Food safety of cobots

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There is very little information on food safety of collaborative robots i.e., cobots available in the literature. Organic substances e.g., raw materials from the processes can be transferred with the cobots. These organic residues in structures increase the risk of organic cross-contamination and growth of pathogens. This will act as food safety threats in the food process. Hopefully, this project on food safety of cobots, which is financed by the research fund of Töysä Savings Bank, will act as an impulse for further research on food safety of cobots to be used in high hygiene areas.

The aim was to obtain information about the food safety of cobots. The structure of cobots were analysed. The cleanability of materials used in cobots was also analysed by comparing the plastic material in joint covers with stainless steel. In the first part of the work photographs were used to analyse the structures. The tests used in this work were protein and allergen tests as well as petrifilm AC to obtain the total bacterial count. The material choices, irregularities in surfaces and wiring of parts can cause significant food safety risks. Improved design of both structures and surfaces are needed when developing equipment, e.g., cobots, to be used in high hygiene areas in the food industry.

1. INTRODUCTION

1.1 General information about cobots

The technologies in safe, green, and sustainable food processing should be built on the integration of hyperflexible robotics including machine learning, machine vision, hyperspectral imaging, sensors and artificial intelligence. Today robots are mainly used in packaging, but hygienically designed cobots with new sensor technology creates new opportunities. There is very few research reported about cobots in the food industry (International Federation of Robotics, 2022a). Tölli (2019) has written about the history and the standards of cobots and Koukkari (2016) has examined cobots in heavier applications. Traditional industrial robots are fenced so that persons cannot get close to the robot for safety reasons (International Federation of Robotics, 2020).

The fourth industrial revolution (Industry 4.0) was implemented in the beginning of 2000, when many new technologies based on AI and robotics had developed, so that they could be used in practice. It is to be stated that Industry 4.0 with further development has enabled new opportunities for employees in their work in the food process (Sang-Soon & Sangoh, 2022). One of the first definitions of the fifth revolution (Industry 5.0) was employed in late 2015. Then the focus was on industrial sustainability. Later definitions of Industry 5.0 comprehend customization of the manufacturing processes through collaboration between AI and humans.

The food safety as a part of the fourth industrial revolution must be built on hygienically designed robots and cobots. Furthermore, industry 5.0 will be about the possibility to efficiently make technologies, e.g., robotics, work for the humans in a safe way (Ball, 2022). Romanov et al. (2022) stated that the design of the food safety in robot applications is important. These cobots can lower the contamination risk of food when compared to food treated manually, when the cobots are designed hygienically. Today, a collaborative robot usually has a six-jointed arm that can turn a tool at the end of the arm to any angle within the cobot's operating radius. Strengths of cobots are accuracy and tirelessness, but the cobot is not able to work in problem-solving situations. It is not flexible like a human. Thus, the cobots are not intended to totally replace humans. The cobots can be used in reducing repetitive jobs, which exhaust the personnel (Robots Done Right. (n.d.); Lempiäinen, 2022). Tasks between the cobot and the workers are being swapped. Cobots are usually given heavy, repetitive and non-ergonomic tasks. In this case, the cobot works independently. When necessary, it reacts to contact, for example by dodging or stopping.

Globally, the number of industrial robots is growing rapidly (International Federation of Robotics, 2022a). In Finland, the growth of robots is slower compared to the rest of the western world. In the food industry, the number of robots is small compared to other industries. In 2021, 532 robots were installed in the industry in Finland (Lempiäinen, 2022). It is to be stated that the number of industrial robots in cleanrooms is low. From food industry perspective, traditional industrial robots are used much less than in electronics and automotive industries, where they are used in e.g., handling, welding and assembly tasks (International Federation of Robotics, 2022a).

The machine learning is a method with which the system enables classification of data or images into comprehensive, practical information (Koukkari, 2016). Machine learning and data analytics can be used to improve productivity in the food supply. Traditional machine vision technology with AI can be used in quality control of organic materials and of irregular shapes (Young, 2020; Sang-Soon & Sangoh, 2022). Previous studies related to machine learning in the food industry have been related to tomato ripeness, strawberry maturity, meat freshness as well as quality changes in both pork and fish (Sang-Soon & Sangoh, 2022). Despite improved food safety standards, foodborne disease outbreaks remain at a rather high level both in Europe and in the United States of America (EFSA & ECDC, 2022; CDC, 2023).

Workers in a factory sorting food by hand, could be assisted by cobots equipped with machine vision and other improved sensors. There are both pros and cons in using cobots in the food industry. The pros are e.g., diminishing the impact of workers' hand hygiene. The cons can be e.g., the surface hygiene of cobots if they are not maintained and cleaned properly. Hygienically designed cobots can improve product quality efficiently and may also manage labour gaps, which could persist in the future. The use of robots can help controlling cross-contamination in food processing plants (Newton, 2021). It can be stated that some food processing sectors can benefit from niche robots

automated for specific tasks. As an example, a stainless steel cheese maintenance system with stringent hygiene standards has been installed in the Leupolz Emmental dairy in Germany. In this system, a six-axis Stäubli TX200L HE industrial robot was chosen for moving cheeses. This robot is in contact with the cheese. Therefore, it must comply with the stringent hygiene requirements. The Stäubli robot is designed to operate in challenging food industry conditions. The dairy personnel stated that contamination buildup of condensate and lubricants via the axes' joints could not be avoided. This challenge had to be solved, because the Stäubli robot arm is toughing the unwrapped cheeses. The dairy chose to use a robot arm with encapsulated joint points. Thus, the robot is designed to protect food from both lubricants and condensate (International Federation of Robotics, 2022b).

1.2 General information about equipment requirements

The general framework for food safety is given in the Regulations (EC) 178/2002 (about the general principles and requirements of the food law, the European Food Safety Authority and procedures in matters of food safety), (EC) 852/2004 (on the hygiene of foodstuffs), (EU) 10/2011 (on plastic materials), (EU) 1169/2011 (on substances causing allergies or intolerances) and (EU) 382/2021 (on the food safety culture). In addition, rules on materials and articles intended to come into contact with food are given in the regulation (EC) 1935/2004 and furthermore also in the regulation on good manufacturing practice for these materials (EC) 2023/2006. Design requirements for food equipment are given in the Directive 2006/42/EC. The European food legislation consists of both horizontal and vertical measures. Remember to check that the regulation is in force i.e., that you follow a consolidated version of the regulation. (Lelieveld et al., 2014; Wirtanen 2002)

The standard of hygiene in food processing, EN 1672-2:2020 is also giving proper advice. Furthermore, European Hygienic Engineering & Design Group (EHEDG) has published more than fifty guidelines, which provides practical suggestions how food production facilities, process lines, and equipment should be designed, so that they are cleanable and can be maintained properly. In these guidelines, there are examples how to combat hygienic risks and find acceptable solutions. Detailed information on hygienic design of both closed and open equipment can be found in several of the EHEDG Guidelines. Common hygiene requirements for equipment used in preparing and processing food and feed state that the food safety must be in focus. The equipment functionality and the hygienic design principles can be inconsistent. Generally, compromises can be found. In case no compromises are found the functionality must be sacrificed, because non-hygienic equipment will contaminate the food processed. In the standard EN 1672-2:2020 there are principles, which can commonly be applied to food and feed processing equipment. Hygienic and/or aseptic systems comprise individual components, equipment, measuring and management systems and automation in food and feed production.

The choice of surface materials is important in designing and building process lines and equipment for food and feed production. The process lines and equipment must be easy to clean and maintain. Thus, the surfaces must be smooth and in good condition i.e., without crevices, cracks, comers and dead ends. Note, that joints, screws, bolts, nuts, threads and also gaskets are vulnerable spots for accumulation of biofilm. Nearly all commonly used materials in food processing support biofilm formation. Most of the adherent bacterial cells have been found in the grain boundaries of stainless steel and thus the surface structure of stainless steel is very important in avoiding build-up of biofilms in the equipment. Stainless steel is the most used material in food processing equipment, because it can be treated using e.g., mechanical grinding, lapping, electrolytical polishing or mechanical polishing to improve the surface smoothness. Experiments carried out with pathogens and spoilage microbes on elastomers and rubbers, which are used e.g., in gaskets, have shown that the cleanability of surfaces is important. These rubber and elastomer surfaces are prone to microbial growth that some of the microbes even decomposed rubber as energy sources för growth. The smoother a surface is and the younger a biofilm is the easier it is to eliminate the microbial colonies from the process equipment and the process lines (Woodling & Moraru 2006; Burkert et al., 2013; Park & Kang, 2017; Ciacotich et al., 2022).

2 METHODS

2.1 Two cobots

The focus in the two theses was on studying two different cobots (Haapala, 2023; Korkiamäki & Samppala, 2023). The chosen, studied cobots were available for teaching and training purposes in the SeAMK laboratories: UR5 by Universal Robots and GoFa by Asea Brown Boveri.

2.2 Structure analysis

The structure of the above mentioned cobots were photographed and analysed accurately. The aim of structure analysis was to find places, which can be challenges to food safety according i.e., crevices, comers and dead ends (Directive 2006/42/EC; Annex I).

2.3 Cleanability of plastic joint covers compared to stainless steel surfaces

The cleanability of surface materials is important for food hygiene. The cleanability of plastic joint covers were compared to stainless steel (AISI 304) surfaces. The experiments were performed in triplicate. The tests formed were:

1) petrifilm for aerobic counts,
2) protein test and
3) milk allergen test.

The order of the testing was: first microbial testing and thereafter chemical testing on proteins left on the surfaces. The surfaces to be tested were soiled with a creamy cheese sauce, which had been left at room temperature overnight before soiling. The soil was dried on the test surfaces, whereafter they were cleaned. The soiling of the test surfaces were performed both once and several times before the cleaning. The cleaning procedure:

1) 15 min soaking in warm water +
2) rinsing +
3) soaking for 15 min in foamed detergent +
4) rinsing +
5) drying +
6) testing.

Samples were taken before and after washing.

3 RESULTS

3.1 Structure analysis

There are plenty of risky spots on the cobot arms (Pictures 1a & 1b). The photographing shows that growth of microbes can be a big problem in screw joints, in gaps and crevices, and on uneven surfaces (Pictures 2a & 2b). Furthermore, the wiring must be developed. The biggest risks are wide gaps and screw connections.

Cleaning of cobots are difficult to perform, especially when the Ingress Protection (IP) rating is low. The IP rating of the cobot shows the protection towards cleaning exercises. The IP rating consist of two digits, the first shows the protection from solids and the second the protection from moisture. Both investigated cobots had an IP of 54, which means that they are protected against dust and water splashes from all directions. The controller of the cobot and possible add-ons have lower IP-ratings. Those values varies between IP 20-40 (Smiley, 2020).

In food safety, the most important cobot part is the grippers, which touch the food product. Thus, the food safety is of utmost importance and the equipment should be cleaned properly. When the IP rating is 65, it means that the equipment is dust proof. This type of equipment stands immersion in water for very short periods but not what is requested in a cleaning procedure. In case the IP rating is 66 the equipment is protected against powerful water jets. Thus, the IP rating for an equipment to be cleaned should be either 67, which means that it stands water treatment for 15 – 90 min, or 68, which means that it is watertight under pressure (Smiley, 2020). There are plenty of grippers on the markets.

3.2 Soiling of plastic joint covers and stainless steel surfaces

The plastic joint cover material seemed to repel water during cleaning and thus these surfaces were a bit greasy after the cleaning when compared to the stainless steel surfaces, which were cleaned normally. Testing based on protein tests is rapid and appropriate i.e., it gives information on the cleanliness rapidly. Petrifilm AC is easy to use and microbial results on surfaces are obtained after an incubation of 1-3 days. However, the incubation in the microbial tests means that the results are obtained too late to prevent contaminated food products to reach the market. The drying of accumulated soil on the surface impaired the cleaning results. The longer the dirt remains on the surface the worse was the result (Table 1). Repetitive soiling for several days without cleaning weakened the obtained cleaning results considerably. The microbial results (Table 1) show that the cobots must be cleaned every day it has been in-use and are in touch with unpacked food products. The stainless steel surfaces were cleaned more successfully than the plastic joint covers. This type of or similar

results can be used in choosing/investigating both materials in cobots and cleaning agents on cobots.

4 CONCLUSIONS

Information about equipment surfaces and structures can be found in both the machinery directive 2006/42/EC and the EN-standard 1672-2:2020. The photographing showed the cobot structure, which are problematic in terms of food safety. The shape of some parts e.g., the joints and the covers, and a low waterproof rating of the cobots make cleaning challenging. This has been discussed both in the theory and the practical parts. Screws, connections and end points of the arm are usually the most difficult shapes to clean. Photographing as well as microbial and chemical analysing of the structures have been used in the documentation.

The wiring can also hamper the cleaning. When installing additional parts, the cord has to be pulled along the arm of the cobot. The tool's watertightness must be considered because it is lower in some cobots. By installing safety-enhancing features under the shell already at manufacturing, food safety is promoted.

Based on the obtained results, the cleaning of stainless steel surfaces was more successful than that of the plastic joint covers. In the tests taken after cleaning, the results of the joint covers showed much weaker results than those of the stainless steel surfaces. From the results, it can be concluded that the dried, accumulated dirt on the surface weakened the cleaning results. The stainless steel surfaces were much easier to clean than the plastic joint covers. Furthermore, the material of the joint covers seemed to repel some water during cleaning. Thus, the surface seemed a bit greasy after washing compared to the stainless steel surfaces, which seemed normally clean. In determining the equipment hygiene, the use of rapid tests was suitable in this work. Using protein and allergen tests gave a good assessment of the cleanliness of the materials. Quick, chemical measurements show possible dirt residues left on the surfaces. It is to be noticed that microbial methods take more time due to culturing and colony formation.

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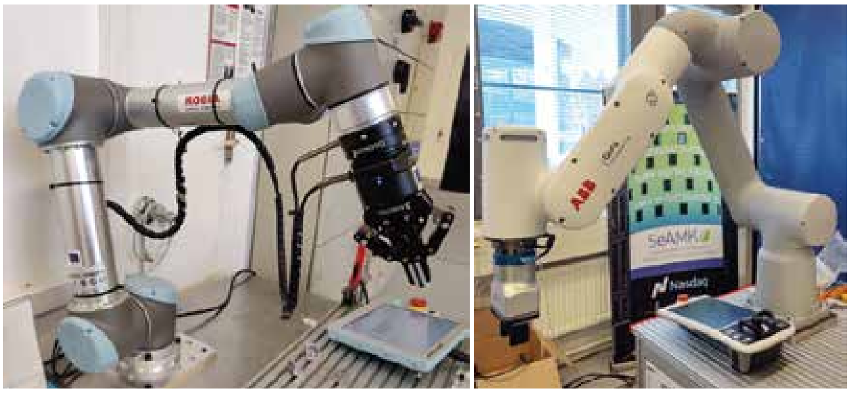
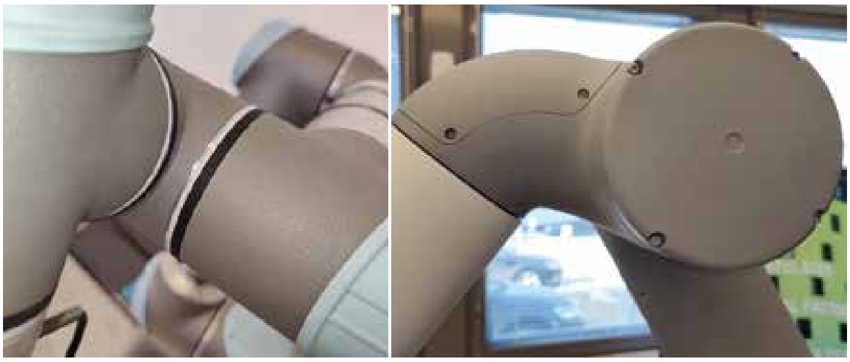


Picture 1.
Six-jointed cobot arm: left) UR5 and right) GoFa (Photos: Samppala, 2023).



Picture 2.
Hygienically week points on the cobot arms: left) UR5 and right) GoFa (Photos: Samppala, 2023).

Test series with replicates	Results before cleaning (cfu/100 cm²)		Results after cleaning (cfu/100 cm²)	
	Plastic joint cover	Stainless steel	Plastic joint cover	Stainless steel
	< 1	< 1	Not performed	Not performed
Reference surface	< 1	< 1	Not performed	Not performed
	< 1	< 1	Not performed	Not performed
	TNTC	TNTC	22	1
Soiled once	TNTC	TNTC	34	3
	TNTC	TNTC	41	2
	TNTC	TNTC	12	8
Soiled several times	TNTC	TNTC	46	27
	TNTC	TNTC	121	58

Table 1.
Culturing results of both plastic joint covers and stainless steel

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