12 mm without egg-strings.

11.2.1 The Meshing Settings

This type of flow simulations sets a high demand to refinement in the meshing, since the model consists of such small parts and the most interesting part, the louse, is so tiny compared to the total model. Therefore is it used a local mesh around the louse in the simulation. See Figure 44 for more details.

The figure below shows the meshing around the louse.

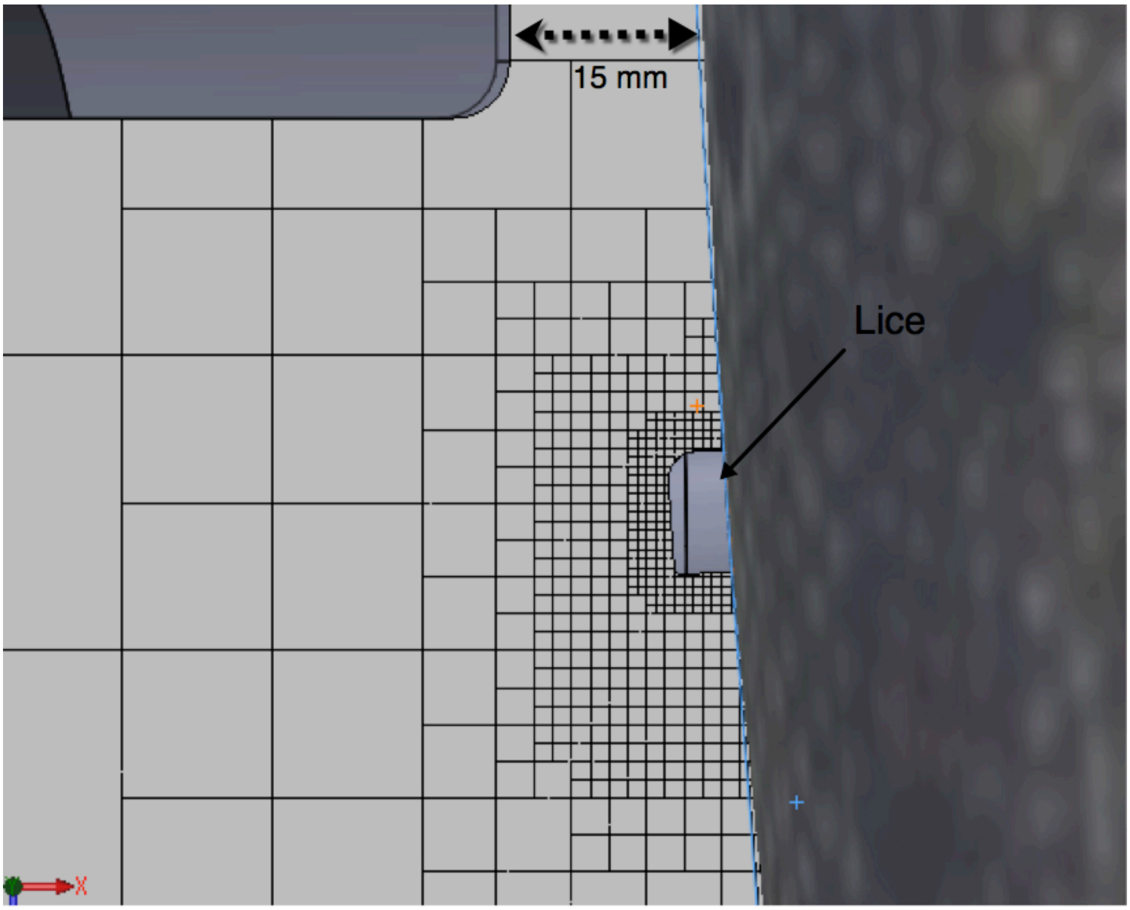


Figure 44: Cut plot of meshing. Initial mesh set to 4 and Local Mesh set to 6.

11.2.2 The Simulation Results

The simulation is based on several assumptions. The first one is that the salmon will swim very close to the outlet. It is simulated a distance of 15 mm from the salmon to the inside of the tube.

Velocity

The concept is based on a water flow, which should rip the lice off the salmon. This makes it interesting to investigate how high the water flow speed will get. The figures below shows the water speeds for two different water flow rates.

The figures below show a section view of the model, where the model is split in the top plane. Figure 45 is a simulation where the water flow rate is set to 40 liter per second and the lines show the flow trajectories. It can be seen from the figure that this flow rate leads a water velocity of 12 m/s in the nozzle.

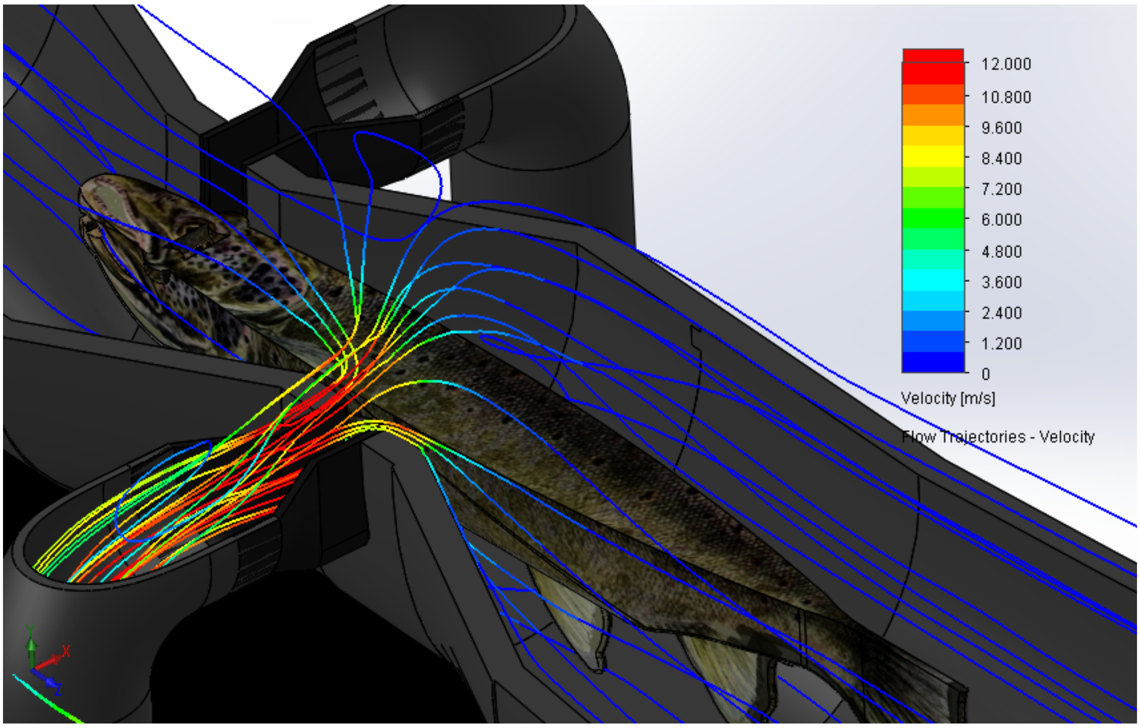


Figure 45: Flow trajectories of velocity of water flow rate of 40 liters per second.

Figure 46 shows the flow simulation when the water flow rate is set to 30 liter per second. The flow trajectories show a lower water velocity, with between 7 and 8 m/s.

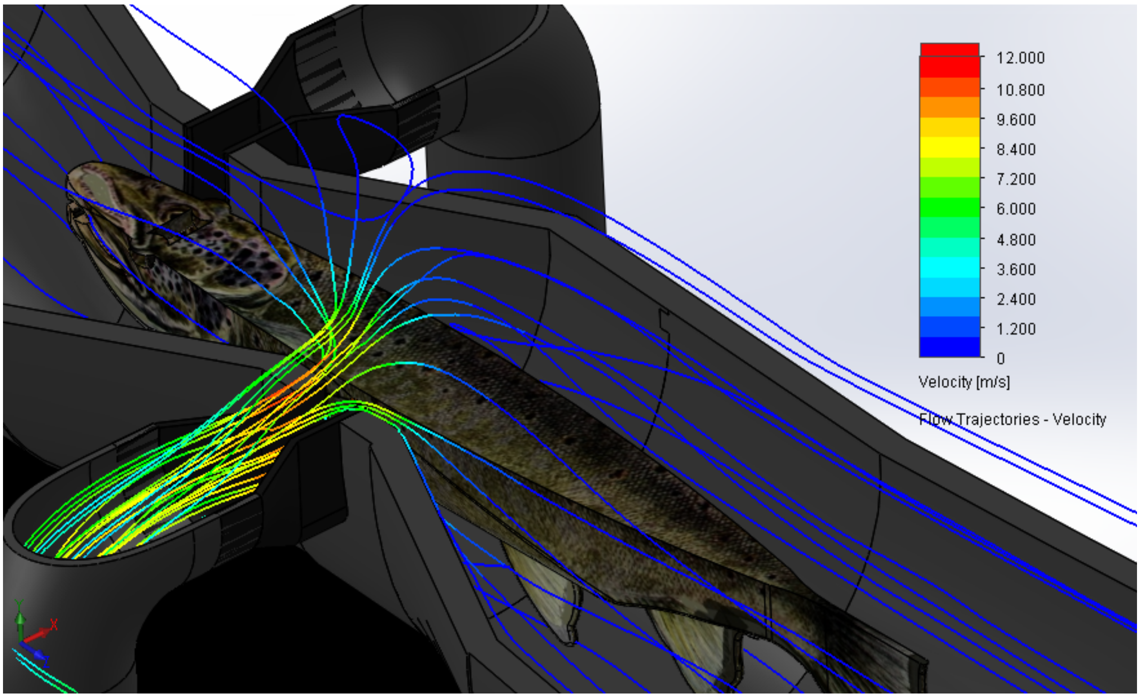


Figure 46: Flow trajectories of velocity of water flow of 30 liters per second.

Figure 47 shows the water velocity when the water flow is distributed in the horizontal plane across the louse. The simulation shows that the water velocity is about 8 m/s in front of the louse but is much higher in the nozzle. If the louse is an adult female louse, the high velocity in the nozzle attracts the egg-string and loosens them from the louse. This will be discussed more in the result chapter.

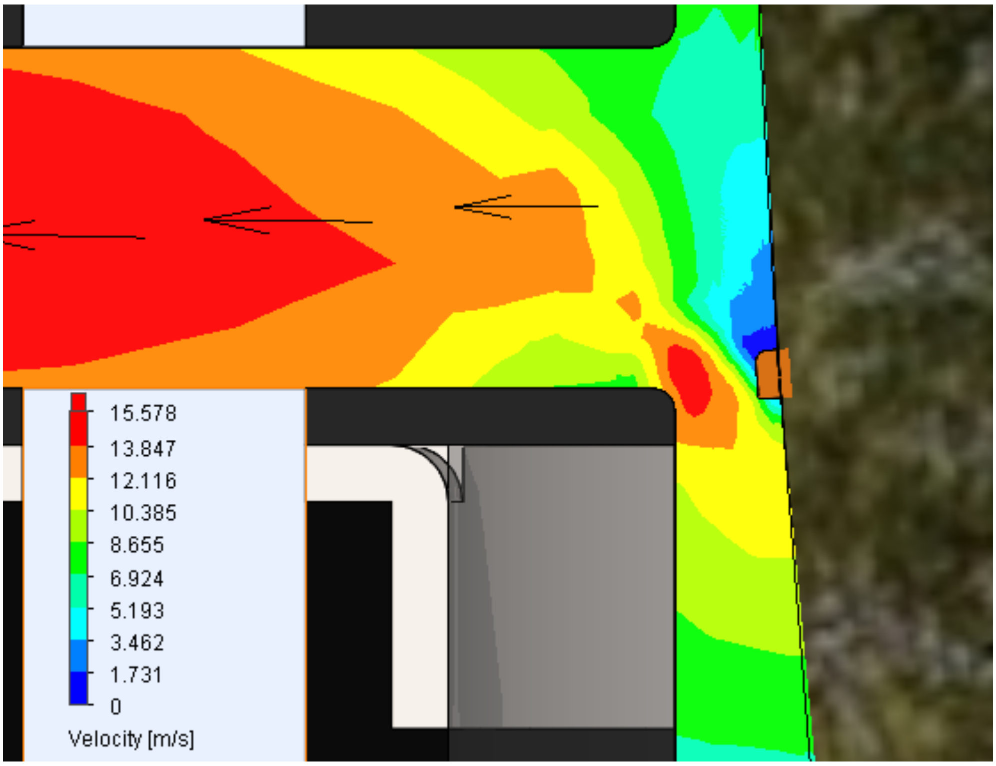


Figure 47: Cut plot of velocity at water flow of 40 liters per second.

Pressure loss

Pressure loss or pressure drop is the defined pressure difference between two points of a fluid carrying network. The loss drop occurs from frictional forces and can get very high for high velocity flows. Since this model involves high velocity flows is it interesting to investigate the pressure drop in the model.

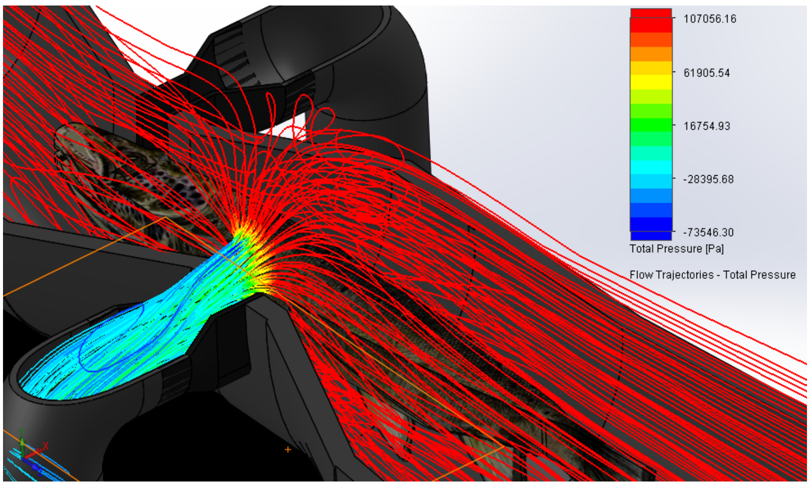


Figure 48: The narrow opening where the water is sucked in mainly causes the total pressure loss.

Forces

The main reason for the simulation is to look at how the water flow will impact the louse attached to the salmon. The simulation has been simulated with three different water flows as boundary conditions; 20, 30 and 40 liters per second. The results of forces acting on the louse can be seen in the table below, as well as a surface plot of the shear stress on the louse and the salmon.

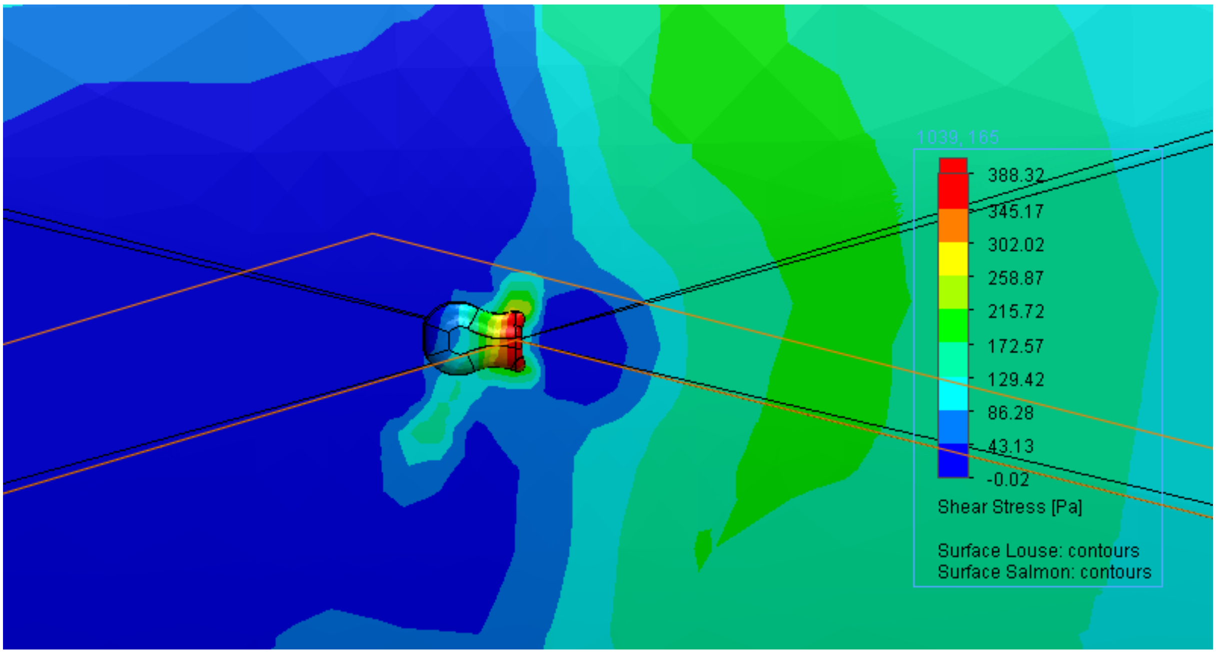


Figure 49: Surface plot of louse and salmon showing shear stress with water flow at 40 liters per second.

The simulation is done at several different conditions. It has been interesting to see the difference in forces acting on the louse depending on the initial conditions like the rate of the water flow. In Table 18 are the results from the simulations presented.

Table 18: Forces acting on the louse at different flow rates.

Flow rate [liters/s]	Force X-direction [N]	Force Y-direction [N]	Force Z-direction [N]	Force Sum [N]	Pressure Loss [Pa]
20	-0.14	0.04	0.03	0.15	26 520
30	-0.04	0.06	0.39	0.30	75 207
40	-0.50	0.13	0.08	0.52	132 171

11.3 Evaluation of possible challenges

The following challenges are linked to the concept, and the challenges need to be considered when the concept is being developed further.

Challenges linked to the tube

- The tube is designed to be very narrow, this means that many salmon might not swim through. Some form of luring might be necessary to assure the salmon to swim through.
- The length and shape of the tube can be hard to swim through. I have tried to design it so it would be possible to swim through, but this should be tested further.

Challenges linked to position of the salmon

- The forces acting on the louse from the water flow is dependent on how close the louse is to the water outlet. This means that the salmon has to be relative close to the outlet. This might be a challenge, and it is possible that it is not enough with the special shape of the tube to achieve this. Although it is likely that the salmon would get pulled toward the outlet due to the suction, but it is not clear have the salmon would react to the scenario. This theory should be tested in practice.

Challenges linked to the pumping system

- The idea is that this concept should be put inside the net pens and continuously work to reduce the increment of louse. This means that it will be times when there is no salmon swimming through, and then it has to be developed a sequence for the pumping system at rest. And then it also is interesting to look at the response time from the pump is at rest to when it as to pump for full force again. This measure can be interesting and crucial for the success of the concept.
- The pumping system is assumed to create a lot of noise, and it can be a challenge to attract salmon if it is a lot of noise. It can be assumed that the salmon living with these noise conditions will get used to it.
- The flow simulation results made me question the concept. I fear that the needed water flow can be too high to be achievable. I assumed that the needed force to remove a louse was about 0.5 N, which came from the statement made from Dalvin Sussie who said that the needed force was as small as a pull with a tweezer. With this demand of force was the necessary water flow according to the flow simulations equal to 40 liters per second. To put this into common perspective is a garden sprinkler using about 1000 liters per hour, which will equal to about 0.3 liters per second.

Challenges linked to operating constantly

- From one of the key issues came the desire to make a concept that was working constantly to reduce the increment of lice infestations. The factor that limits this is the rate of how often the salmon swims through the treatment. To maximize the amount of salmon swimming through there has to be done some tests. But it is possible that it will be sufficient to place it on the depths where the salmon is swimming very close together, and also placing it in the swimming path where the salmon shoal is swimming in circles. However, their reaction to such a device has to be tested.
- Implementing the mindsets from the agriculture, which is presented in chapter 1.11, might be a great way to seek for methods for making it necessary for the fish to go through the treatment method, and therefore provide the premise to make it operate constantly.
- The salmon should go through the treatment quite often dependent on the duration of the growth of the lice, which is dependent on the water temperature. But for example if the treatment works best on the pre-adult stages and later will it be necessary to treat every salmon once in three weeks (see chapter 1.5), because this is the time it takes for the female to develop from pre-adult to adult.

12 CONCEPT RECOMMENDATION

This chapter is giving a CAD presentation of the concept with 3D drawings of different parts included in the concept.

Figure 50: The full model.

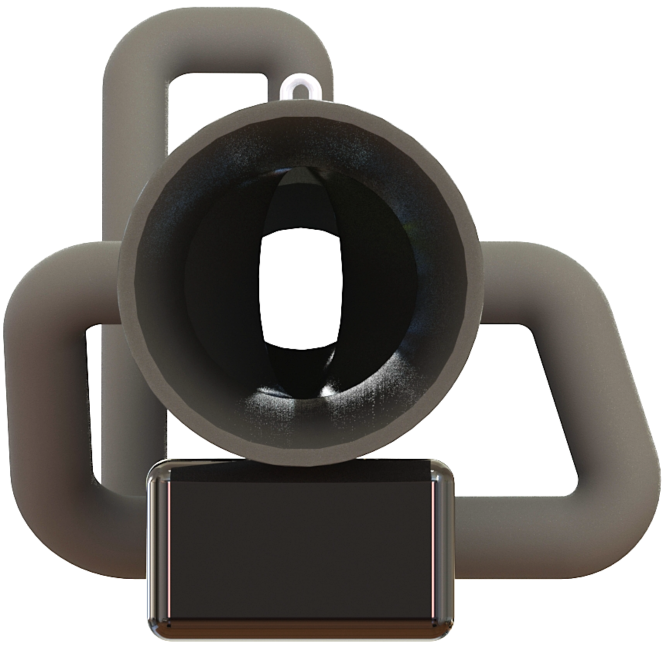


Figure 51: Model showing the concept from a fish viewpoint, where the inside shape of the tube can be seen.

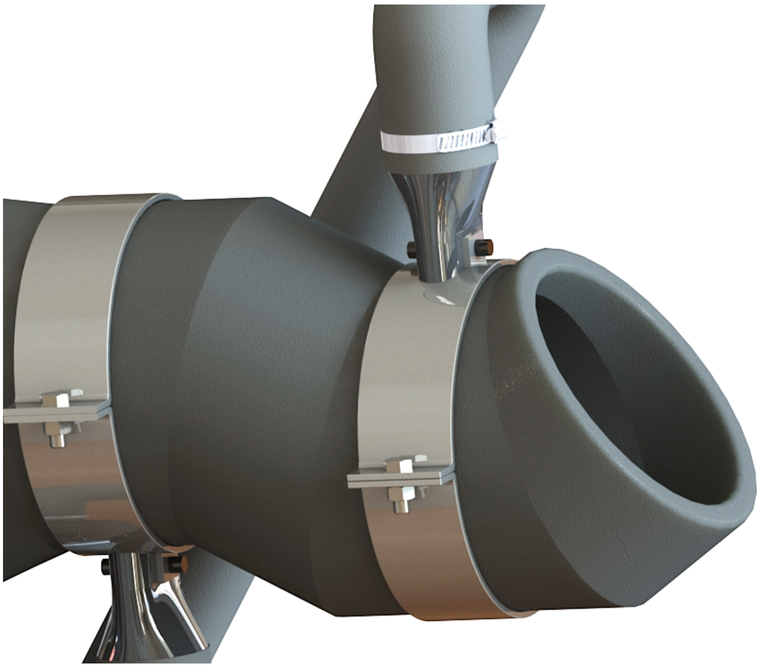


Figure 52: The rear of the concept and the exit for the salmon. It illustrates the idea of tube, where the fish has to adjust also in the vertical direction to get through. And this will narrow the gap between the water outlets (over and under) and the fish, which is desired.

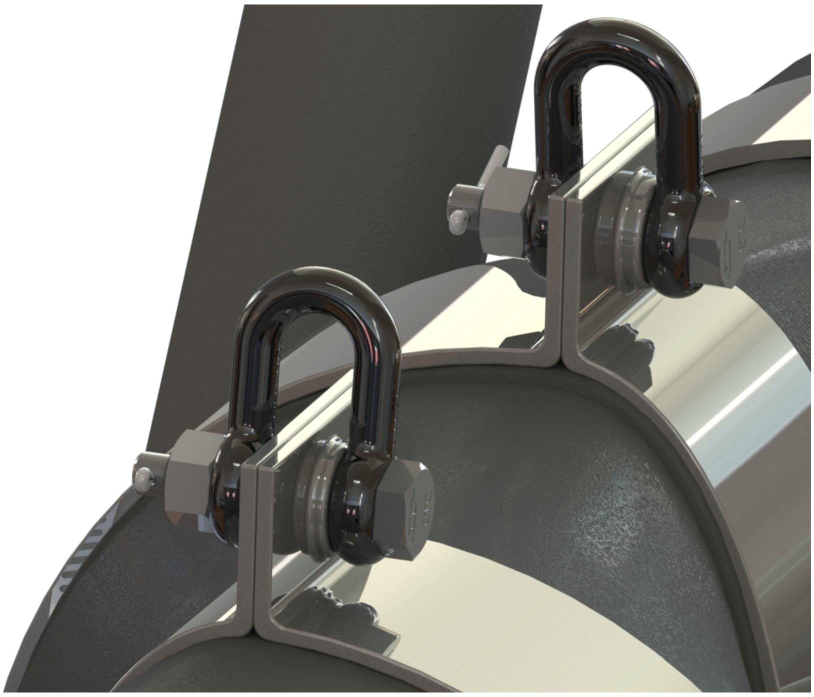


Figure 53: Showing the assembled shackles to the brackets.

The shackles are there to hold the concept up in vertical direction. However, it is assumed that the final solution would also need some bearing for the pump. Because it will have a lot of weight, and the pump will work as a load to keep the whole product stable since the pump will be connected to the tube by some wires. The final solution with wires and the connection between the pump and the tube is not developed in this project.

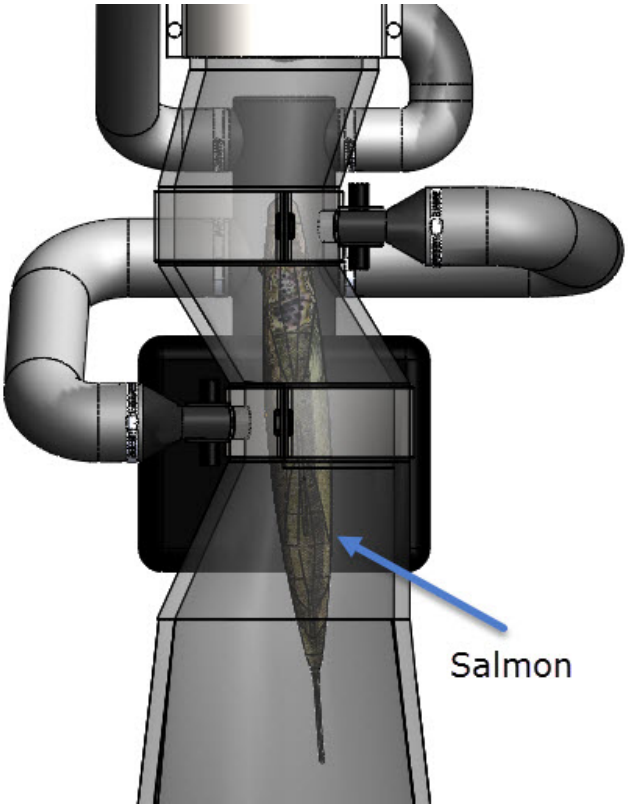


Figure 54: Illustrates the swimming path of the salmon through the tube, where the salmon has adjust both horizontally and vertically, almost like a slalom course.

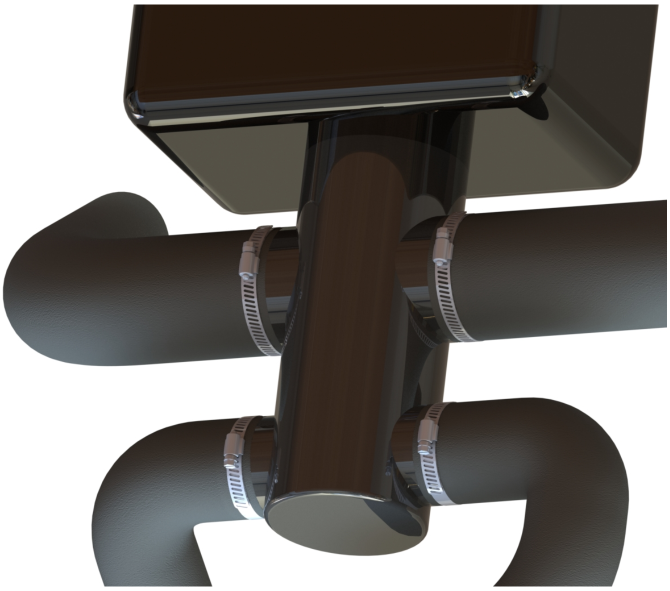


Figure 55: Connection between pipes and the pump through the pump distributer.

The figure of the connection between the pipes and the pump shows where the four pipes are connected to the same pump. This is done to make it possible to have only one pump.

13 PROCESS EVALUATION AND DISCUSSION

This chapter is a review of evaluations and discussions related to the project process.

Wide project objective

The project objective was to investigate and examine if there could be developed a mechanical treatment method to solve the problem with salmon lice in the salmon farmed industry. This is an extremely wide objective, which has lead to a lot of challenges. The objective was intentionally chosen this wide to set a platform for a creative thinking and an innovative concept development process. This led to that I spent a lot of time on charting the problem by researching around existing treatment methods. Initially it looked to me as if many of the currently used treatment methods worked all right. However, there was a problem with the salmon´s welfare and the treatment processes often required a lot of manpower and therefore involved high costs.

Challenging to identify the problems with existing treatment methods

The salmon farming industry was pretty new to me when the project started, and I had never seen a lice treatment in person. This required that I spent a lot of time on the research phase and it was essential to find the disadvantages linked to the existing treatment methods. Since the knowledge of disadvantages could be used to develop new concepts for a treatment method.

Through my visits to the salmon farming plants I got a bigger understanding on how a salmon farming process is done. This gave me the necessary knowledge on how the concept should be to have a possibility of success. I gained a lot of useful knowledge by talking to the breeders and see how the daily operation at the plant was conducted. It was desirable from my side to see features or material types used at the plants, which could be adopted into the brainstorming phase of the concept development and possibly also take apart in the final solution.

Concept development

The concept generating was an innovative phase, where I tried to think as wide as possible without any limitations. However, I felt that my mindset already had gotten a bit limited by the research phase where I read a lot about the existing solutions. I felt it necessary to spend a lot of time on the research phase, since I was totally new to the business. In the aftermath I see that it would have been more valuable to just learn the basics of lice treatment and then do the innovative phase before reading about existing treatment methods. Regardless, this project has given me a good experience on how such process should be conducted.

During the research phase I was trying to get to know as much as possible regarding how the lice was attached to the salmon. It was however hard to find out for example how well the lice was attached to the salmon, and how great force that was needed to pull it off. However, Dalvin Sussie at the Institute of Marine Research assured me that it was low forces needed to delouse the lice from the salmon. I also presented my final concept to him, and he had no previous knowledge of this treatment method. He could therefore not claim if the treatment would work or not. However, he meant that this method would probably work best on mature female louse, since they have a relative huge back body that is not attached to the salmon, and also because they have egg strings. This was good news, since it is the mature female louse and especially the eggs, which is interesting to get rid of in the net pens to prevent reproduction of lice.

Screening

The screening process of the concepts was conducted based on the demands defined under the concept definition. The demands were defined by the technical, economical and environmental requirements found necessary based on my understanding of the salmon farming business. These requirements came from my research phase, consultation with my supervisor and contributions from my external company visits. This lead to the presented absolute and qualitative demands and it also led to the weighting of the quality criteria used in the screening process. Usually the concepts are screened based on quantitative criteria, but this was not conducted in this project. The reason is that there would be very difficult to estimate the costs of production and cost of usage, and I chose therefore to exclude this from the screening process.

Solution

This Master thesis is only the initial stage of many years of work. The developing process of a new product for resolving the lice problematic in the salmon farmed industry is a huge task, and a schedule of 4,5 months in this context only makes it possible to scratch the surface. I have tried to concretize the challenges linked to the solution I have chosen and therefore made the basis for further work.

My concept can prove to be functional, however to be certain it has to be conducted a physical test. A physical model needs to be built and a pumping system has to be implemented. The flow simulation shows the results from the forces acting on the lice attached to the salmon. However, there is a lot factors in the simulation that does not correspond to the reality. The most important one is that the simulation assumes that the model is static, which means that the salmon and the louse are solids and not moving. This would make a difference for the louse in particular when the louse is attached only in the front of the body, and the rest is freely floating, for instance for the adult female with long egg strings. In many cases would these egg strings be sucked into the nozzle (see Figure 47). There is likely that this would increase the force acting on the louse, and rip it off the salmon.

14 CONCLUSION AND FURTHER ASPECTS

The objective of this Master thesis was to identify and examine the possibilities for a mechanical treatment method to solve the salmon lice problem in the salmon farmed industry. Furthermore, the purpose was to develop proposals for concepts with the aim of satisfying all the defined requirements. This objective was achieved, and it is developed a concept where the salmon is swimming through a funnel-shaped tube with a pumping system as the treatment method.

14.1 Results and recommendations

The final result of this project is a funnel-shaped tube, which changes the centre point in the longitudinal direction. The treatments of salmon lice are being conducted from four water outlets positioned at the tube, where lots of water is being sucked in by a pumping system. The exerted water flow is meant to extract the lice off the body of the salmon. The solution makes it possible to treat the salmon constantly and with low maintenance and operation costs. It also provides a possibility for treatment with a high accuracy and efficiency, without exerting a tremendous stress factor to the salmon.

The following elements are developed and included in the result:

- A **trapping system** for the salmon, where it will swim into a funnel. The system should be positioned inside of the net pens so it will interrupt the swimming path for the salmon shoal.

- A **pumping system**, which will contribute the actual lice treatment of the salmon. This system is connected to the trapping system. The treatment uses a vacuum pump for pumping water around the salmon. The result is that the attached lice will get ripped off, and then follow the water current into the pumping system.

The positive side-effects of this combined treatment system is evaluated to be the following:

- Zero handling of the salmon
- Gentle method with no damages on the salmon
- Zero starving of the salmon due to the treatment
- Continues delousing method because the treatment is placed in the net pens where the salmon live
- Increased efficiency
- Highly focused on the adult female louse, due to her size and her freely hanging egg strings.

14.2 Further Work

The developed concept in this project requires further work and testing in order to be sure of it's functionality. The list below shows a number of activities that needs to be taken into consideration in the further work of this project.

- Building a full-scale prototype and test a real scenario with a salmon, which will determine if the concept is plausible.

- Selecting the appropriate materials and metric measurements for the final product. The materials selected needs to be biocompatible with sufficient properties against fatigue and fracture. It also has to have a high corrosion resistance.

- Continue to develop a system for cleansing the pumped water free for salmon lice. Another concept development phase should begin to achieve a concept for solving this problem.

- The docking system for the final product needs to be designed. Desirable it should have a docking system where the final solution can be moved both vertically and horizontally.

- When the final solution has been finalized there has to be developed a cost evaluation for the manufacturing and the final operation of the solution.

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