D6.5 - PicknPack report

Integration of prototypes and test of complete adaptive packaging system

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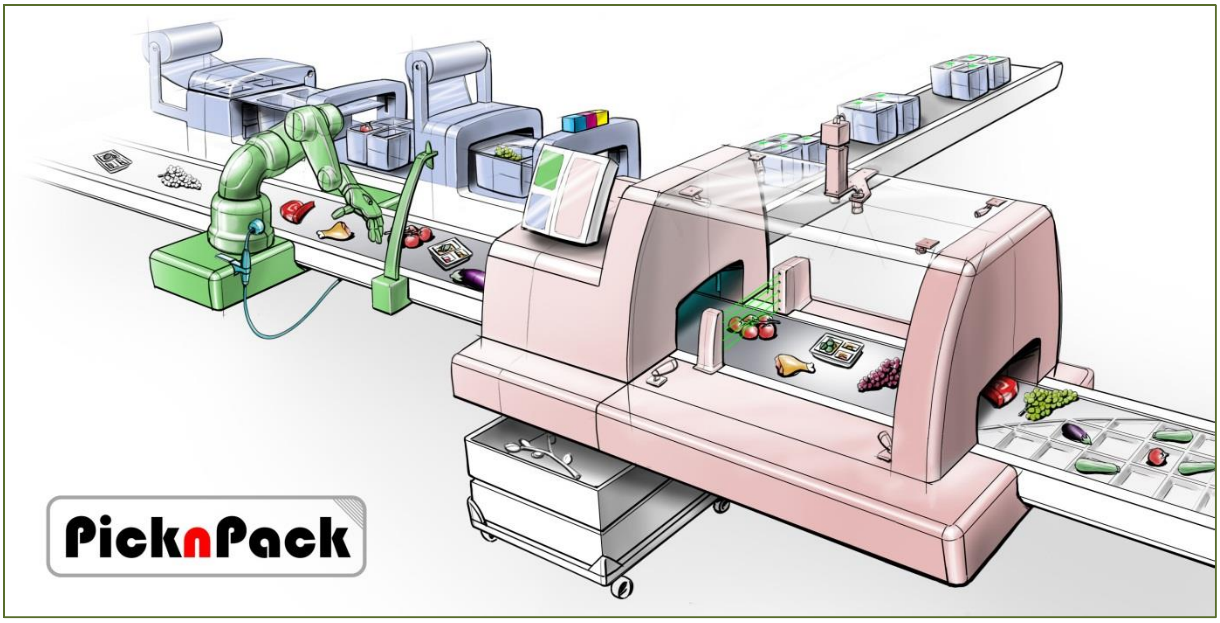

Flexible robotic systems for automated adaptive packaging of fresh and processed food products

Dissemination level		
PU	Public	X
PR	Restricted to other programme participants (including the EC Services)	
RE	Restricted to a group specified by the consortium (including the EC Services)	
CO	Confidential, only for members of the consortium (including the EC Services)	

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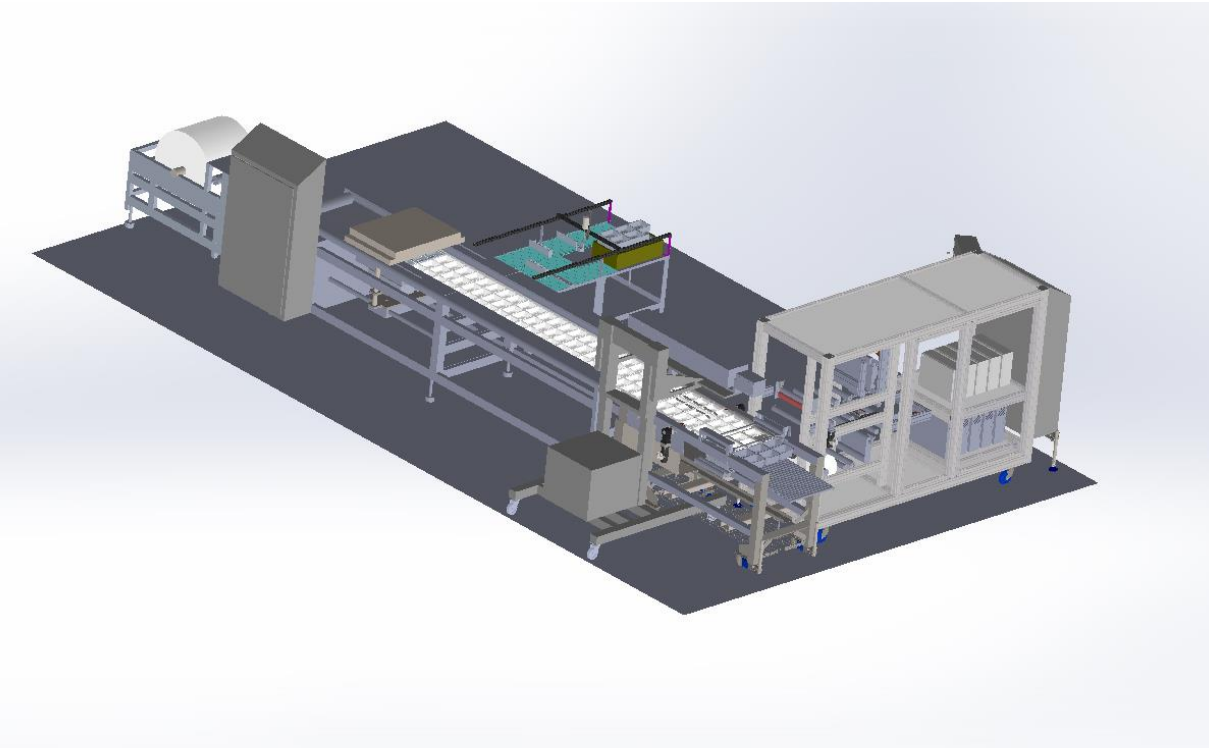
Table of Contents

1 Introduction

This work package aims to develop an innovative adaptive packaging system able to efficiently produce food packaging in small batches of 1-1000 packed food products.

D6.5 is the documentation of the integration and test of following prototypes before month 28 (1st February 2015):

- Digital mould
- Sealing and cutting system
- Integrity check system
- Flexible heating system
- Decoration system



2 Integrated adaptive packaging system

The nature of D6.5 is a prototype.

Figure 1 – Photos of the integrated adaptive packaging line in Copenhagen early in 2015

The packaging system will in February 2015 be shipped to Wageningen in order to be integrated to a complete working PicknPack system.

3 Digital mould

WP6 has been working on several flexible mould systems. For inline demonstration, it was decided to use the brick mould system.

3.1 Brick mould system

Figure 2 - Prototype of Brick Mould built into Vacuum Mould for the actual Thermoformer

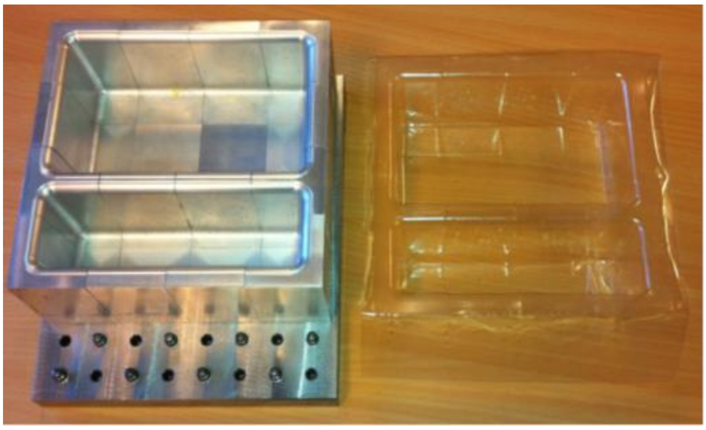


Figure 3 – Prototype of a brick mould

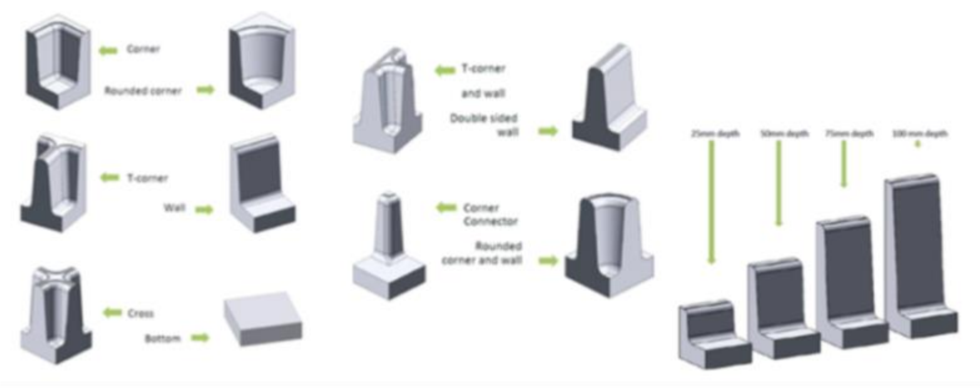


Figure 4 – bricks of brick mould

WP6 has designed and produced a prototype of an innovative mould system. The system produces trays as seen on the photo in figure 3. WP6 hope to create a fast system with only few minutes lead-time between design and production.

WP6 has selected to use the brick mould system in PicknPack as it stands out as the best system after many tests with many other prototypes. WP6 had some discussions about using the word digital mould for the brick mould system. It was decided to make this system digital as follows:

1. The design is done with bricks because this is the most natural way to work in the food industry
2. The design is scanned and converted to a digital model either using marking on the bricks or a vision system
3. The data from the mould is now digital and can be converted to inputs for all other processes in PicknPack.

3.2 Pin mould

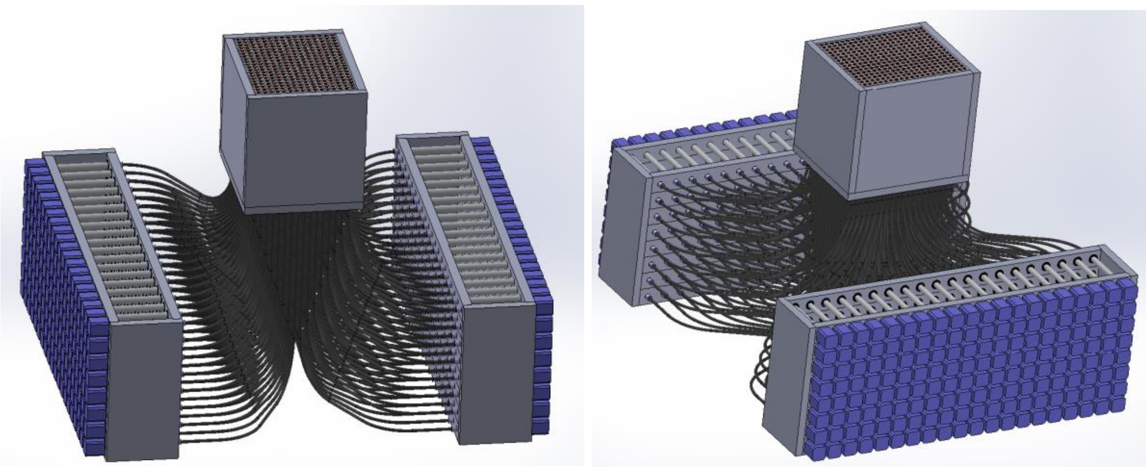


Figure 5 – Digital mould with many pins operated with cables and servo motors

The mould has a number of pins able to move up and down. We produced three fixed prototypes with different resolutions and tested the performance in a packaging machine. We noted resolution and quality is a trade-off between price and quality. Figure 5 and 6 document that a resolution using pins of 5 mm still need a lot of pins to form a full mould. But 5 mm pins still have a rather poor quality of the mould. This is the reason why the brick mould was selected for in-line demonstration. The pin mould system will still be demonstrated but off-line.

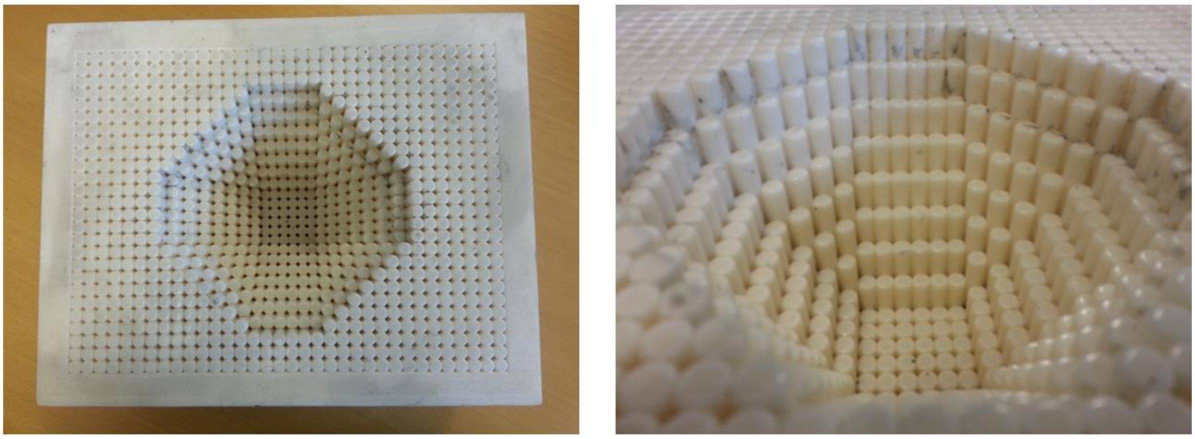


Figure 6 - Mould with 5 mm pins

Figure 7 - Tray produced in a mould with 5 mm pins

The quality of a tray made in a mould with 5 mm pins is not acceptable. In order to upgrade quality either the pins must be smaller and/or a flexible layer between the pins and the plastic should be built in, and thus providing for a smooth surface.

3.3 Off-line digital mould

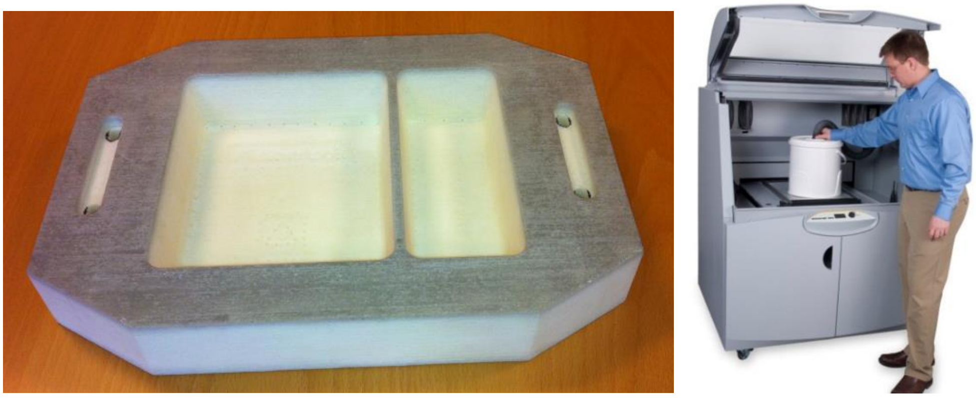


Figure 8 – Digital produced plaster moulds produced off-line

Based on a standard 3-D printer for prototypes you can produce moulds which are able to produce about 1-3,000 trays and with a surface, which is also more smooth.

The moulds will in the off-line system be produced off-line and shall be mounted on the thermo-forming-machine before the production. In order to meet the demands of PicknPack, which requires change of formats within seconds an extreme fast changing system is needed.

The total time from design of wanted mould format to production will be the production time for the 3-D-mold format + the mould change time.

Figure 9 - Tray made in a plaster mould from a 3-D printer

The plaster/concrete/ceramic/aluminium technology produces flexible moulds able to be used for more than 1,000 items in a very high quality.

Lead time for these technologies is 4-10 hours for 3-D plaster technology and 1-2 hours for CNC milling of concrete moulds. However, 3-D modelling is in a fast development these years and is expected to be more efficient, fast and inexpensive within a few years.

Moulds can be implemented in a standard thermo-vacuum-forming machine.

This system will also be demonstrated off-line with the existing components in booths next to the other demonstrations.

4 Flexible sealing and cutting

Figure 10 - Laser equipment to be used in the PicknPack line

Figure 11 - A view into the laser marking head and a sample of the foil to be sealed

Figure 12 - Frame for laser to be used in PicknPack line. There will also be built screens around the laser marking head

The laser welder and cutter will be placed in the end of the packaging line after the trays are filled and where the printed top film is applied. The top and the under film are mechanical locked together at the same level under the laser. The laser will weld and cut by a controllable mirror system.

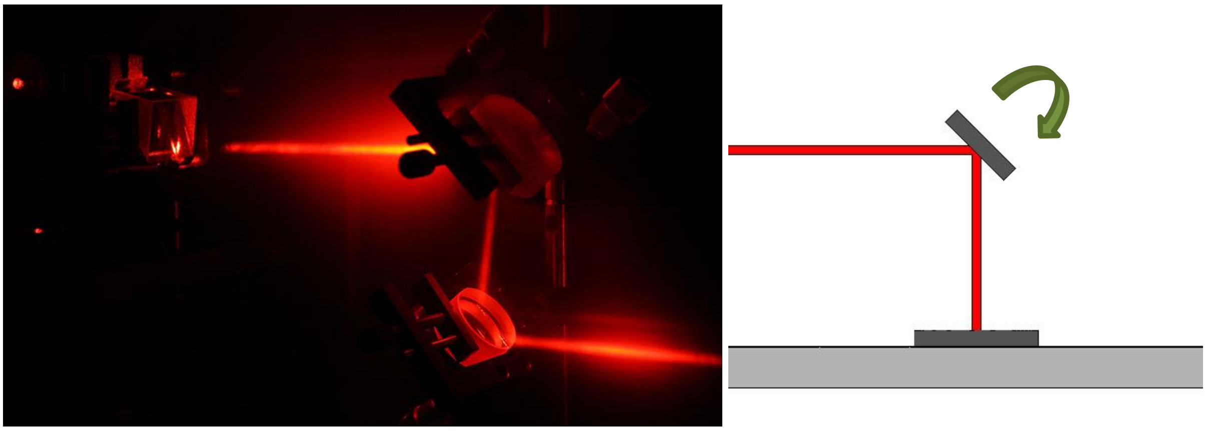
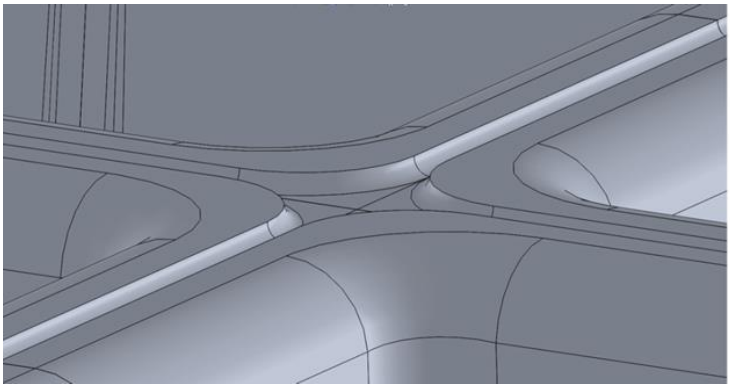


Figure 13 – The laser with controllable mirror system

The laser must be able to follow this stop-go situation and process as follows:

1. Welding the two films together demand that the movement is stopped
2. Perforation of the packaging for MAP can be done both in stop and go
3. Cutting the trays out from the films can be done both in stop and in go after the top film is cut

The cutting system has a demand, that cutting points have to have a distance between top and bottom films. The mould for the tray sides need a little groove to create this distance.



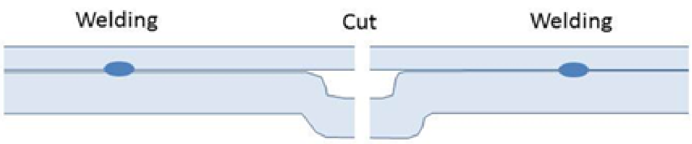


Figure 14 – Ditches or grooves in brick moulds create a distance for cutting

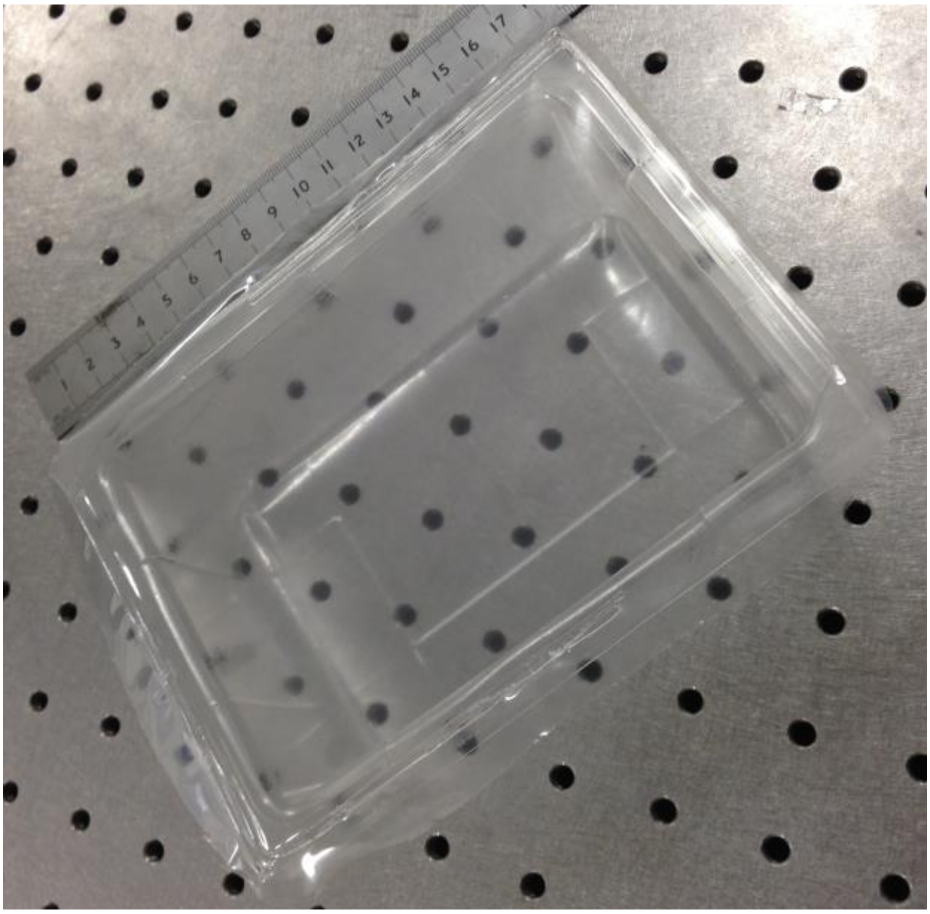


Figure 15 – Tray made in the brick mould that is laser welded

Trays made on the brick mould were tested on a prototype laser build by University of Lincoln with success.

The experiences from these tests indicate a problem with having time for both sealing and cutting in the stop time. It is important that the under and over web is perfectly indexed under sealing which need a stop. If the over web is cut under stop-time it will be possible to perform the remaining parts of the cut under the creeping movement.

The experiments also indicate that the sealing process will be the bottleneck to reduce the stop time.

5 Integrity check system

The integrity checking system is based on a hyperspectral imaging set-up. Two different detectors were used, being a VIS-NIR system (400-1000 nm) and a SWIR system (1000-2500 nm). Tests were performed on different package sizes in order to study image quality and potential issues with reflection. Illumination, which is provided using classical halogen sources, was optimized using ray tracing software so to minimize reflection issues, and to make illumination homogenous. Figures 11 and 12 show the set-up and a typical image of an empty package at a given wavelength (900 nm).

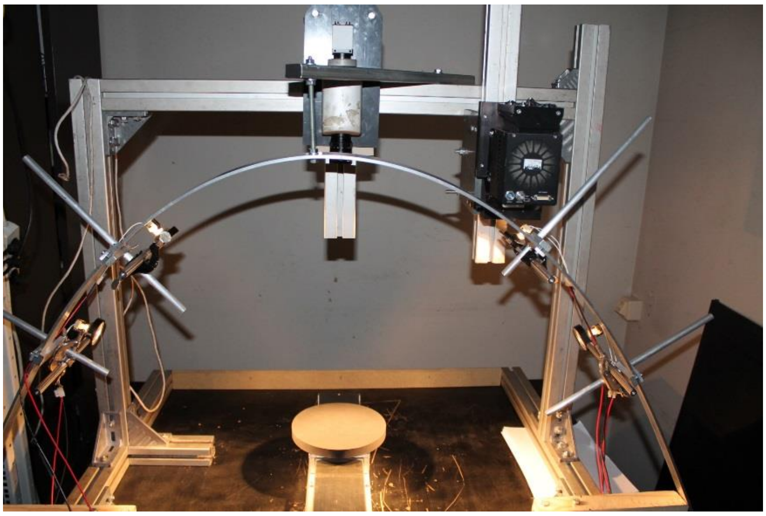


Figure 16 - Hyperspectral set-up used for the measurements.

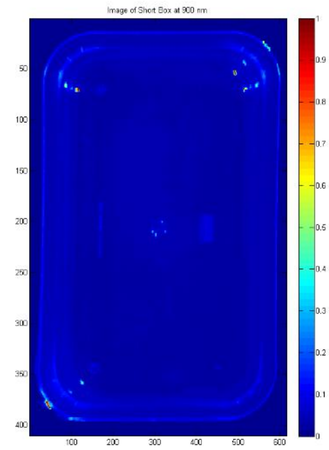


Figure 17 - Image of an empty package at 900 nm.

Our measurements show that imaging is promising in the detection of seal contamination. Tests were performed on different test material, aligned with the case studies that are handled during the PicknPack project. A commercial tray sealer was used (Figure 13) to produce PP packages (as PP will be the material handled in PicknPack).

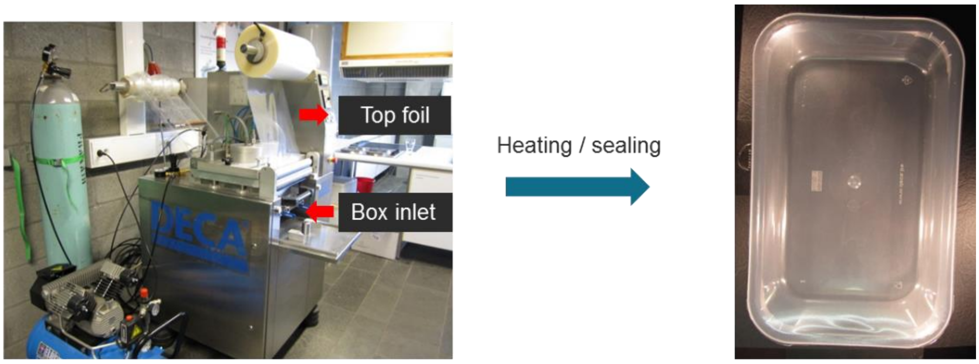


Figure 18 - Sealer and resulting PP tray.

During the tests, we investigated the potential of hyperspectral imaging on soiling of the seal region with:

- Tomato skin (Figure 19 (left)
- Tomato juice (middle)
- Cheese (right)

To this end, packages were contaminated half with the material, and half of the seal remained clean for comparison. This is visualized in Figure 19 for the three types of contamination.

Figure 19 - Contamination of seals with tomato skin (left), tomato juice (middle) and cheese (right). For each package, only one half was contaminated.

Based on analysing the hyperspectral data cube, it was clear that the difference between clean seals and contaminated seals was visible in a broad area roughly between 650 nm and 900 nm. Figure 20 shows the spectral data of the different regions (clean and contaminated) in the broader spectral region.

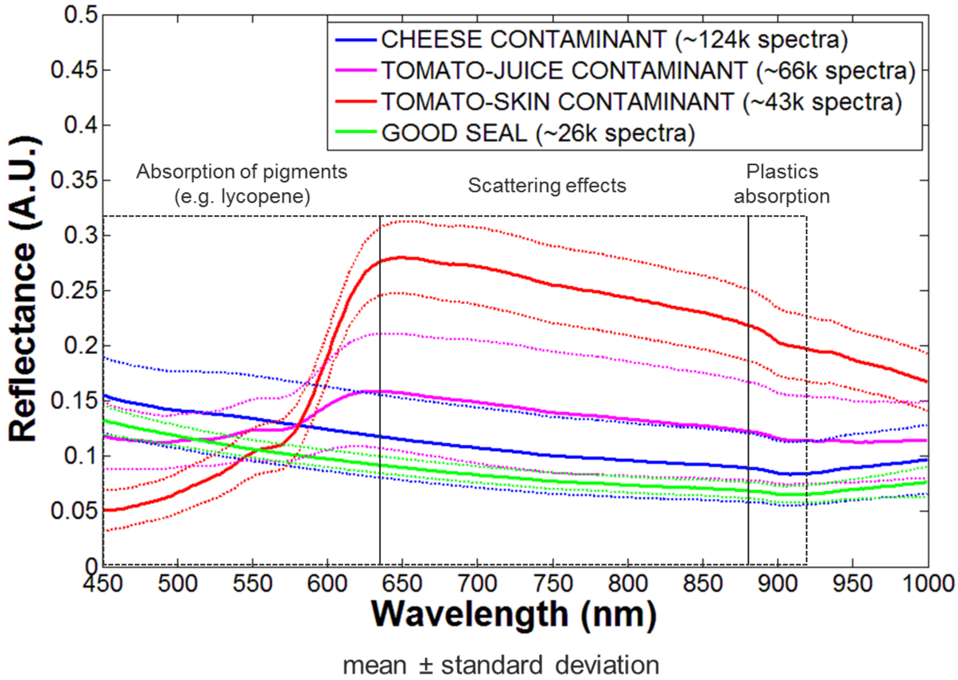


Figure 20 - Spectral fingerprint of the clean and contaminated seals in the VIS/NIR region. Mean ± SD are given.

The tomato skin led to strong absorption in the lower spectral region, whereas the cheese contamination did not. For all contamination it is observed that reflectance is significantly higher in the broad region between 650 and 900 nm. As expected, contamination leads to a higher variability in spectral information. On the higher wavelength side, the plastic absorbs the light and reflection decreases.

In order to separate clean and contaminated seals, a SIMCA model was built using the PLS toolbox in Matlab®. Models were validated on other packages than the calibration set to check robustness of the approach. Figure 21 shows the result for tomato skin. On the left side, the contaminated seal is shown, whereas on the right side the clean seal is shown. In the processed image (left), a red color indicates good seal regions, whereas green regions show bad seals. It is clear that good seals indeed are correctly classified (red), and that for the tomato contamination the good seal regions are interrupted when contamination occurs.

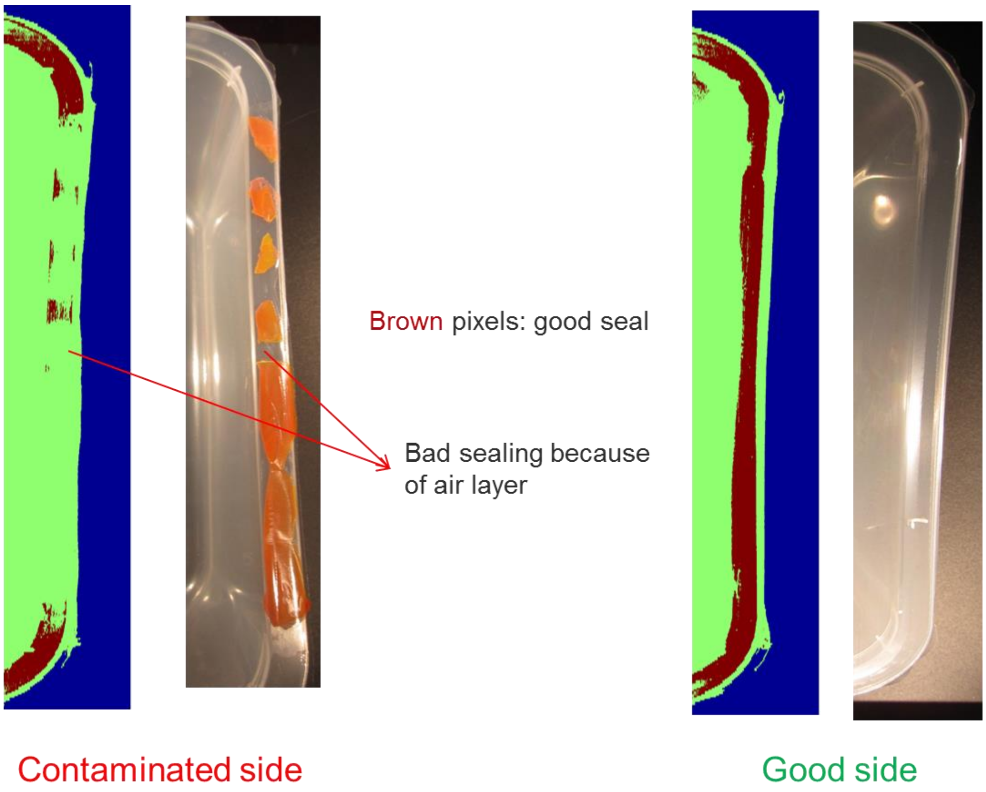


Figure 21 - Example of good and contaminated seal (tomato skin contamination).

The same type of figure is produced for tomato juice and cheese contamination (Figures 22 & 23).

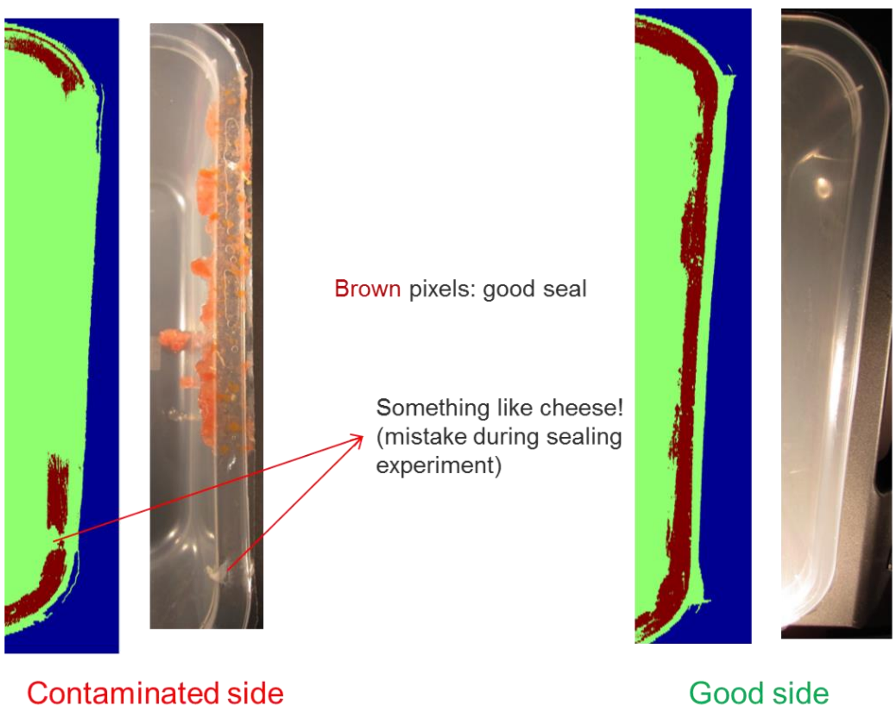


Figure 22 - Example of good and contaminated seal (tomato juice contamination).

For cheese, detection is inferior when compared to tomato. This is mainly due to the fact that the melted cheese, which has a very thin layer thickness in the region of the seal, gets transparent during heating. It is, however, noted that detection remains possible mainly due to the fact that besides the seal region the cheese remains well detectable and having cheese on the left as well as on the right side of a given seal means that cheese is present in the sealing region.

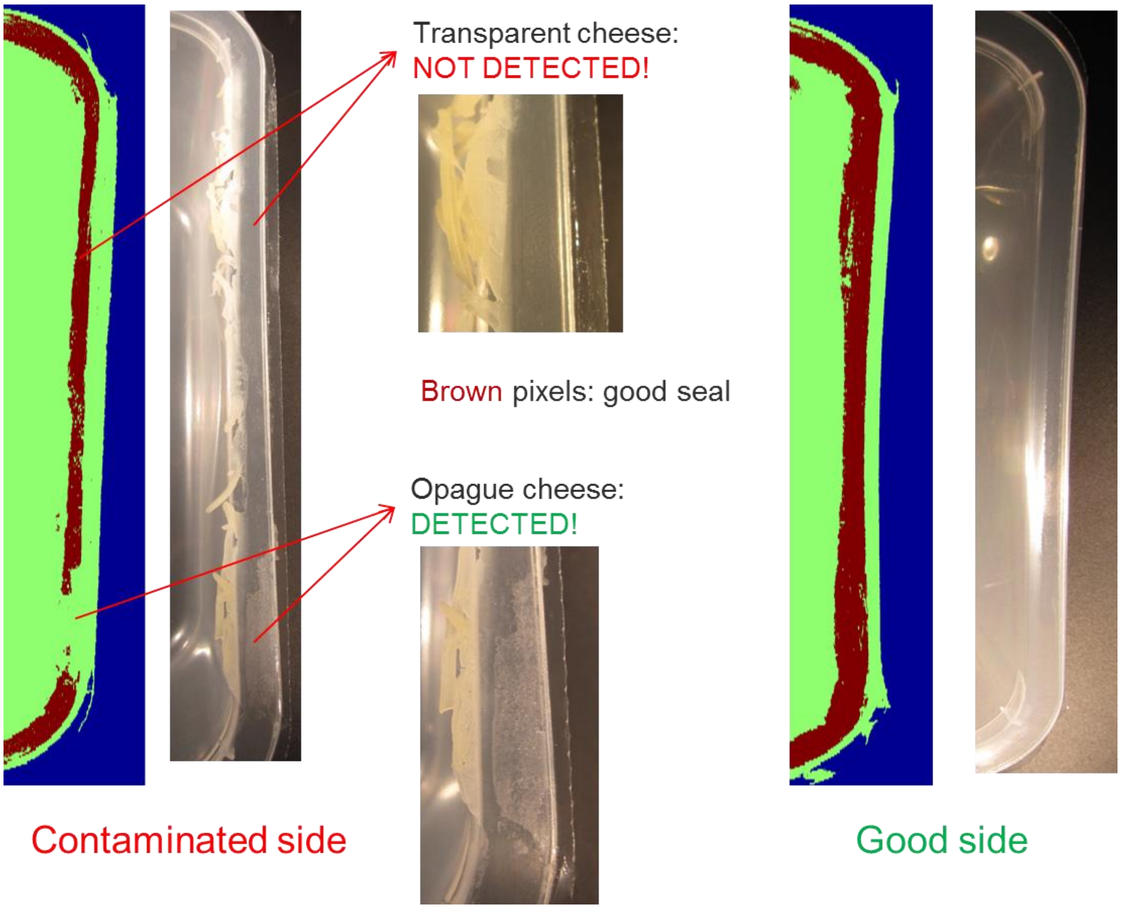


Figure 23 - Example of good and contaminated seal (cheese contamination).

Based on these results, the prototype set-up was designed, much in analogy with the hyperspectral quality inspection system developed in the framework of WP 4. The main difference is here that a snapshot system is used, so working with the product during the stand-still phase, rather than during the creep. The hyperspectral camera system is integrated in the design of the laser sealer frame which is used at the same time (i.e. during the stand-still).

6 Flexible heating system

6.1 Technical introduction

Thin metallic reflectors and susceptors of microwave electromagnetic radiation (or simply microwaves) are inalienable elements of modern active packaging solutions for microwaveable foods. The effects of reflection and susception of microwaves in thin metal objects are controlled by their electrical conductivity (or resistance), thickness, and radiation frequency. Obviously, the mutual relations are as follows:

- The higher the frequency, the better the reflection and the worse the susception
- The thicker the sheet or the film of the metal, the better the reflection and the worse the susception
- The higher the conductivity, the better the reflection and the worse the susception

Thus, for a fixed frequency, the criteria of a thin metal layer transformation to the total reflector or the optimal susceptor (=optimal absorber of electromagnetic energy) can be expressed in terms of both *thickness* and the so-called *surface (sheet) electrical resistance*. This last is the resistance-to-thickness ratio for this layer that is measured in Ohms/square or Ω/□). These criteria are of course physically equivalent, but implemented differentially on manufacture and application of reflectors and susceptors for active microwave packaging:

Usage of the thickness criterion is based upon comparison of the layer thickness with the so-called *skin depth*. The skin depth is the depth below the surface of the conductor at which the eddy-current density caused by alternating electromagnetic field falls to 1/e (about 0.37) of its value at the surface. The skin depth depends on the resistance and frequency (the higher the resistance, the larger the skin depth; however, the higher the frequency, the smaller the skin depth). The skin depths of some bulk metals at 2.45 GHz is as follows:

- Silver (smallest of all materials) – 0.33 μm
- Aluminium – 0.86 μm
- Stainless steel (304) – 4.3 μm
- Titanium – 3.3 μm

Obviously, silver and aluminium are the best candidates for implementation of active packaging since they allow higher flexibility of the layer. Whereas cost-effectiveness dictates the usage of aluminium. Thus, in order to become a total reflector, the layer thickness must exceed 2.7 of the skin depth, or approximately triple skin depth. The layer of bulk aluminium must therefore be approximately 3-μm-thick to become a total reflector of 2.45 GHz microwaves, while the silver layer thickness needs to be just 1 μm. Obviously, the thickness of the susceptor must be much less than the skin depth.

Experiments show that typical thickness of aluminium susceptor layer providing for 50 % absorption is of the order of 1 nm.

6.2 Laboratory studies

The only metallic inks that are currently available commercially and allow processing under conditions, which are compatible with polymer films on which the metal has to be printed, are silver inks. Thus, the deposited material is a porous silver film formed on the plastic film or tray after sintering of the inks. Its electrical conductivity is significantly different from the conductivity of the bulk silver and depends on many factors, which are difficult to control, for example, temperature and roughness of the sealing film. Therefore, the conductivity of the printed and sintered coating should be measured in order to control its capability to reflect 2.45-GHz microwaves.

The depositions made for proof-of-concept studies of the PicknPack concept for packaging of microwaveable ready meals were carried out using 200-μm-thick polyethylene-terephthalate (PET) substrate films, which were kept at the process temperature of 60° C. In order to reach the necessary conductivity/thickness of the deposited silver layer, the printing was carried out in several passes of the printing head (actually, from 1 to 9 passes). The printing resolution varied from 120 to 360 dpi. The inks were sintered at 150° C during approx. 30 min.

Figure 24 - Inkjet printed silver coating on PET film installed in the experimental cell for the validation of its reflective power in a microwave oven

<u>The coating that demonstrated ideal reflective behaviour in the ‘microwave oven’ tests was deposited for 9 passes with 360 dpi resolution.</u> The water inside the cell covered with this sample remained cold after at least 10 min. of microwaving, and the electrical breakdown did not occur. For comparison, the water in the cell without coated film on the top reached the boiling temperature after 10 min.

The sample that already demonstrated somewhat absorptive (resistive) behaviour in the microwave oven (i.e. it is not a total reflector), was fabricated for 6 passes with the same resolution, on the same substrate, and using the same sintering procedure. Its sheet resistance was measured to be 0.200 ± 0.05 Ω/□ and the thickness of approximately 3.5 μm. This sample pictured after the 10 min ‘microwave test’ is shown in Figure 25. The rippling of the PET substrate dew to initial thermal sub-melting caused by the joule heating of the silver layer can be easily seen in this picture.

Figure 25 - The sample with the silver coating printed for 6 passes with 360 dpi resolution.

6.3 Deposition of susceptors

Since the implementation of inkjet printed continuous metal microwave susceptor with the sheet resistance of 200-500 Ω/□ is not feasible, another solution was proposed and used. In contrast to the continuous metal coating susceptors, which are pre-heated by joule heat losses of radiofrequency eddy currents, the printed susceptors are heated by the radiofrequency displacement currents caused in a distributed capacitor. These distributed capacitors are formed by relatively small conductive metallic ‘islands’ printed on a dielectric substrate, e.g. on a polymer film or a paper sheet. These conductive islands may be either totally or partially reflective with regard to 2.45 GHz microwave radiation. One of the possible distributed capacitor patterns is shown in Figure 26.

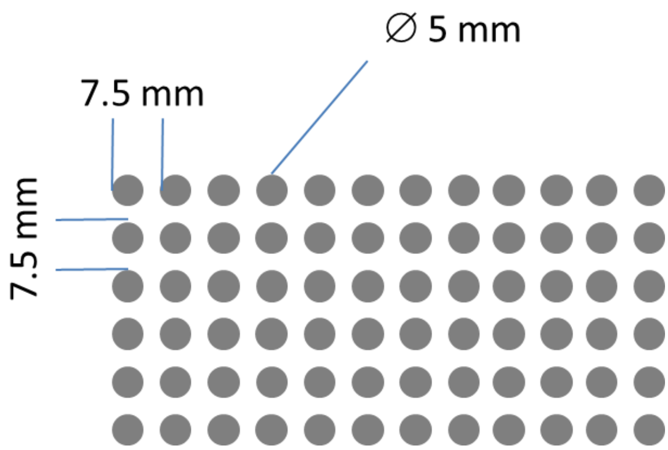


Figure 26 - Pattern of totally reflective circular islands allowing heating up to 120-150oC.

However, the susceptor effect was also achieved in our experiments using the low-resolution one-pass inkjet printing of silver. In this case, the deposited silver dots and the PET substrate formed the distributed capacitor.

6.4 Experimental validation of susceptors

The susceptors have been validated in a very straightforward manner: After 1 min. of microwaving, the distribution of temperature resulted from absorption of microwave energy has been imaged by a thermovision camera Testo 875. This does not allow full characterization, but gives the possibility to make sure that the susceptor effect is observed. Anyhow, the development of the inkjet printed susceptor technology is not finished yet. We hope to find a better method for in-line characterization of the working temperature and efficiency of the susceptor.

The thermal images of the distributed susceptors right after 1 min. of microwaving are shown in figure 27.

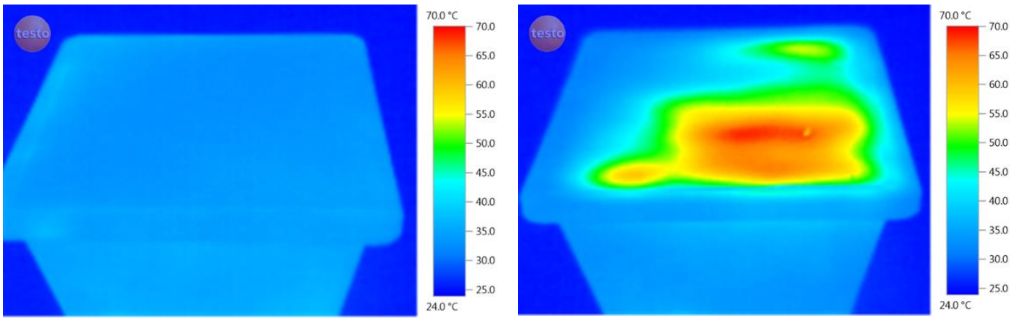


Figure 27 - The thermal images of a plastic tray: left picture – the tray is open, right picture – the tray is covered by a PET film with a distributed inkjet printed silver susceptor deposited for one pass with the resolution of 120 dpi.

The susceptor shown in figure 28 is an actual sample of a pattern of totally reflective islands. It is based on the structure shown in Figure 26. So far, these patterns have only been made of aluminium and deposited on different substrates by means of CVD technique at the Tribological Center of DTI. However, there is absolutely nothing restricting inkjet printing implementation of the same pattern. DTI and XAAR plan to carry out some depositions and validation experiments with these susceptor structures in the near future.

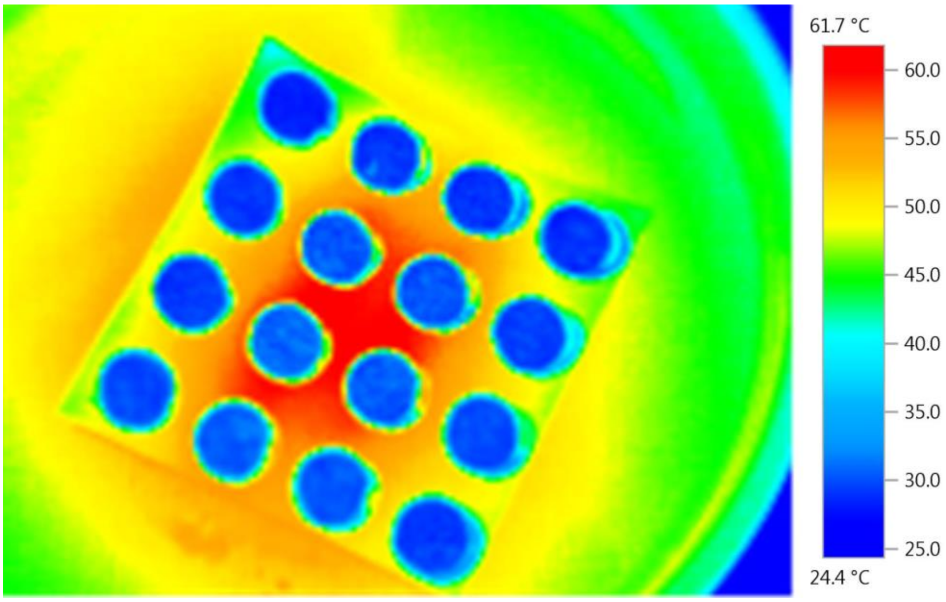


Figure 28 - The thermal images of a printed susceptor formed by a paper substrate and a totally reflective islands of aluminium film. The metal pattern remains cold while the substrate is heated up by the radiofrequency electrical displacement currents caused by

6.5 Conclusions

- The inkjet printed total microwave reflector was for the first time fabricated and validated in this study.
- The successful proof-of-concept experiments of inkjet printing of microwave susceptor has been carried out.
- The future work is to be done in order to develop inkjet printed flexible susceptors viable for application in PicknPack project for packaging of microwaveable ready meals.

As a conclusion for the flexible heating systems, WP6 has, together with the Project Board, decided to proceed with the research and make space on the line to apply these systems later in the process as WP6 do not believe to have an industrial system ready within the time frame of 2014.

For these reasons, PicknPack do not expect to demonstrate the flexible heating systems in-line. PicknPack will demonstrate these technologies off-line as an integrated part of the demonstration event.

7 Flexible decoration

WP6 has done several successful tests decorating plastic films in different colours.

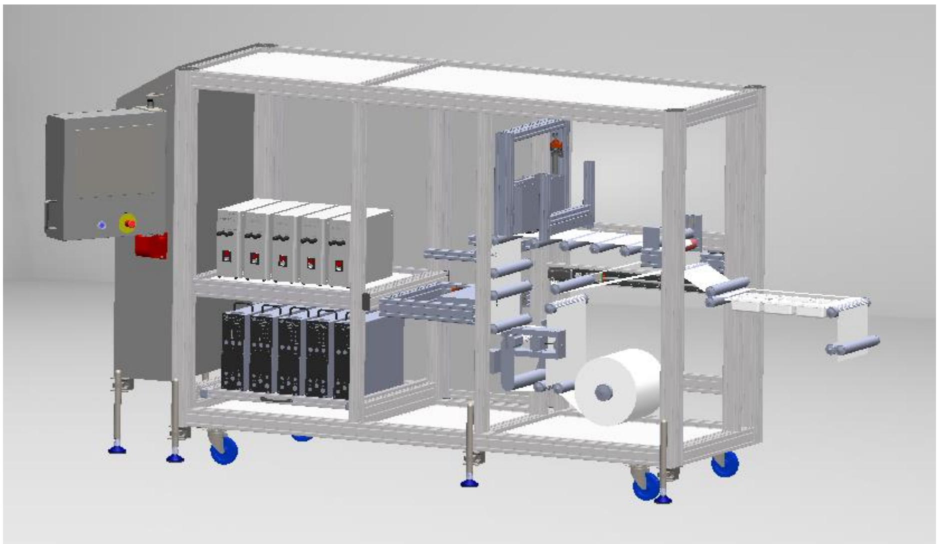


Figure 29 - Two colour jet-ink printer

It has been decided to decorate in two colours for the demonstration unit, which will give an excellent impression of the opportunities in flexible in-line decoration. Extra colours can be added at extra costs. WP6 has discussed the wish to add more colours on the printer. The printer design is made so it is possible to add several extra colours. As the print equipment for four/five-colour decoration in the full 300 mm web width is too expensive for our limited budget WP6 has selected to demonstrate in two colours in a high quality.

The printing system is designed in a way that individual information and decorations for batch sizes down to single units are printed onto the top-film, before it is sealed onto the tray. Work has also been performed to identify suitable low-migration UV-curable inks for this process, as it is a crucial part of the process that no ink components migrate into the food products. The inkjet print head selected for this process is the Xaar 1002 print head model, which allows to print in a grey-level-mode at 360 dpi, resulting in high apparent resolution and image quality. A unique feature of these print heads is the continuous ink recirculation past the back of the nozzles during jetting, which means that air bubbles or unwanted particles are carried away, resulting in highest printing reliability. These features make the Xaar 1002 the most suitable print head for this type of single-pass printing as employed in PicknPack, where it is important that the printed information like text and barcodes does not contain any defects that makes it unreadable.

Beside this approach direct on the packaging line, DTI has decided also to experiment with another solution for a printer. DTI will try to rebuild an existing colour office printer with four colours to be able to print shaped and bended cardboard to be converted to sales boxes. During a bachelor project investigating this possibility it was found, that an ordinary office printer can print on many kinds of cardboard ready cut and pre-imprinted for folding, if they are only fairly even at the sides.

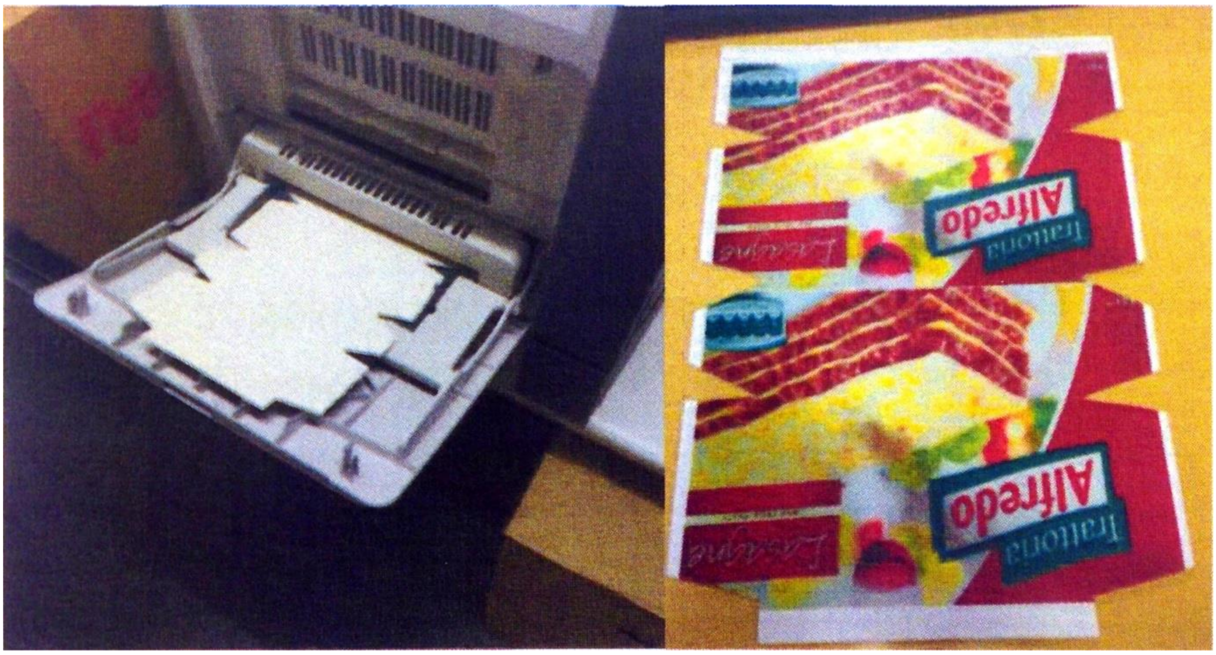


Figure 30 - Precut cardboard printed on ordinary office printer

DTI hope such a system can also be used for web printing of both plastic and paper based materials. Production speeds for such a design will be perfect for the ready meal industry, but in the low end for other business areas.

Figure 31 – Different samples printed with Xaar ink-jet technology

8 Integration of the line of WP6

The constant strive was made to keep flexibility and integration of the PicknPack line. We think, that the flexibility we have reached with the brick mould, the on-line printer and the laser is quite high. However, some more features are needed in order to make the user of the line also think that it is both flexible and easy to use.

Figure 32 - A design station is required where design of trays and printing of topfoil is decided

Together with the design of the trays, the design of the printing of the top foil is also required. When the total package design is ready, the information will be send to the mould brick changing mechanism, and to the inline printer situated further down the line.

The manual assembling of the brick mould is a very user friendly feature. But if you have, say, 10 lines all equipped with this brick mould, it will give a huge flexibility, but will also give quite some work with changing of moulds.

As an extra option, WP6 is now evaluating if we are going to build a simple machine to build the brick mould out of digital data. Most likely WP6 will document such a solution. This machine only has a little impact for the demonstration, but we hope to be able to show it.

The mould exchange mechanism in the thermoformer is designed in a way, so it might be able to place this brick changing mechanism directly at the mould inlet. If we succeed with this the mould format change will be fully automated. If not, it will be necessary to carry the finished mould format from the mould brick changing mechanism to the mould inlet at the thermoformer.

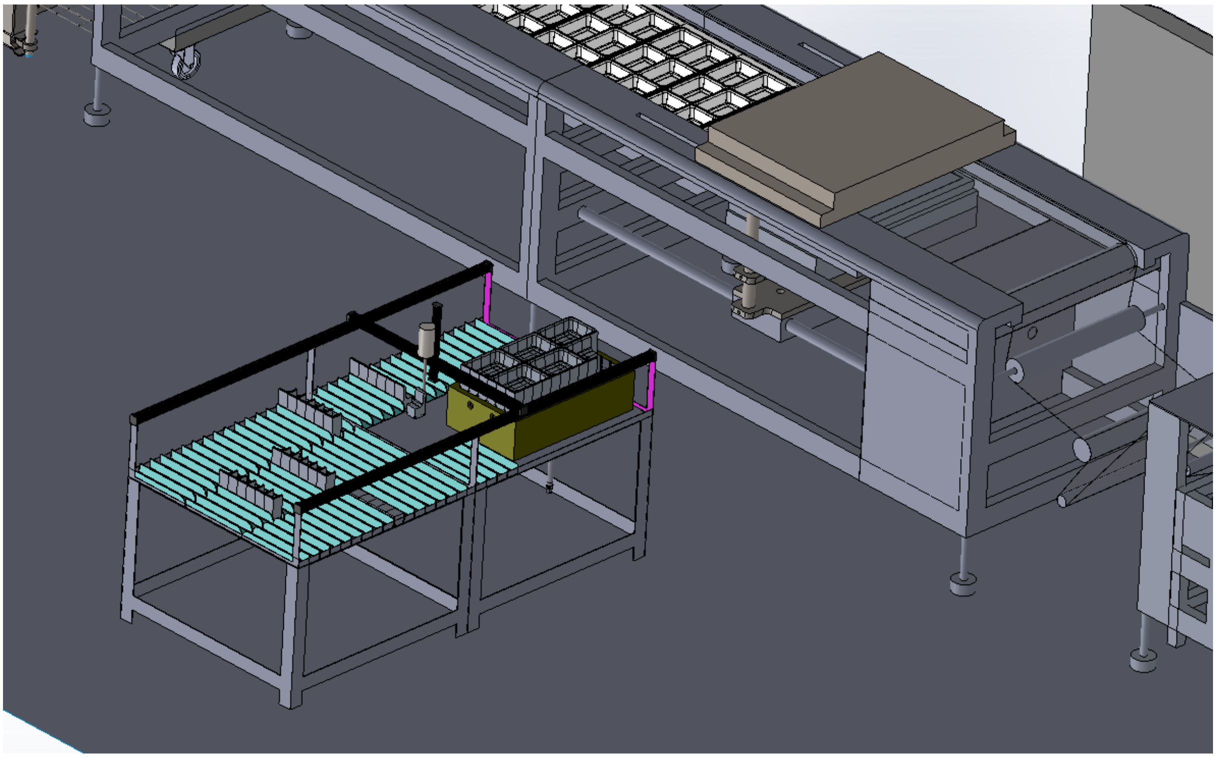


Figure 33 - Brick mould changing mechanism next to thermoformer

With this automatic system to change the brick mould to another format, it will be even more convenient to design or choose the tray size and depth on a computer.

The line should change automatically according to the tray design. This is mainly part of WP7

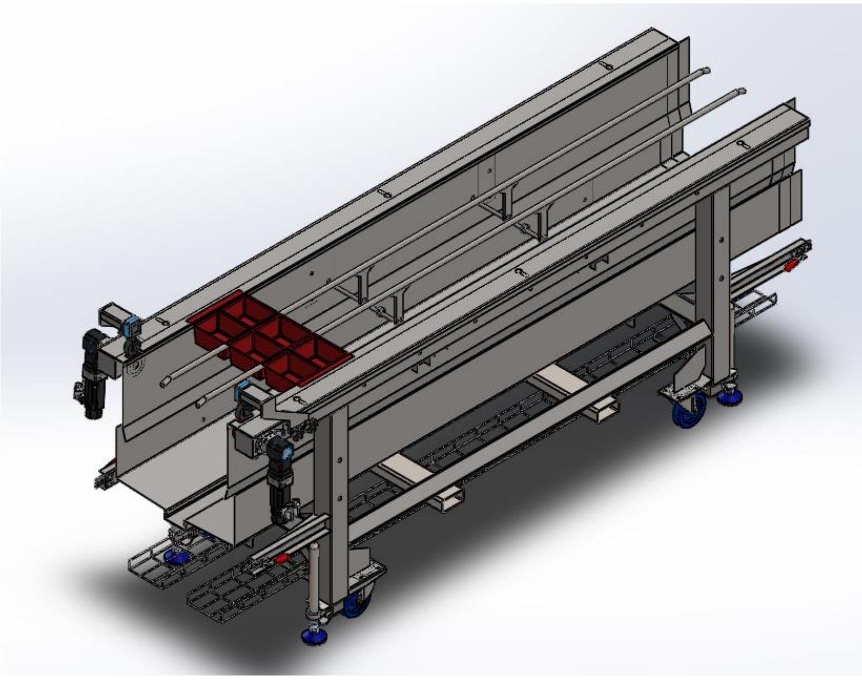


Figure 34 - Sectional Frame in hygienic design with adjustable supports. Thanks to WP7.