UV Torpedo® Conveyor:
Increasing product shelf life of fresh salmon fillets

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Executive summary

It has long been recognised that the surface contamination of fish, in this case Listeria Monocytogenes on salmon, can significantly reduce its shelf life. JenAct and Marine Products Scotland investigated the efficiency of UV disinfection systems for treatment of fresh salmon fillets. The trials were conducted in the production environment at Marine Products Scotland where the new JenAct's UV Torpedo® Conveyor was put through its paces. The main aim was to determine whether UV disinfection systems do indeed have a place in the fish processing industry and, in particular, the salmon industry as means for quick, economic and chemical-free decontamination of products.

The team conducted several rounds of microbiological tests together with long-term testing and product shelf-life analysis. All trials led to the conclusion that UV germicidal radiation (UVC or UVGI) greatly reduces spoilage microorganisms on salmon fillets and provides significant extension of product shelf life. The treatment with UV germicidal radiation completely wiped out the microorganisms which were present on petri dishes prior to the "deadly" journey through the JenAct's UV Torpedo® Conveyor.

Listeria was also placed directly onto salmon fillets and different methods were used to find out how the uneven surface of the fillet affected the quality of UV treatment. The Listeria was entirely eliminated on surfaces of up to 80% of salmon fillets treated at the speed of 6m per minute. This was in line with our prediction that, on some of the fillets, the solution with bacterial contamination entered into crevices and pits of the salmon fillet and became hidden to UVC radiation, which is usually absorbed within a thin layer of the treated surfaces.

By any measure the trial has been a success, and although the results show that work still needs to be done to perfect the process, the UV conveyor has now become an integral part of the Marine Products Scotland production line. The next generation UV conveyor is currently in production and we look forward to reporting its results in due course.

Introduction

Wet decontamination techniques have been traditionally used to remove microorganisms from foods and surfaces. Although efficient, these technologies are not suitable for all types of products and surfaces: they may damage some foods or some surfaces, and require environmental control (provision of clean water, reuse and disposal). Their use may not be suited to all applications.

Dry decontamination techniques, such as UV disinfection, can offer significant benefits compared to wet techniques. The main benefit is that UV treatment does not require water or chemicals. This reduces water use and potential chemical disposal, which ultimately leads to cost savings. Dry decontamination of food or food contact surfaces helps to assure safety and quality, and extend the shelf life of the final food product. The treatment of dry foods, delicate fresh foods, work surfaces and packaging are the common and most straightforward applications.

On the other hand, the dry decontamination techniques are relatively novel and their use and efficiency hugely depends on conditions in each application. In order to achieve maximum efficiency and reliability of the disinfection process, the systems must be mostly customised and the following parameters carefully considered during the design phase:

- Required disinfection performance
- Thermal management
- Food industry standards and health & safety

Very often the requirements listed above contradict each other and compromises have to be made. For example, maximising disinfection levels may result in an undesirable increase of temperature of the treated product.

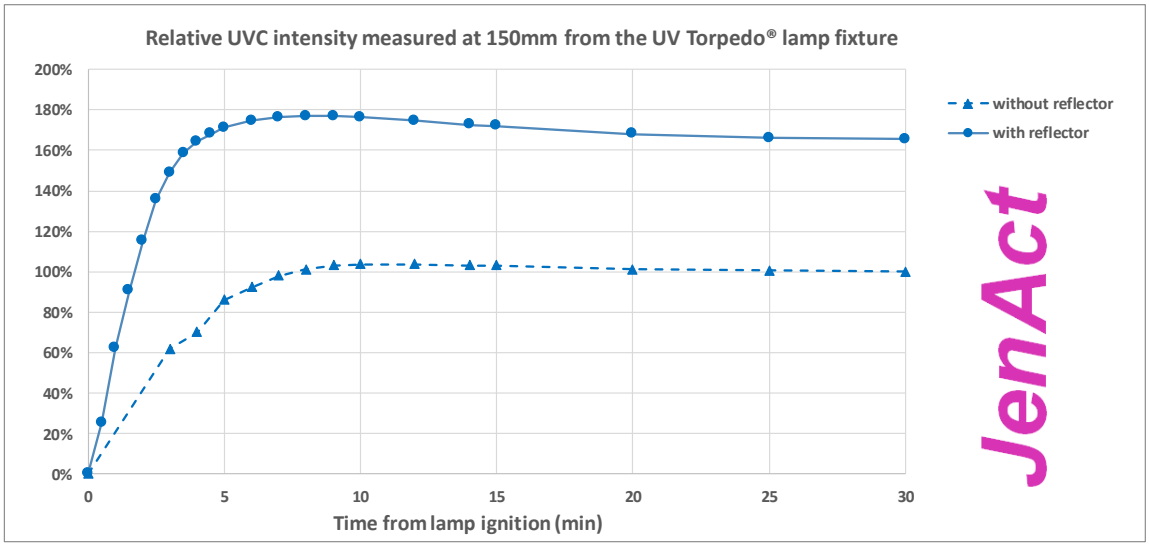
We carried out this case study to test whether carefully designed UV disinfection systems have their place fish industry and bring significant benefits when used for direct treatment of soft tissues products, in particular salmon fillets.

UV Torpedo® Conveyor

UV Torpedo® Conveyor was designed and manufactured by Jenton International Ltd, parent company of JenAct Ltd. Jenton International has been involved in the UV industry since the mid-1980s and has developed a formidable reputation for being able to combine theoretical knowledge with the development of industrial process equipment. The UV Torpedo® Conveyor is a stainless steel, fully wash-down conveyor with integrated shatterproof UV-C lamp fixtures and provides 360 degrees' disinfection of fresh salmon fillets. The conveyor is controlled and monitored via touch-screen HMI, allows an operator to set the belt speed and monitors the service hours for each UVC lamp.

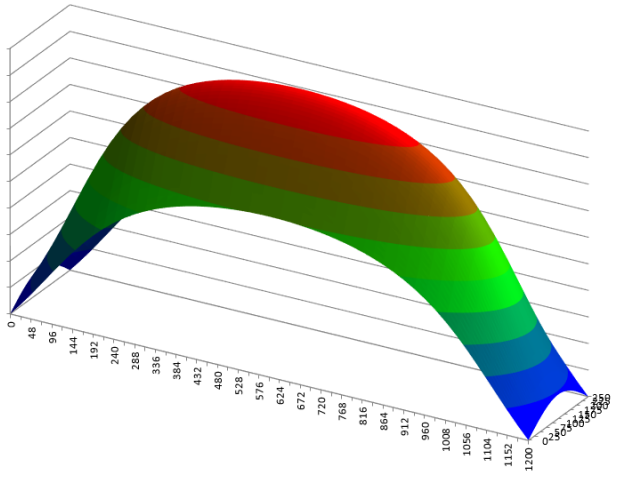
The UV conveyor also accommodates two UVC sensors, which monitor the intensity of UV germicidal radiation inside the UV treatment zone. A detailed analysis of UV dose and intensity was carried out using two other calibrated radiometers, ILT1400 for analysis of output of individual fixtures and EIT UVICURE PLUS for the measurements of the UVC dose delivered to a product on the conveyor belt.

Systematic research prior to the design of the conveyor was aimed at maximising the UV dose delivered to the treated product. At the same time, we specified that the temperature within the close proximity of the UV lamps was below 30°C so that proteins within the product were not affected by the heat generated from the lamps. This led to a development of a shatterproof IP65 UV lamp fixture with an integrated custom-designed reflector. Our built-in reflector increases the UVC output of the UV lamp by staggering 66% while the surface temperature of whole lamp fixture is low (see graph below).



Unlike in other UV disinfection systems, the built-in reflector in the JenAct's lamp fixture does not have to be cleaned during entire life time of the UV lamp, which assures its continuous performance. In case of any accidental breakage of the lamp quartz, the shattered lamp is kept within the enclosure of lamp fixture by an FEP sleeve making this a food-safe solution.

We have also conducted an extensive analysis of the placement of the UV lamps inside the conveyor. To aid this development, we developed a UV irradiation model and later verified it using calibrated radiometers. An example of UVC intensity map below the UV Torpedo® lamp fixture is presented in the picture on the right.



Another challenge the team faced was to ensure that the whole product was treated, thus it was necessary to provide a means of moving the product on the wire belt so that the shadowing did not occur. Furthermore, meticulous attention was also given to the design of wire-belt supports within UV treatment zone.

UV disinfection efficiency – theoretical analysis

The disinfection rates achieved with the conveyor greatly depend on the speed of the wire belt. The table below shows the UVC intensity measured by built-in UVC sensors and UVC dose data measured using UVICURE PLUS radiometer. Listeria Monocytogenes bacteria was chosen as a critical contaminant and the disinfection rates for both top and bottom of the product were calculated using a D90 dose of 156J/m^2.

Speed (m/min)	Average UVC intensity (W/m^2)	Measured UVC dose top (mJ/cm^2)	Estimated UVC dose bottom (mJ/cm^2)	Calculated disinfection (top)	Calculated disinfection (bottom)
6	40	65	32.5	99.99%	99.20%
9	40	43.3	21.7	99.8%	96%
12	40	32.5	16.3	99.2%	91%
15	40	26	13	97.9%	85%

The UVC dose at the bottom of the product was estimated following number of measurements during which the measured UVC dose value varied between 55% and 70% of the value measured on top of the belt. The worst case scenario was then set to 50% and data in the table above calculated accordingly. It can be seen from the data in the above table that when the conveyor is clean and the lamps are new, the calculated minimum disinfection rate is always above 90% for the pre-set belt speed of 12m/min.

UV disinfection efficiency – the reality

A number of different trials have been carried out at Marine Products Scotland. The initial goal was to assess whether the UV disinfection system could be used for the reduction or total elimination of Listeria Monocytogenes on salmon fillets. After very encouraging trials in June 2014 on a UV Conveyor test bed, a production scale UV Torpedo® Conveyor, which is described above, was commissioned in September 2015. Multiple tests and trials then followed and the summary of all trials carried out prior to April 2016 is presented below.

Initial verification of UV disinfection (June 2014)

280 CFUs (Colony-Forming Units) of Listeria Monocytogenes were planted on the surface of each fresh salmon fillet and number of control samples were analysed after passing through JenAct's UV Conveyor test bed at various speeds (3m/min, 6m/min, 9m/min and 12m/min).

The average CFU count after a single pass through the conveyor at belt speeds of up to 9m/min was below a detectable range of 10 CFUs. At the belt speed of 12m/min, the average CFU count confirmed the calculated 1-log kill rate (90% inactivation of Listeria Monocytogenes).

Speed (m/min)	UVC intensity (mW/cm2)	UVC dose (mJ/cm2)	Calculated inactivation rate	Average CFU before UV	Average CFU count after UV	Inactivation rate (average)
3	5.7	95.2	**> 99.9%**	280	< 10	> 96%
6	5.7	47.6	**99.9%**	280	< 10	> 96%
9	5.7	31.7	**99%**	280	< 10	> 96%
12	5.7	23.8	**97%**	280	13	95%

Although all treated samples still tested positive on Listeria Monocytogenes, the inactivation rates were very encouraging and prompted development of a prototype of a UV Torpedo® Conveyor for fresh salmon industry. The prototype of UV Torpedo® Conveyor was commissioned in September 2015 and further trials followed.

Increasing product shelf life (autumn 2015)

This set of trials was carried out using a production scale UV Torpedo® Conveyor. Samples were tested to determine if UV germicidal radiation can extend the shelf life of the product by reducing the bacterial count of spoilage organisms. This was carried out on vacuum packed portions. The results on vacuum packed portions showed no Listeria from P+8 – P+20. Enterobacteriaceae were increased at P+14 and TVC's at P+14. The subsequent testing for P+18 and P+20 was within normal limits. The detailed results are listed in the table below.

Day of Life	E.coli	Enterobacteriaceae (P)	Listeria spp	Salmonella spp	Staphylococcus coagulase (+)ve	TVC @30°C for 48h
	cfu/g	cfu/g	in 25g	in 25g	cfu/g	cfu/g
P+8	< 10	60	None Found	None Found	< 20	1.3x10^3
P+10	< 10	620	None Found	None Found	< 20	1.6x10^4
P+12	< 10	2.8x10^3	None Found	None Found	< 20	3.4x10^4
P+14	< 10	> 1.0x10^4	None Found	None Found	< 20	9.2x10^5
P+16	< 10	8.4x10^3	None Found	None Found	< 20	1.3x10^6
P+18	< 10	250	None Found	None Found	< 20	4.8x10^4
P+20	< 10	280	None Found	None Found	< 20	5.4x10^4

Verifying UV disinfection on an ideal surface (March 2016)

As control measure of efficiency of the UV treatment, clean plastic petri dishes were inoculated with 5ml of Listeria suspension containing 26 CFU per ml and a higher amount of 1045 CFU per ml. Each dish went through the UVC tunnel at the speeds of 6, 9 & 12m/min. The table below lists the observed results. The 100% inactivation rates on all samples in petri dishes verifies the findings that the nature of the product surface significantly affects levels of disinfection.

Speed (m/min)	Average UVC intensity (W/m2)	Listeria Monocytogenes CFU before UV	Listeria Monocytogenes CFU after UV	Inactivation efficiency	Log reduction per 1ml
6	36	130	0	**100%**	1.4
9	36	130 / 5525	0	**100%**	1.4 / 3.0
12	36	130 / 5525	0	**100%**	1.4 / 3.0

Exploring limits of UV disinfection (March 2016)

Being aware of the nature of surfaces of soft tissue products, we aimed to quantify the efficiency of UV radiation in reducing the bacterial count of Listeria on fresh salmon portions. In particular, the goal was to explore the limits of the technology and determine whether a total elimination of Listeria Monocytogenes can be repeatedly achieved.

We placed Listeria directly onto salmon fillets as a 0.05ml solution with 5CFUs to find out how the uneven surface of the fillet affects the quality of UV treatment. After the samples passed through the conveyor, the initially contaminated surface was swabbed and the whole fillet placed in the bag.

The inoculated fresh salmon fillets passed through the UVC tunnel at speeds of 6, 9 & 12m/minute. For each speed of the conveyor the following samples were taken:

- **25 top swabs** - The top side of the fillet was inoculated and the fillet placed on the conveyor with the top side facing up. The top of the fillet was then swabbed immediately after the UV treatment.
- **25 top products** – Entire fillet was placed in a bag after swabbing.

- **25 bottoms swabs** – The bottom of the fillet was inoculated and placed on conveyor with the inoculated side facing down. The bottom of the fillet was then swabbed immediately after the UV treatment.
- **25 bottom products** – Entire fillet was placed in a bag after swabbing.

The subsequent analysis revealed that an average of 70% of all swabs were free of Listeria for the belt speed of 6m/min. In comparison, only about 25% of whole fillets treated at 6m/min showed zero contamination. This was in line with our predictions that the solution with bacterial contamination entered into crevices and pits of the salmon fillet. The bacteria then remained hidden from UVC radiation and could not be inactivated. The full results are presented in the table below.

Speed (m/min)	Negative top swabs	Negative bottom swabs	Negative top products	Negative bottom products
6	60%	80%	24%	25%
9	36%	52%	8%	28%
12	44%	72%	0%	36%

Conclusion

The trials and results presented above demonstrate very well, that carefully designed and engineered UV disinfection systems achieve significant reduction of potential microbiological contamination even in the most challenging applications. It is also critically important to note, that all the way throughout the trials, the appearance and taste salmon fillets were unaffected.

Although the treatment with UV germicidal radiation is not yet a bullet-proof solution and a total elimination of biological burden cannot be warranted, it significantly reduces the bacterial contamination on salmon fillets and enhances the product shelf-life.

Work is continuing apace to develop and refine the solution both at Jenton International's R&D facility and at Marine Products Scotland. We have identified several key areas that had to be improved and the team believes that the next generation UV Conveyor will be even better.

The team is keen to include other companies in this project and would be very interested in discussing UV surface decontamination with other fish processors and the food processing industry in general. In the first instance please contact Dr Bilek at the address below.

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