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IMPROVING CLEANABILITY BY INNOVATING DESIGN

Lars Andre Langoeyli Giske[1*], Ola Jon Mork[2], Emil Bjoerlykhaug[2]

[1]Optimar AS dept. Stranda, Svemorka 45, 6200 Stranda, Norway
[2]Department of Ocean Operations and Civil Engineering, NTNU, Larsgaardsveie 2, 6009 Aalesund, Norway

[*]e-mail: lars@stansas.no

Abstract

Providing safe-to-eat consumer fish products is a key objective for the Global Aquaculture Industry. Cleaning of the process equipment is crucial to meet the demands for fish quality, but also environmental issues and human safety must be taken into consideration. Design of Easy-to-clean fish processing machineries is an efficient and innovative perspective which could be a game changer in the Aquaculture Industry.

Based on the generic hygienic design principles stated by EHEDG and experience collected in a in a research project in the Norwegian Aquaculture Industry, this paper presents four specific design concepts for state of the art fish processing machineries, which is an attempt to interpret EHEDG guidelines to actionable design changes suiting the Norwegian Aquaculture Industry and the type of Original Equipment Manufacturers serving this industry. The development of the design concepts is done by extensive prototyping work, and continuous testing and evaluation in real industrial environment, and there have been numerous iterations in the development of the design concepts. The design concepts have been implemented into several industrial applications for fish processing machineries, and have been under operation at fish processing factories for more than 6 months.

The Hygienic design concepts implemented on fish processing is expected to reduce the risk for *Listeria monocytogenes* and other bacterial contamination in the fish processing factories, reduce the demanding cleaning work in the fish processing factories, reduce usage of chemicals and water in the cleaning process. The experience collected after over 6 months support the expectations. The paper also elaborates future research work in the area of hygienic design principles and concepts.

***Key words**: Design, Design for Cleaning, Cleaning, Innovation, Fish processing.*

1. Introduction

Equipment and machines in the aquaculture industry must be designed to facilitate easy cleaning and disinfection and ensure food safety [1], and thus this is also a requirement from fish processing plants to Original Equipment Manufacturers (OEM's). This paper will follow the design innovations to improve the ease of cleaning the equipment done by an OEM in the Norwegian aquaculture industry. The design studied is related to one specific product group, namely conveyors.

The Norwegian aquaculture industry is big, with domestic sales of salmon and trout around 46 bill. NOK (4.45 bill. EUR, or 5.24 bill. USD) in 2015 in Norway, and with exports of almost 50 bill NOK (5.01 bill. EUR 5.9 bill USD) in 2015 [2]. The industry is making a lot of money since the price per kilogram of fish is high. There are several factors that could be improved to further increase the earnings, one of which is to cut the costs of cleaning.

1.1 *Listeria* spp.

Fail-safe procedures for the production of *Listeria*-free products have not been developed. The most critical areas for the prevention of contamination are: plant design and functional layout, equipment design, process control operational practices, sanitation practices, and verification of *Listeria monocytogenes* control.

L. monocytogenes can adhere to food contact surfaces by producing attachment fibrils, with subsequent formation of a biofilm, which impedes removal during cleaning. The attachment of *L. monocytogenes* to solid surfaces involves two phases: 1. Primary attraction of the cells to the surface and; 2. Firm attachment following an incubation period.

Various studies have demonstrated that *L. monocytogenes* is resistant to the effects of sanitizers, like the effects of tri-sodium phosphate (TSP), especially after a colony has grown on the surface and biofilm has formed. It is more resistant to cooking processes than other pathogens. *L. monocytogenes* is susceptible to irradiation. Generally, the extrinsic factors that have the greatest effect on microbial growth kinetics are: temperature, oxygen availability and relative humidity [3]. *Listeria* spp. is found "everywhere", or in: earth, water, vegetation and raw fish, but in small quantities, so it is expected that some listeria will find its way into fish processing facilities [4], however the important point is to clean it away after the processing is finished to keep it from forming biofilms and growing.

It is clear then that equipment which is poorly designed with regards to cleaning could be a source of contamination which could lead to, in the most extreme case, death. Another aspect of equipment which is poorly designed for easy cleaning is the considerable additional expenses for processing plants [5]. When the equipment is poorly designed, it is more difficult to clean, which exposes the equipment for more wear and tear due to harder use of chemicals, which eventually could degrade the lifetime for the equipment. In addition, it is a hazard for contamination, and it could be necessary to replace the equipment.

1.2 Cleaning

When producing salmon and/or trout, the factory has to be cleaned every day in order to avoid growth of bacteria, especially the previously mentioned *L. monocytogenes*, which is the most unwanted bacteria [6], and the main concern. It causes 2,500 serious illnesses and 500 deaths annually in USA, it can survive 0 - 45 centigrade and it grows well in damp environment. *Listeria* also thrives in neutral to alkaline pH but not in highly acidic environments. The growth rate in pH from 5 to 9.6 depends on substrate and temperature. Human listeriosis may occur in humans if they eat meat with listeria, with meningitis or meningoencephalitis as most common manifestations in adults.

Currently, cleaning of fish slaughterhouses is performed manually, and often during night since the slaughterhouse utilizes two shifts to slaughter the daily quota of fish. The main objective of the cleaning task is to remove bacteria, biofilm and other contamination hazards. It is important to prevent growth of bacteria in the fish slaughterhouses.

The labor is time consuming and takes place in a harsh environment with a lot of chemical use. There is a high passage in the workforce. The current way of cleaning a fish processing plant is largely conceived by trial and error, and little formal research has been done other than the formal demands from Mattilsynet (Norwegian Food Safety Authority) stating that only approved disinfection aids are to be used [7], together with different cleaning companies having done their internal research.

There are increasingly tougher quality demands both from customers and from governments, and there is a growing requirement for documentation of the processes of slaughtering fish, and therein the usage of cleaning chemicals and logging of cleaning procedures. The cleaning of equipment used in fish slaughterhouses is closely related to the fish quality, and eventual outbreaks of *Listeria* spp. is very unwanted and damaging both to the fish factory and the industry as a whole [8, 9].

As of today, the process of cleaning fish slaughterhouses is a costly process for the factories, with an average of 10 workers each night for 6 - 7 hours. Each worker is earning around 600,000 NOK (60.307 EUR, or 71 USD) each year due to a relative high basic salary level in Norway and additions to the salary due to nighttime work and doing work in hazardous environment.

Firstly, this paper will give overview of the Norwegian Aquaculture Industry in which the research in this paper is set as explained in the previous section. Then, some of the cleaning hassles that currently exist in the Norwegian Aquaculture Industry are presented in the two subchapters following the introduction. Chapter 2 is divided into six parts: 2.1 gives an overview of the theory backing the research method presented. Subchapter 2.2 describes how the research method is implemented and how the experiments presented are being conducted. 2.3 presents the work done around material choices in the Norwegian Aquaculture Industry and the link to EHEDG guidelines. Chapters 2.4, 2.5 and 2.6 presents and discusses results of design concepts related to functional requirements, surfaces and installation and other remarks regarding Design for cleaning, respectively. Finally, in chapter 3, conclusions and further work is presented.

2. Design for cleaning

2.1 Theory

"Design for X" is a method of focusing on a limited number of the most vital components of a design at a time [10]. Design for cleaning is introduced as a concept in product development, which focuses on making the product easier to clean. This is related to the operation phase of the life cycle of the product. This is an effort to keep focus on reducing cleaning costs and cleaning time in the operations of fish processing plants. This is builds on "hygienic design" in the sense that hygienic design is an evaluation of how well the design prevents a contamination risk after the equipment is built, whereas Design for cleaning is taking the cleaning process into consideration when designing the product with an end goal of making the cleaning easier, thus mitigating contamination risks.

The process of gaining knowledge about how to do the design changes could be said to be a form of experimental research with field experiments. An experiment is often used to validate a hypothesis [11], and the hypothesis which are being evaluated are defined as design concepts. The design concepts are tested in the field, in this case in several actual fish processing plants.

The European Hygienic Engineering Design Group (EHEDG) has released a document of Hygienic Equipment Design Criteria. It "describes the criteria for the hygienic design of equipment intended for the processing of foods. Its fundamental objective is the prevention of the microbial contamination of food products" [12], and consist of several guidelines divided into chapters regarding materials, functional requirements and hygienic design and construction.

2.2 Method

The guidelines proposed by Hauser *et al.*, [12] are reviewed and interpreted, in addition to considering the guidelines proposed from Nikoleiski [5]. They are then conceptualized into specific design concepts for a specific case-product for a specific OEM in the Norwegian Aquaculture Industry. The design concepts are derived by close interaction between the OEM and several fish processing facilities, combining the knowledge of both and taking the wishes from the fish processing facilities into consideration. Several stages of design reviews were crucial to reach end design concepts.

Virtual prototyping was used extensively in the design phase, and the most promising concepts were built in actual sized prototypes. The prototypes that were built were further tested at the fish processing facilities. The designs were evaluated and feedback from the fish processing facilities to the OEM led to further design enhancements and other concepts which again was tested and evaluated, in an iterative process for testing design concepts.

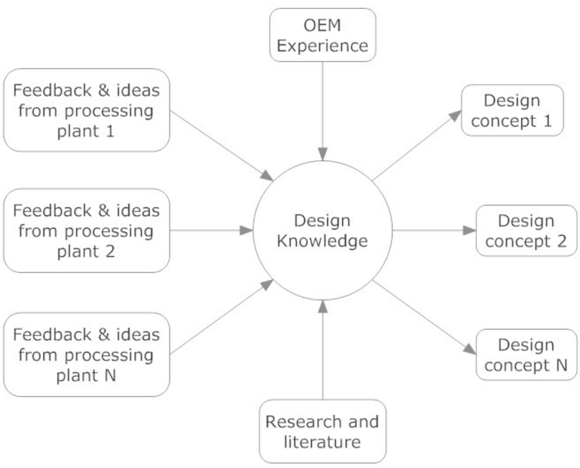

Figure 1. Concept development process

The design changes proposed came from several sources. Some changes came from one or several fish processing plants to the OEM, while other changes were a result from brainstorming internally in the OEM design environment. Even further ideas to design concepts came from reading books and research articles referenced in this paper.

In this case study, one particular product from the OEM is evaluated as previously mentioned. This is the conveyor product family, which has a lot of variants. During the work, the design was revisited from scratch. Design inputs came both from customers and the OEM, and inside the OEM both welders and fitters were involved in the design process together with both experienced and new engineers. The proposed changes apply to all of the different conveyors inside the product family, and the focus has been on changes that could be implemented in several products and are more of a general type of change. Following will be a description of how an OEM in the Norwegian Aquaculture Industry has changed their equipment design in an attempt to interpret the design guidelines proposed by EHEDG.

2.3 Material choices

The guidelines presented in EHEDG chapters 4.1 General, 4.2 Non-toxicity, 4.3 Stainless steel and 4.4 Polymeric materials are all concerning material choices: they should be non-toxic, mechanically stable, corrosion resistant, and have a surface finish that makes them suitable. Due to demands from the industry, these guidelines must be followed, and thus they are also followed in the case product. All parts of the design concepts are made either in AISI 304 or AISI 316 steel, or where applicable polyoxymethylene (POM) or polyethylene high-density (PEHD) 500 polymers. This is compliant with EHEDG chapters 4.3 Stainless steel and 4.4 Polymetric Materials which lists the best materials to use when the ease of cleaning is the focus, and these materials are also non-toxic, corrosion resistant and are mechanically stable.

2.4 Functional requirements

The guidelines presented in EHEDG chapters 5.1 Cleanability and decontamination, 5.2 Prevention of ingress of micro-organisms and 5.3 Prevention of growth of micro-organisms are concerning functional requirements with regards to cleaning and contamination that equipment should adhere to.

EHEDG chapter 5.1 Cleanability and decontamination states that equipment should be easy to clean. EHEDG chapter 5.2 Prevention of ingress of micro-organisms and chapter 5.3 Prevention of growth of micro-organisms in the same document discusses issues of ingress of microorganisms and preventing them to grow.

The first design concept regards simplifying the cleaning of surfaces. When two surfaces are bolted together, as shown in Figure 2, ingress of water happens in all gaps due as shown in Figure 3 . This water could be contaminated with microorganisms, which clearly violates 5.2 and 5.3.

This problem is further illustrated in Figure 4, which shows an old design from an OEM. It is evident from the figure that the surface area in contact here is large, and much water could be trapped in between which gives microorganisms a place to grow.

Equipment such as shown in Figure 3 is seldom disassembled for cleaning, and when it is there is often biofilms formed in between the surfaces. Disassembly for cleaning is very costly. It is a time-consuming task which requires skilled workers, and shutting down a fish processing plant presents a severe loss in revenue.

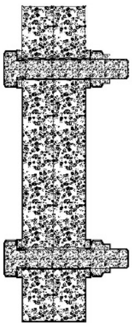

Figure 2. Contact surfaces

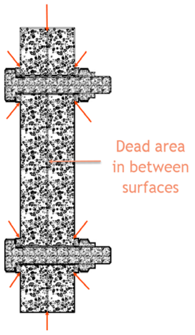

Figure 3. Contact surfaces ingress points

Figure 4. Contact surfaces on real product

A new concept is illustrated in Figure 5, which introduces bushings to separate the two surfaces and reduce the area in contact. Only the small area of the bushing is in contact.

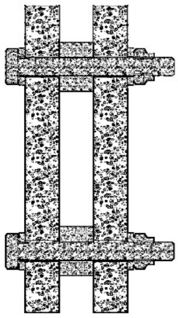

Figure 5. Bushing between surfaces

It is the OEM's experience that a bushing length between 5 and 7.5 mm is sufficient to clean in between the surfaces, and the bushing should have a diameter no less than two times the bolt diameter. Feedback from several fish processing plants and examination from the OEM states that overall this reduces the amount of water trapped and biofilm formed, despite the increase in the number of ingress points, marked in red on Figure 6 Bushing between surfaces ingress points, and thus this concept is a good approximation to EHEDG chapters 5.2 and 5.3.

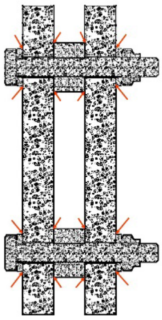

Figure 6. Bushing between surfaces ingress points

The concept is further illustrated in Figure 7 and Figure 8, which shows bushings between contact surfaces on two different products, marked by orange rings. By allowing only small surface areas of contact in general, one could prevent the growth of microorganisms and bacteria build-up.

Figure 7 shows bushing being used on a different product than a conveyor, illustrating that the design concept is not limited to conveyors only.

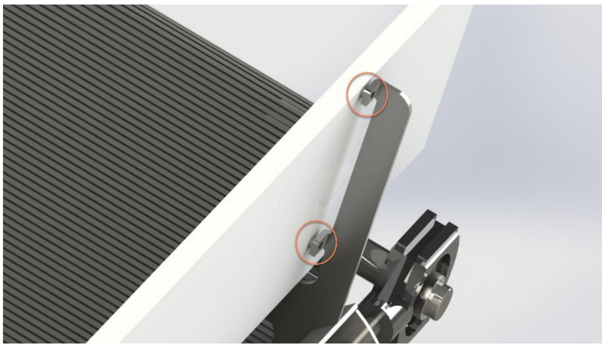

Figure 7. Bushings on real product

Figure 8. Bushings on real product

2.5 Surfaces and installation

EHEDG chapter 6.2 Surfaces and geometry states that product contact surfaces must be free for imperfections, direct metal joints should be welded, misalignments must be avoided, corners should be rounded and threads should not come in contact with food. The surfaces should tolerate the product and the necessary detergents and disinfectant, and be non-absorbent.

Continuous welding is used everywhere possible, and as discussed previously, where it is not possible, bushings are used to minimize the surface area of contact. Other improvements to welding is to create welding points instead of long continuous welds, if the structure allows it. This reduces bending of the steel due to welding, and shortens production (welding) time. The welding point could be 2 cm in length for instance, and then creating a gap between the surfaces. In the OEM's experience, a gap of 7.5mm is a gap that allows thorough cleaning between the two parts being joined together, whilst still keeping the structural integrity in place. This is illustrated in Figure 9.

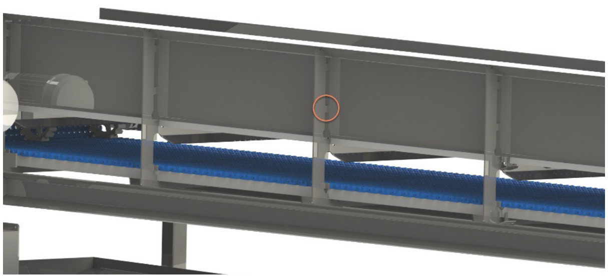

Figure 9. Welding points

Welding points such as these must be designed with close attention that the structural integrity is sufficient. For a load bearing weld, other lengths may be preferred, the 2 cm suggested is used for a non-load bearing weld outside the structural framework of the conveyor.

Equipment must be designed such that water drains off and risk of condensation on and inside equipment should be avoided according to guideline EHEDG chapters 6.4 Drainability and lay-out and 6.5 Installation respectively. Previously, square pipes have been used to great extent for structural framework for machines and equipment. The flat surface on top often gathers potentially contaminated water. This is illustrated in Figure 10.

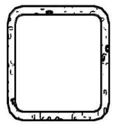

Figure 10. Square closed profile

This is avoided by flipping the square tube 45 degrees, creating a diamond-shape. However, the processing plants in the Norwegian Aquaculture Industry have been demanding round profiles/tubes for some time, illustrated in Figure 11. A round tube allows water to drain of very effectively and is widely used. Closed profiles, whether round or square, must be welded shut in the start and end. It is the OEM's experience that these welds will have microscopic pores in which microorganisms could ingress and bacteria growth will happen inside.

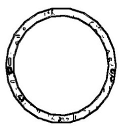

Figure 11. Round closed profile

A design concept improving this is shown in Figure 12. An open profile eliminates the risk of condensation during installation, and the ingress of microorganisms.

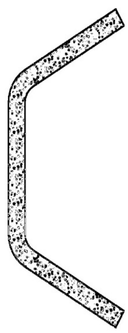

Figure 12. Open profile

The difference between a closed profile and an open profile in actual conveyor products is shown in Figure 13 and Figure 14, respectively.

Figure 13. Closed profile in real product

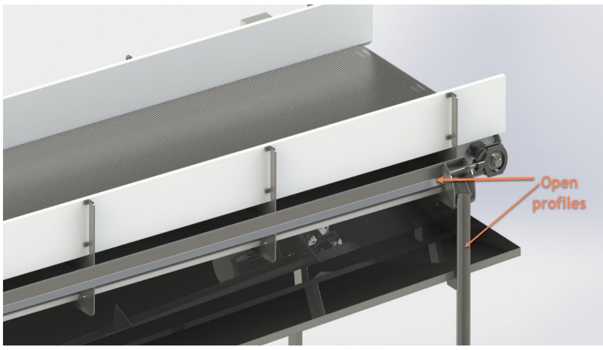

Figure 14. Open profile aon real product

Pay attention to the bearing installation in Figure 12 compared to in Figure 13. When using a closed tube, the way the bearing is fastened is by mounting a threaded bar into the profile, which allows ingress of bacteria into the pipe. Ingress of bacteria happened in the lower tube in the picture above too, due to microscopic pores in the weld as discussed previously, but not as much as in the top tube. Pay attention that an open profile also is used for legs and sidewalls.

2.6 Other remarks regarding design for cleaning

The surface finish/surface roughness should have an acceptable Ra-value according to 6.3 Surface finish / surface roughness. The materials used in this industry satisfies these requirements and thus the design concepts also comply with these guidelines. Welding is used extensively for steel-to-steel contact, with an emphasis on making the welds continuous and smooth, corresponding to guideline 6.6 Welding. Bolted connections are avoided where possible, to the extent it does not imply a significant increase in production costs.

When introducing the open profile like pictured in Figure 12 and testing it at actual processing plants, the feedback was that the profile was more of an obstacle to cleaning inside the belt than the tube or pipes which were used previously, because the open profile had to be larger than the equivalent closed profile due to stability and strength. This violates Guideline 5.3 to some extent, even though the goal, avoiding build-up of microorganisms inside closed profiles, is reached with the design. The design was further enhanced by moving the open profile below the belt, further down towards the floor in the construction, in Figure 15.

Figure 15. Improved open profile

In products where an open profile framework is not ideal due to strength and stability, the OEM have switched from using square tubes to round tubes. These do not gather as much water and has better drainability, as suggested in EHEDG chapter 6.4 Drainability and lay-out. They are also preferred from customers since a rounded tube is friendlier for the operators inside the processing plant when it comes to bumping into them. The transition between the two is shown in Figure 16 and Figure 17.

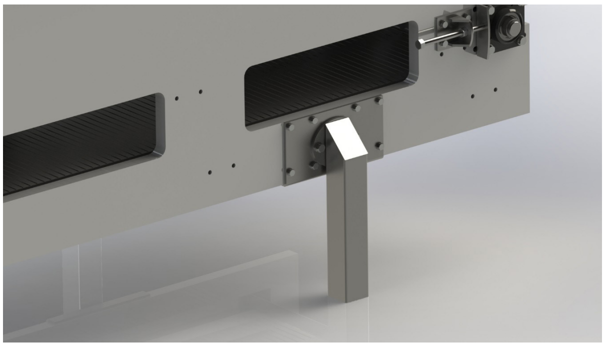

Figure 16. Square closed profile on real product

Figure 17. Round closed profile on real product

The results are further compliant with Machinery Directive 2006/42/EC. As discussed in [5], the EHEDG Guidelines are stricter than the Machinery Directive. All the changes make the equipment easier to clean and disinfect, and they minimize the risk of any substances accumulating or entering the machinery.

The design principles introduced has in some cases led to increased production time and cost, because using custom profiles requires more labor than using off-the-shelf available profiles, such as tubes and pipes. In addition, the profiles must be continuously welded to other parts of the steel frame, requiring more welding than what is necessary with standard profiles. However, due to the reduced cleaning time and effort needed, the fish processing plants are willing to pay the extra cost for these design improvements. Adding bushing to reduce surface area contact also requires more labor than mounting the two surfaces together directly, but also this is an acceptable increase in production cost and time.

3. Conclusions

- Design for cleaning is a new way of thinking about design in the Norwegian Aquaculture Industry. It focuses on making products easier to clean in their day to day use, thus reducing the risk of bacterial build up which could contaminate consumer products. It is important to notice the balance between Design for cleaning and design for some other parameter, as discussed in "Design for X" literature. In Design for cleaning, production time and cost is not the focus, the value added for the customer in the operational phase with a Design for cleaning focus far outweighs the potential drawbacks.

- The principles from EHEDG applies to all equipment and machines, and in this paper only a case study on conveyors has been done. Further work related to Design for cleaning is to implement the lessons learned from this case study to other products which are important to clean as well. Machines and equipment which are in direct contact with the end consumer product are the most important to keep a Design for cleaning focus on, since it is here a potential poorly cleaned area does the most damage (causes contamination to the end consumer product).

- Feedback from processing plants to the OEM states that a "Design for cleaning" mindset when designing processing equipment provides considerable customer value for the processing factories, as such design concepts directly saves cleaning time, and thus money. It also reduces the potential for bacterial outbreaks and contamination which is always a big concern.

- Further work could also be done to EHEDG Guidelines, in that some of the concepts and guidelines could be further clarified by illustrations and sketches, such as the ones that have been presented in this paper. This would provide valuable clarification of the principles discussed and remove doubts in how to design equipment for industries where hygiene is critical.

Acknowledgement

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