Final Report

Executive Summary

The RPET-FC project has met all project objectives and deliverables set out in Annex I of the grant agreement. These include:

- 75% faster rPET thermoforming cycle times, thermoforming speed has increased from an average of 20 to 35 cycles per minute using innovative prototype tooling developed during the RPET-FC project.
- 30% lighter rPET trays due to innovative tray and thermoforming tooling design which resulted in better material distribution in the trays and facilitated reduced material usage.
- Cutting accuracy has improved by 90% using innovative prototype floating cutter design resulting in reduced set up times and less material wastage.
- Innovative denesting feature research during the project facilitated high speed automated de-moulding and food packing of rPET which is demanded by end users.
- 100% post consumer (PC) rPET prototype with high IV and improved mechanical properties.
- 85% PC rPET coextruded formulation with enhanced sealing properties. Sealing temperature process window widened as material will seal excellently at temperatures up to 40^{o}C lower than current industry standard.
- 85% PC rPET coextruded formulation with enhanced gas barrier properties. Gas transmission rates for this innovative rPET formulations have been demonstrated to be up to 70% lower for O_2, 84% lower for CO_2 and 50% lower for H_2O vapour were achieved using these innovative prototype formulations.
- Using the PAS 2050 CF standard, the consortium calculated that a CF of 1.363 kg CO_2e / kg could be achieved for 1 kg of prototype rPET trays containing 85% PC rPET and 1 kg CO_2e / kg could be achieved for 1 kg of prototype rPET trays containing 100% PC rPET. These figures correspond to a 61% and 71% carbon footprint reduction compared to industry standard virgin plastics food trays.
- Carbon footprint reduction of in excess of 88% was achieved for the prototype rPET material developed in the project
- On the basis of these figures the consortium can achieve between 2.1 and 2.5 tonnes of CO2 savings per tonne of rPET trays developed to replace industry standard packaging.
- Taking these figures forward the consortium partner Holfeld plastics alone will be in a strong position following demonstration to end users to switch their manufacturing to the new prototype material by 2013. In so doing will reduce its carbon footprint by between 21,000 and 25,000 tonnes. By 2015 Holfeld Plastics will convert all its manufacturing to rPET (18,000 tonnes) leading to a further reduction of carbon footprint of 16,800 to 20,000 tonnes.

- For every tonne of tray material switched to rPET a saving of 1.8 tonnes of oil (non renewable fossil fuel) will be saved. By 2015 Holfeld Plastics will reduce oil consumption by up to 240,000 barrels per annum.

To accomplish the objectives of the RPET-FC project, the consortium by researching a series of prototype iterations have developed a number of innovative rPET thermoforming tools and rPET material formulations. In addition to accomplishing the objective originally set out in Annex I, as the opportunity arose during the project to assess the potential for deposition of natural antimicrobial/antioxidant compound 'Citrox' as a coating onto rPET packaging using atmospheric plasma technology, we have conducted additional research to develop this active packaging rPET formulation. This was outside the objectives of the original RPET-FC project, however, the consortium believe this formulation has significant potential for the food packaging industry and conducted a preliminary research and evaluation of the technology. Active rPET packaging formulation developed with Citrox during the project showed antimicrobial activity against a wide spectrum of Gram + and Gram – bacteria including a number of know food pathogen such as E. Coli, Salmonella and Campylobacter.

Summary description of project context and objectives

RPET-FC is an EU funded development project linking together five EU member state SMEs and three research organizations. RPET-FC addresses the specific objectives of capacities research by supporting low to medium technology SMEs in response to an increasingly competitive European and international market.

The primary objectives set out in the rPET project, which have for the most part been achieved:

- Develop a state of the art high-speed A/B/C seating, nesting and de-nesting and stacking system for food trays, integrated within a flexible multi-cavity low volume thermoforming manufacturing process. (Prototype thermoforming tooling developed for manufacture of rPET trays with innovative denesting suitable for high speed automated end user processes)

- 50% savings on labour, handling and energy per factory (achieved by 75% increase in throughput speed and 90% improvement in cutting accuracy)

- Increase thermoforming tooling process efficiency which is currently too slow to cost effectively compete with high volume third generation hard automation process lines unless the speed of the flexible automation thermoforming tooling can be brought in line with the throughput of the hard automation process (achieved by 75% increase in throughput speed on prototype thermoforming tooling)

- To improve the competitiveness of the SME food processing and equipment manufacturing communities. Through greatly reduced production cycle time, in conjunction with single minute exchange of die (SMED) system of manufacturing. (Achieved by 50% reduction in stacking station tool weight from 50 kg to less than 25 kg which can be manoeuvred manually into position by the machine operator)

- Cost neutral food tray that are 100% recyclable and with a carbon footprint reduction of 2.37 tonnes CO_2 eq. per tonne of rPET trays produced (Carbon footprint reduction of between 2.1and 2.5 tonnes CO_2 eq. per tonne of prototype rPET trays achieved)

- In the original RPET-FC Annex I of the grant agreement the consortium indicated the potential for job creation by 2015 to be in the region of an additional 55 jobs (Post project completion the consortium has revised this figure upward to 105 additional job once the innovative food tray prototypes can be successfully demonstrated to the large end user multiples operating in the European food industry)

The objective of the project is to provide SME food processing companies new low carbon footprint recycled polyethylene terephthalate (rPET) prototype food trays that will facilitate high-speed stacking, packing and safe transportation of a whole range of food products.

The new prototype food trays will utilise less virgin material, will be made from 100% recyclable rPET and will have the capability to replace current industry standard virgin polypropylene (PP) which has a poor environmental performance.

The RPEC-FC project pinpointed several characteristics of rPET material performance that would need to be developed. This included improving mechanical, sealing and gas barrier performance. In addition potential for active packaging technology for implementation with rPET food trays would be researched.

To accomplish these objectives prototype rPET material formulations would be developed that would advance rPET performance beyond current state of the art while retaining 100% recyclability of prototype tray and excellent environmental performance with regard to low carbon footprint. The consortium set an objective of 90% reduction in carbon footprint of materials used compared to industry standard.

The RPET-FC project identified a considerable number of technical issues related to high volume, high speed thermoforming of rPET materials which required significant research and development, before this low carbon footprint material could become a viable replacement for current industry standard virgin polypropylene in the European food packaging industry. These included:

- Cooling efficiency in rPET thermoforming moulds would need to be dramatically advanced to facilitate processing speeds that match industry standard polypropylene.

- Sealing of rPET trays is much more challenging that industry standard polypropylene and as such tolerances for sealing flange/rim uniformity/flatness/roughness are much tighter.

- rPET material is prone to mark during plugging operation using current state of the art plug materials and profiles. Plug mark are aesthetically unpleasing and unacceptable to downstream end users.

- Current state of the art for cutting rPET material requires long set up times, has poor cutting accuracy and performance resulting in unacceptable levels of down time and material wastage.

- As rPET polymer is much stiffer than polypropylene. Tags produced as a function of the current state of the art cutting function can be extremely sharp resulting in tearing of overwrap film utilised by end users and posing consumer safety issues.

- The chemical nature of rPET material, i.e. its high surface energy, which causes a high degree of affinity between trays and a tendency for them to stick together, presents a huge technical issue in the highly automated de-stacking and food packing process lines employed by end users.

- Current state of the art of the thermoforming stacking station flipper design is inadequate for high speed, high volume processing of rPET

Description of main S&T results/foregrounds

During the RPET-FC project the project team have developed and researched a number of new formulations for rPET material in packaging applications. In total five beyond state rPET packaging formulation were developed:

1. High IV 100% PCW rPET, with mechanical, thermal and clarity matching virgin material.

2. Enhanced seal formulation rPET, with wider temperature processing range (seals at temperatures up to 40^{o}C lower that current industry standard) that is capable of sealing through food contamination on the tray sealing rim.

3. Plasma activated rPET for improved sealing performance, with sealing properties matching ESF rPET formulation

4. High barrier rPET, with enhanced gas barrier performance (up to 70% lower O_2 and 84% lower CO_2 transmission rates)

5. Active rPET packaging formulation with antimicrobial and antioxidant properties with natural citrus fruit extract coating.

High IV 100% PCW rPET

The high IV formulation was research to improve the mechanical properties of rPET. To counteract material degradation (reduction in molecular weight/polymer chain length of rPET which results from hydrolysis of PET during multiple processing cycles, see figure 1.1), we have examined the use of multifunctional acrylate chain extenders.

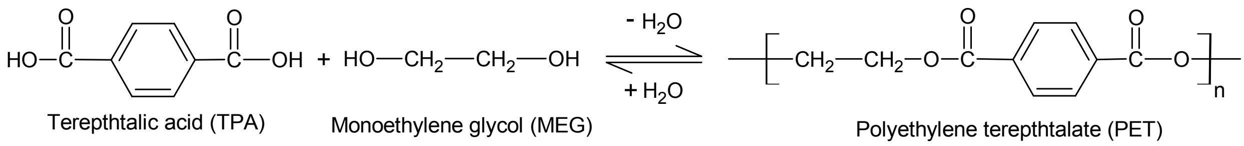

Figure 1.1: Polycondensation/hydrolysis of PET

The degradation of rPET was monitored thought the measurement of rPET Intrinsic Viscosity (IV), which is related to molecular weight. Chain extenders operate through the reconnection of polyester chains based on chemical reactions between the functional groups on the chain extender and the free end groups of the polymers chains (Figure 1.2). The use of chain extenders improved the IV of extruded rPET. The higher IV created higher melt strength during extrusion, improving process-ability of the polyester. The higher IV of the rPET also improved the mechanical properties (tensile strength, modulus and impact strength) of the rPET tray prototypes made from this material.

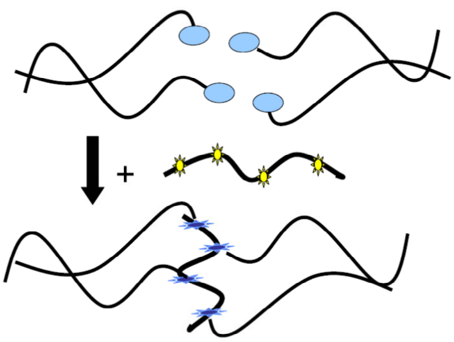

Figure 1.2: Mechanism polyester chain extension of multifunctional acrylates

rPET formulations for enhanced sealing performance

Enhanced seal formulation (ESF) rPET developed in year 1 of the RPET-FC project and comparison conducted with atmospheric plasma treatments to enhance rPET polymer thermosealing performance in year 2

The ability to thermoseal a top film onto a thermoformed rPET tray, and for the resulting package to have strong seal integrity is of critical importance in the food packaging industry.

A strong seal is of particular significance in the fresh meat packaging sector as contamination from meat fluids on the sealing rim can result in poor seal integrity and lead to package failure.

The heat sealing properties of mono recycled PET (rPET) food trays are not sufficient in all packaging applications, especially fresh meat packaging. Thus, standard mono rPET formulations are not considered appropriate for red and white meat packaging. The current industry standard formulation for rPET trays for these applications employs a laminate adhesive low density polyethylene (LDPE) sealing layer. However this rPET/LDPE formulation is not recyclable. One of the main goals of the RPET-FC project was to produce prototype 100% recyclable rPET formulation that would form a strong seal over a wide temperature range and through fresh meat fluid contamination on the sealing flange.

Therefore, it was necessary to design rPET tray prototypes with enhanced sealing performance to meet these requirements. Two methods of achieving rPET trays with enhanced sealing were researched. 1. Co-extrusion of rPET with a PET copolymer with lower glass transition temperature and lower crystallisation rate than standard PET (see figure 1) which was completed in year 1 of the RPET-FC project, and 2. Use of atmospheric plasma technology to activate the surface of mono rPET and deposit coating to improve sealing performance, which was research in year 2 of RPET-FC.

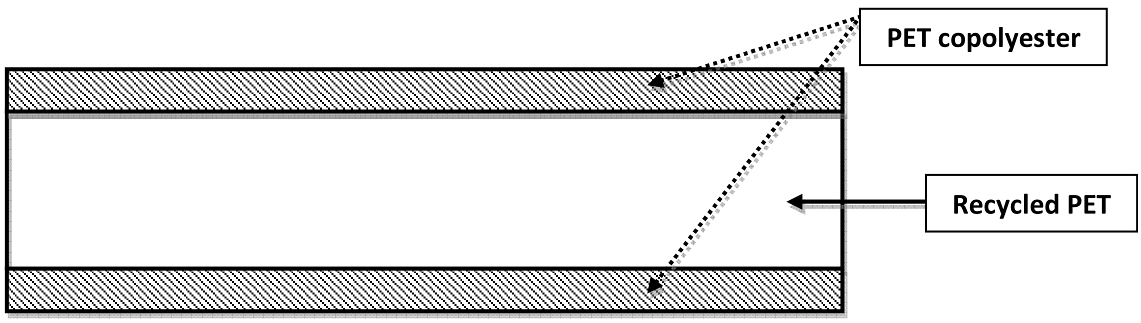

Figure 1: *Structure of 100% recyclable enhanced seal formulation (ESF) rPET material. Developed using co-extrusion technology. This formulation consistently formed a strong seal over a wider temperature range than mono rPET material and had a much improved sealing performance through food contamination on the sealing rim.*

Results

Both ESF and plasma activated rPET formulations resulted in widening of sealing temperature process window (Figure 2). Sealing temperature could be reduced by up to 40^{o}C compared to standard rPET material. In addition both ESF and plasma activated rPET formulation formed seals of superior strength to standard rPET under various food contamination tests. However it was found that the enhanced sealing performance of plasma activated trays dissipated after approx. 16 weeks whereas ESF formulation retained enhanced sealing activity for at least 24 weeks (Figure 3).

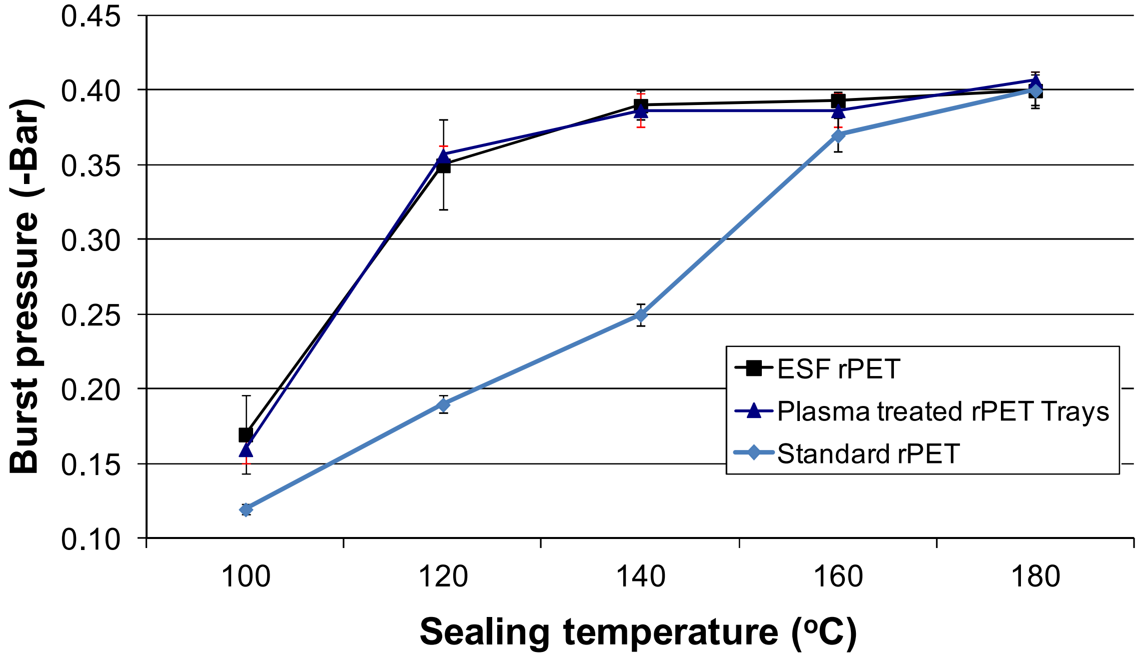

Figure 2: *Comparison of sealing performance of ESF rPET trays versus plasma activated rPET trays*

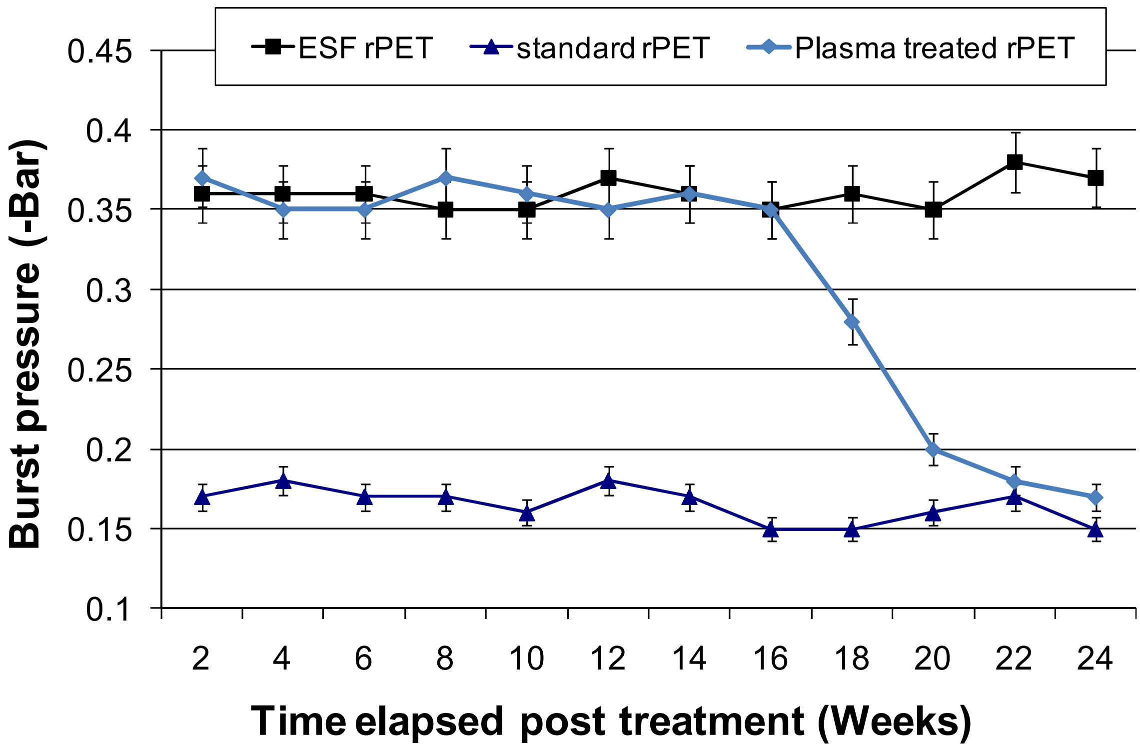

Figure 3: *Effect of time on sealing performance of standard rPET (control), Enhanced seal formulation (ESF) rPET and plasma treated rPET at a sealing temperature of 120°C.*

Conclusions

Plasma activated rPET showed improved heat sealing properties rough equivalent to the ESF rPET formulation developed in year 1 of the RPET-FC project. Both sealing temperature range and ability to seal through food contamination on the tray sealing flange are enhanced. However, sealing performance begins to deteriorate after approx. 16 weeks post treatment. This could be an issue if rPET trays are stored for periods longer than 16 weeks post treatment before use. A cost analysis of plasma activated rPET versus ESF rPET suggests that plasma activation technology would be up to 30% more expensive than ESF rPET if integrated into a manufacturing process. Based on these findings ESF rPET formulation presents a more economical and more robust method of improving rPET sealing properties.

High barrier rPET formulation

Introduction

Modified Atmosphere Packaging (MAP) is rapidly growing in the food packaging market. It improves the product quality and freshness while increasing shelf life, convenience to the consumer and added value to the product. MAP enables fresh produce or perishable product to be packaged when it is fresh and then maintain it in that condition, thereby, reducing distribution costs and enhancing flavours and nutrition value for the consumer.

Food trays used in modified atmosphere packaging (MAP) applications require excellent barrier properties to prevent gas egress and ingress. PET/rPET has an advantage over other commonly used food tray packaging materials such as polypropylene (PP) and high impact polystyrene (HIPS) as its gas barrier properties are between 10-100 times superior. PP food trays currently employed in MAP require the use of multi-layer structures containing gas barrier layers of material such as ethylene vinyl alcohol (EVOH), polyvinylidene chloride (PVDC) and MXD6 (Nylon). The use of these barrier layers greatly increases the barrier properties of PP and HIPS trays (gas barrier properties of these trays are greater than mono PET/rPET trays), however this eliminates the potential for recycling either post industrial waste or post consumer waste of these trays.

PET/rPET trays are generally used without addition of barrier layers, as the barrier performance of mono PET is adequate for most applications and the use of mono material allows the trays to be fully recyclable. However, improving the gas barrier performance of PET while retaining the recyclability of the tray would be beneficial as it would improve shelf life of many foods packaged under MAP.

Development of formulation for high barrier rPET

One of the goals of the RPET-FC project was to address this problem by researching potential technologies to improve PET gas barrier while retaining 100% material recyclability. Several potential methods of improving rPET barrier performance were considered including plasma deposition of SiOx coating, use of oxygen scavenging technologies, and lamination of current industry standard barrier films. However, following extensive research into the prospective methods for improving rPET barrier performance and consideration of 1. potential for success, 2. recyclability of final product and 3. economical viability, we identified co-extrusion of rPET with a high barrier polyester material as the technology that had the best chance of meeting these criteria.

The material formulation that was ultimately researched was the co-extrusion of rPET with the high barrier polyester material polytrimethylene naphthalate (PTN). The chemical structure of PTN is closely related to that of PET (Figure 4). However, PTN was shown to exhibit approx. 18 times the CO_2 barrier performance of PET and approx. nine times its O_2 barrier performance (Figure 5). PTN has a barrier performance roughly comparable to an industry standard barrier material MXD6. However, as it is a 100% polyester material with the potential to be compatible with PET due to transesterification which can occur between polyester chains while the materials are in a molten state. Thus, PTN layer coextruded with rPET had the potential to result in a 100% recyclable prototype compatible with PET recycling streams with no negative influence on recycled PET quality.

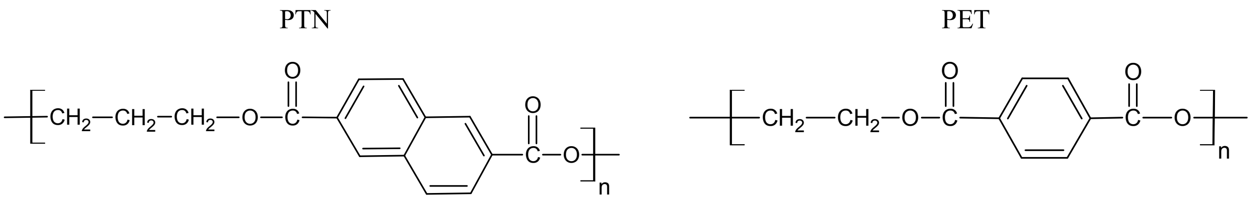

Figure 4: Chemical structure of PTN and PET

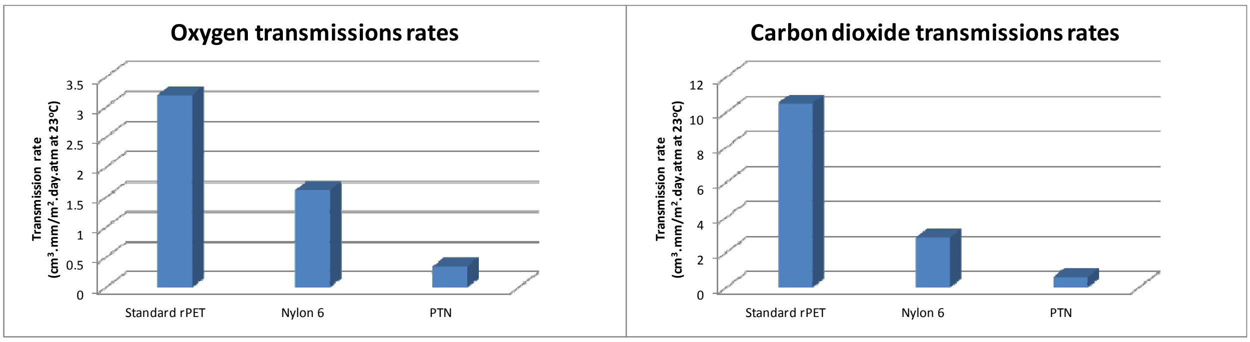

Figure 5: Carbon dioxide and Oxygen transmission rates of PET, Nylon 6 and PTN

Trials

The co-extrusion process involved the two materials (rPET and PTN) being fed into a single die from separate extruders. Two extruders were utilised, a main extruder processing rPET and the co-extruder processing PTN. The flow of the main extruder went through a co-extrusion block designed to orient the material in layers, so that the main flow was sandwiched between two outer layers, an 'ABA' structure. The A layers in this structure to consist of PTN, while the B layer was rPET (Figure 6).

To achieve this 'ABA' structure, a number of research processing trials were conducted in an attempt to attain a strong merging and welding of the extrudates together into a laminar structure before chilling. Due to the different thermal and melt flow properties of the rPET and PTN polyester material several problems were encountered in initial co-extrusion processing trials resulting in delamination of the prototype high barrier rPET formulations. Temperature and pressure profiles of the main extruder and the co-extruder were varied so that polymer melt viscosities of the rPET and PTN materials would be more compatible as they were entering the co-extrusion block. This resulted in prototype high barrier rPET sheet with high affinity between the laminar rPET and PTN layers.

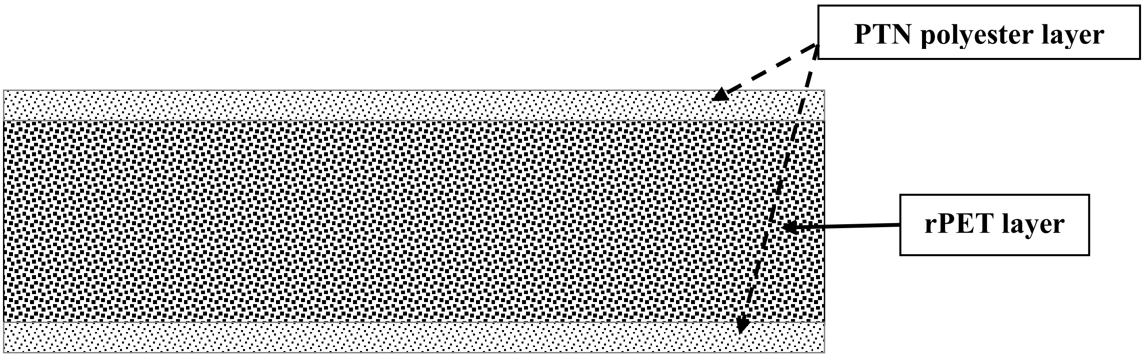

Figure 6: *'ABA' structure of high barrier rPET to be manufactured using co-extrusion.*

When the technological uncertainty relating to the processing of the high barrier rPET formulation had been resolved, several formulations were extruded comprising different ratios of PTN to rPET. To achieve this, modifications to the plates and pins within the co-extrusion block were modified. The following prototype 'ABA' high barrier rPET formulations were produced:

1. 5% PTN/90% rPET/5% PTN
2. 7.5% PTN/85% rPET/7.5% PTN
3. 10% PTN/80% rPET/10% PTN
4. 15% PTN/70% rPET/15% PTN

Barrier testing using of the prototype formulation for Oxygen, carbon dioxide and water vapour permeability was conducted using Mocon Ox-tran, Permatran-C and Permatran-W instruments respectively. An increase of up to 300%, 615% and 400% was observed in the O_2, CO_2 and H_2O barrier performance of high barrier rPET formulations respectively (Figure 7). The barrier performance improved as the ratio of PTN to rPET in the formulation was increased. Thus it is possible to tailor the barrier performance of rPET using these formulations.

Thermoforming and sealing tests were also carried out with these high barrier rPET formulations. Thermoforming of high barrier rPET trays was conducted at normal processing temperatures and conditions with no observable problems. High barrier rPET trays were observed to form a strong seal with a top film at a range of sealing temperatures. Unexpectedly the sealing performance of these prototype high barrier rPET trays was superior to standard rPET, thus providing these formulations with the added advantage of enhanced sealing properties.

A number of recycling trials were conducted to assess the recyclability of prototype high barrier rPET formulations. High barrier rPET formulation was mixed at 10%, 30%, 50% and 70% with standard rPET and re-extruded. The resulting sheet was assessed for clarity, yellowing, gel formation ('fish-eye') and mechanical properties. Sheet produced from these mixtures shown no deterioration in these properties compared to standard rPET.

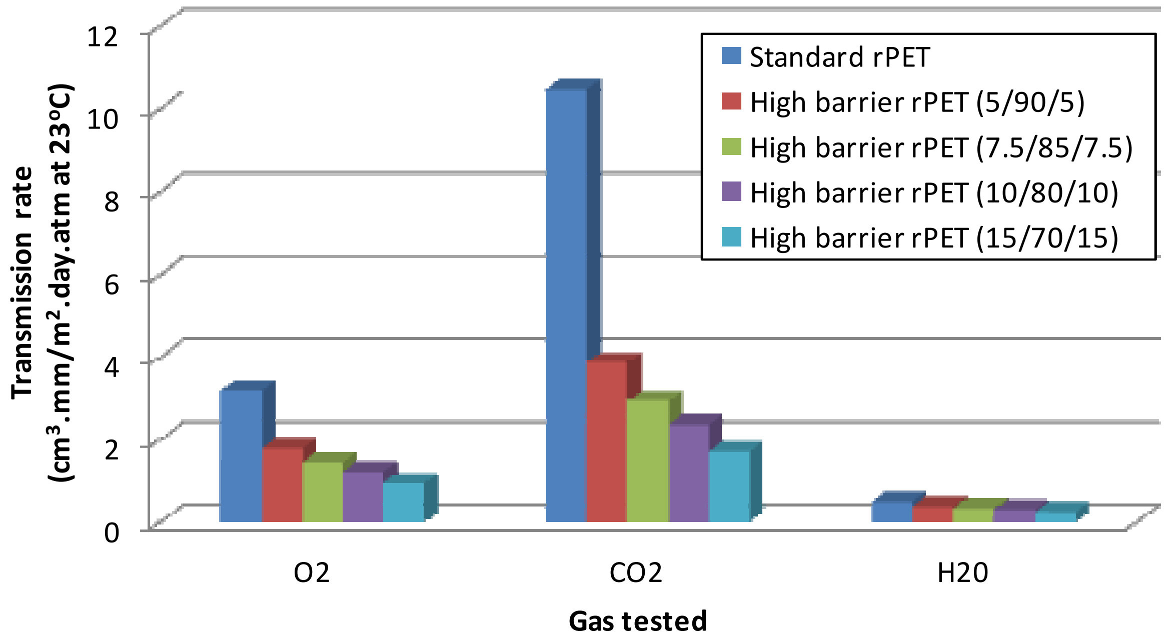

Figure 7: *Barrier performance of prototype high barrier rPET formulation*

Conclusions

Prototype high barrier rPET formulations developed during the RPET-FC project have been demonstrated to enhance the gas barrier performance of rPET. Gas transmission of up to 70% lower for O_2, 84% lower for CO_2 and 50% lower for H_2O vapour were achieved using these innovative prototype formulations. These formulations are 100% recyclable in PET recycling streams as the barrier material used is a polyester material closely related to PET.

Depositing an anti-bacterial/anti-oxidant coating onto rPET plastic food trays

Introduction

In addition to accomplishing the objective originally set out in Annex I with regard to material formulation improving rPET mechanical, sealing and gas barrier properties, the opportunity arose during the project to assess the potential for deposition of natural antimicrobial/antioxidant compound 'Citrox' as a coating onto rPET packaging using atmospheric plasma technology, we have conducted additional research to develop this active packaging rPET formulation. This was outside the objectives of the original RPET-FC project, however, the consortium believe this formulation has significant potential for the food packaging industry and conducted a preliminary research and evaluation of the technology.

Results

Active rPET packaging formulation developed using atmospheric plasma deposition technique with the natural agent 'Citrox' during the project showed antimicrobial activity against a wide spectrum of Gram + and Gram – bacteria including a number of know food pathogens such as *E. Coli*, *Salmonella* and *Campylobacter*. Prototype rPET food trays with Citrox coating showed good antimicrobial activity against microbes present in raw chicken (see Figure 8 below). In addition Citrox coated rPET trays developed in the RPET-FC project showed strong antioxidant activity with cooked sliced turkey packed in the prototype trays under industry standard gas atmosphere conditions (see Figure 9 below).

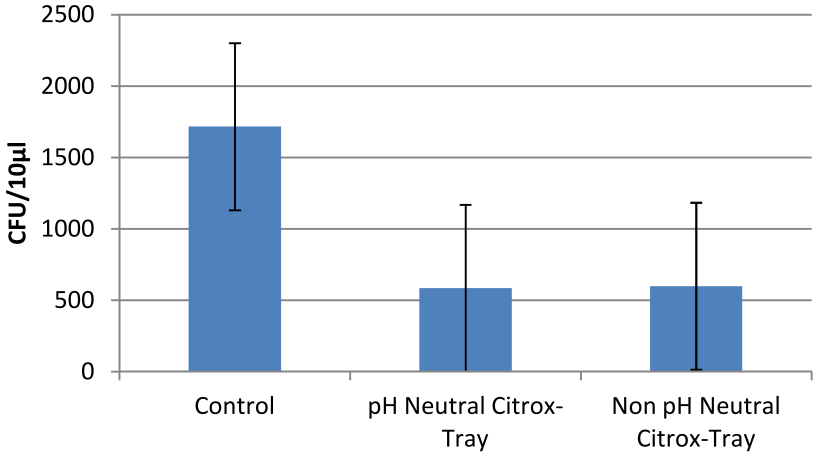

***Figure 8**. Antibacterial activity of Citrox coating under micro aerobic conditions on raw chicken samples packed in rPET trays*

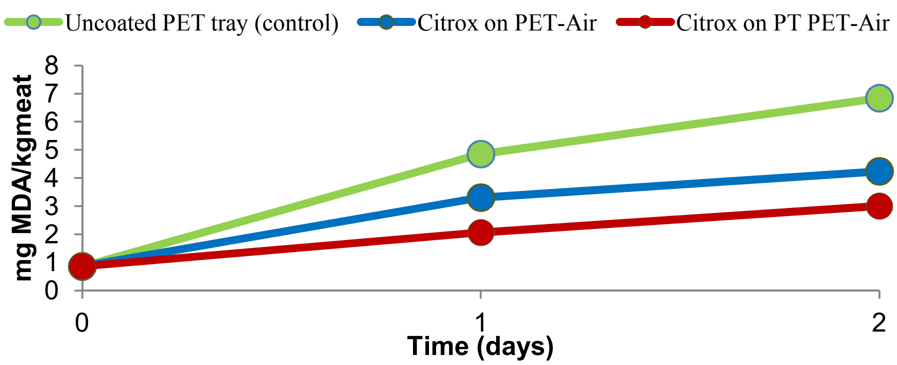

***Figure 9** Antioxidant effects of Citrox coatings on cooked turkey slices*

Summary of anti-bacterial/anti-oxidant coating onto plastic food trays

- Citrox coatings were shown to exhibit antimicrobial and antioxidant properties when applied to the rPET packaging.
- The deposition method was found to influences the coatings' morphology, thickness, roughness and ageing.
- It was observed that the antimicrobial and antioxidant properties are related to the coatings' thickness and roughness. The thicker and rougher the coating are more stable over time. The thicker rougher coatings also show increased activity against bacterial growth and oxidation.
- The pH neutral Citrox was found to retain the chicken and chicken juice colour better over time. Importantly it was also shown to have similar antioxidant activity as the non pH neutral one.
- The use of Citrox coatings either on the packaging material of directly on the raw/cooked turkey samples was shown to be effective against oxidation.

Thermoforming tooling developed during the RPET-FC project

First and second iteration tooling was evaluated in a range of trials on thermoforming equipment and feedback from these trials was used to further develop improved prototype tooling designs for third iteration prototypes.

a. Moulding station

Summary of first and second iteration tooling

The first and second iteration prototype moulding station tooling introduced the concept of innovative individual water cooled flange clamping to improve the uniformity/flatness of the rPET sealing rim. These innovation resulted in some improvement in sealing rim uniformity in production trials, however it was noted that the fixed nature of the flange clamping design was limiting the potential of the concept and to achieved the full benefits this would need to be addressed in the third iteration tooling. In the first 2 iterations two new plug materials were trialled. However, plug profile still required further research.

Third iteration tooling

As the prototype trays developed in this project are to be targeted at the food industry where top sealing is a critical parameter, the flange at the top of the tray must to be as flat and uniform as possible. To achieve this the 3rd iteration pressure box was designed in two separate sections. The main body houses the plugs and clamps the rPET sheet material onto the tool frame, while individual water cooled, sprung loaded flange clamps (Figures 10) make sure that each prototype tray can be formed with a fully uniform and flat top rim. These individual sprung loaded flange clamps (Figure 11) which further improved the fixed flange clamping design from iteration 2. Trials carried out with the 3rd iteration prototype in which the individual flange clamps were fully sprung loaded resulted in a uniform flat sealing flange which is a critical parameter to be achieved in order to ensure superior top sealing capability using rPET material. With these innovative sprung loaded flange clamps any small variances in sheet topography did not result in the normal tray flange variances associated with non flange clamped or indeed fixed flange clamped tools.

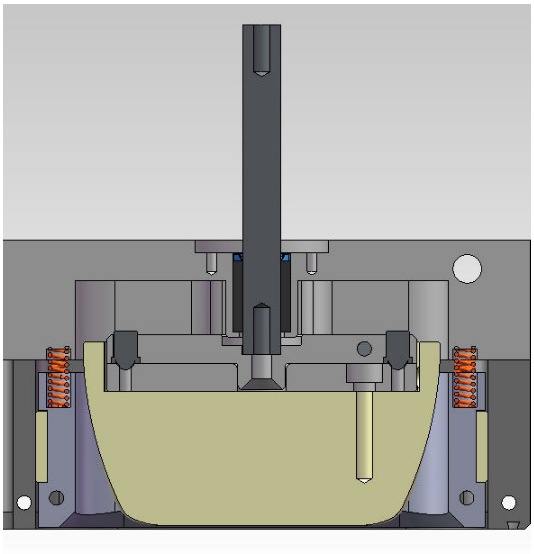

Figure 10: *Cross section of pressure box showing the prototype water cooled individual sprung loaded flange clamp and plug*

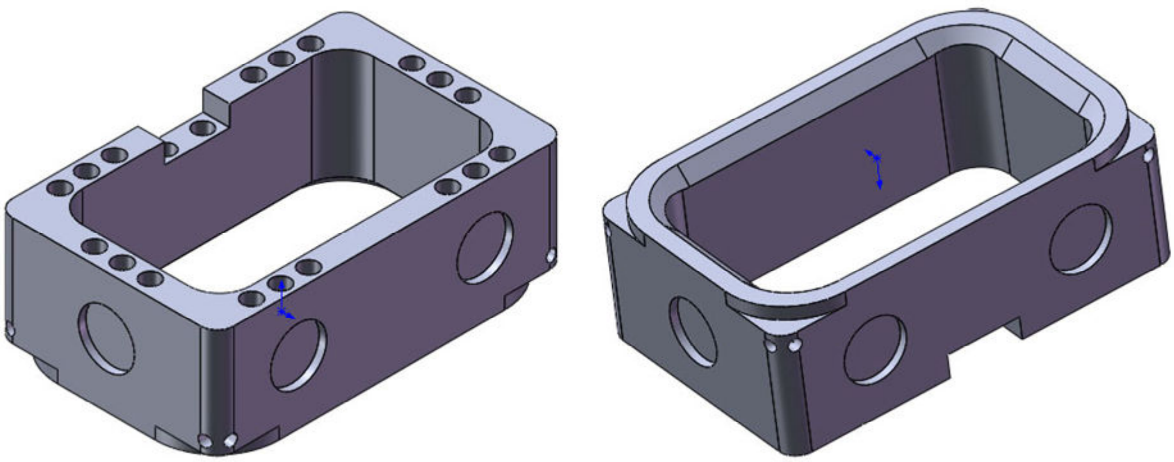

Figure 11: *Prototype flange clamp top (holes for springs visible) and base (contact with tray flange). Individual flange clamping produces a flat top rim to improve heat sealing of product.*

In the 3rd iteration moulding station tool, the design profile of the prototype plug was also modified to a dog-bone profile (Figure 12), which was invisaged would result in improved distribution of rPET material in the tray. This 3rd iteration plug design which utilised Hytac FLX material and the dog-bone profile resulted in a far superior rPET tray. The tougher

Hytac FLX material in combination with the improved profile resulted in better distribution of the rPET material to the tray corners and walls which in turn allow down-gauging of the rPET sheet material by 5%. In addition, the low surface energy and coefficient of friction in combination with the ultra smooth surface finish of the Hytac FLX material resulted in exceptionally high clarity rPET trays with greatly reduced incidence of plug marks. The incidences of plug marks which are aesthetically undesirable in the food packaging industry have been reduce to an imperceptible level (greater than 90% reduction).

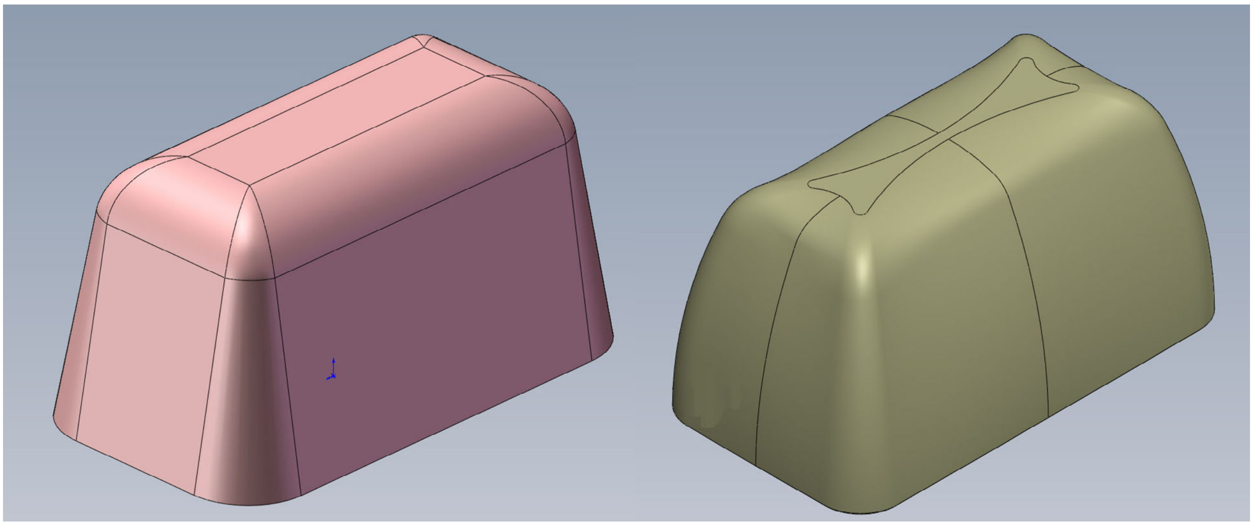

Figure 12: *Plug design – 'Dog bone' design (right) gave better material distribution within the finished rPET tray than conventional plug design (left) allowing down gauging of material.*

b. Cutting station

Summary of first and second iteration tooling

The first iteration of the innovative floating cutter design improved cutting accuracy by 90%, however, we observed in thermoforming production trials that blade heating to be a major issue at the process start up or after a period of down time. To address this in the second iteration an improved floating cutter prototype design was implemented. This design had a permanent point of contact between the heated base plate and the cutting blade and cutting performance in trials was excellent upon start up of thermoforming process and after periods of down time. However, the second iteration design presented a problem with heating of the locator block material, especially after long production trial runs. This problem was addressed in the third iteration tooling design.

Third iteration tooling

Iteration 2 of the floating cutter was re-designed to improve tray location and heat transfer to the cutting blades. This improved design resulted in cutter block being in continuous contact with the base plate. Thus, the blades are always hot making the cutting of the prototype tray more efficient. However, having satisfactorily resolved the issue of heat transfer to the blades, an unintentional downstream problem was observed, namely excessive heat transfer to the locator block. To resolve this problem in the third iteration three layers of B32 insulation was introduced between the cutter and locator blocks to ensure that the locators did not get too hot (Figure 13). To further enhance the performance of the locating mechanism the locator block material was changed to Ertalon LFX, a more durable and longer lasting material than that used in previous iterations. This innovation, when trialled demonstrated excellent cutting accuracy and performance under all conditions trialled, such as high speed, after down time and during long production trial runs.

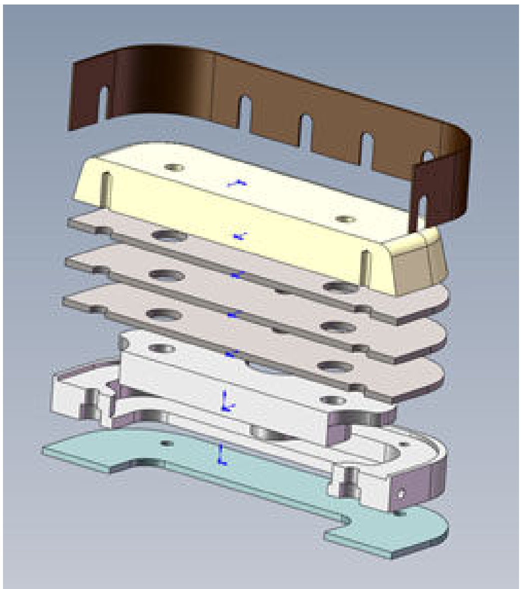

Figure 13: *Cross Section showing exploded cutter block assembly (3rd iteration)*

Another issue identified after iteration 1&2 of the cutting station that need to be addressed was the presence of tags in the rPET tray produced (Figure 14a). The current state of the art in cutting rPET material is for the thermoforming setter to manually nick cutting blades while setting the tool to leave small areas of the tray connected to the sheet until it has relocated to the stacking station where it is punched out. This procedure poses several technical and operational problems related to the fact that it is dependent on the machine setter skill and experience and as such can be inconsistent. This method is inefficient resulting in wastage of time and materials (polymer sheet and blades). It also has the addition downside of producing sharp tags in the rPET trays produced.

Tag-less cutting was developed in the third iteration cutting station design by machining grooves into the cutting anvil plate (Figure 15). This innovative prototype tool allowed cutting of the rPET tray profiles trialled, while maintaining linkages with the sheet to allow indexing between the cutting and staking stations. rPET trays produced during the trails were examine for the presence of sharp ‘tags’ and it was noted that tag were either not evident or were smooth or rounded and not an issue for overwrapping or safety (Figure 14b).

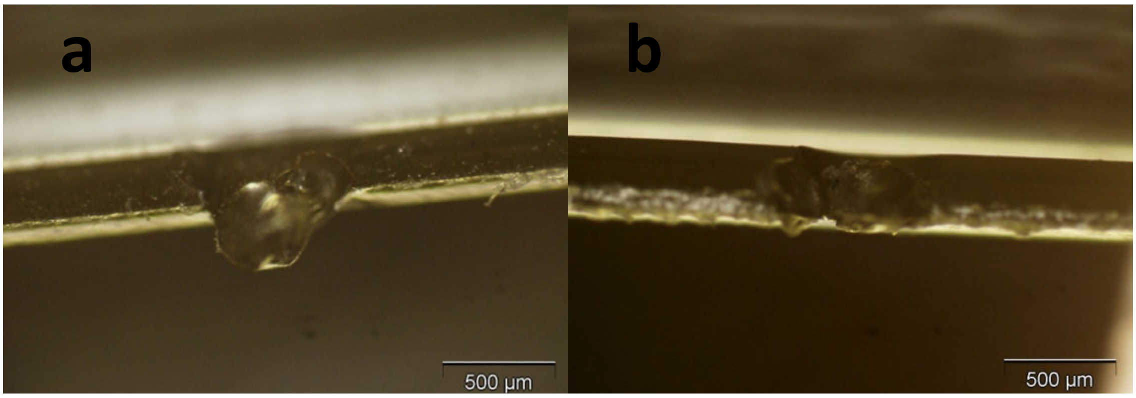

Figure 14: a. *(left) rPET tray flange with sharp tag produced from conventional nicked cutting blade,* ***b.*** *(right) rPET tray flange produced using "tag-less" cut prototype grooved anvil, tags where either not evident or had a smooth/blunt appearance*

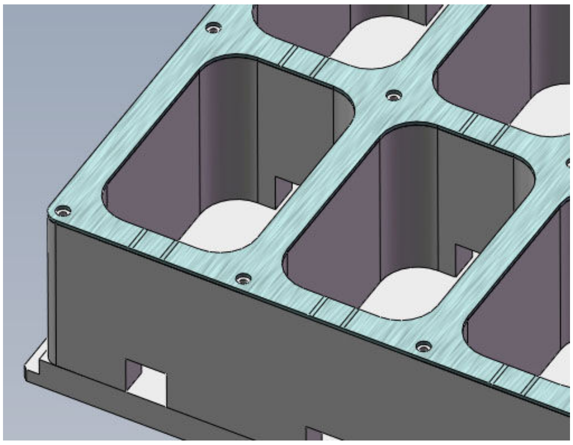

Figure 15: *Section showing "tag-less" cut on the anvil*

c. Stacking station

<u>Summary of first and second iteration tooling</u>

In the first and second iteration of the prototype cutting station design A/B and A/B/C stacking were introduced, a significant reduction in pusher mass was achieved, and the flipper design was modified from state of the art S shaped steel flipper to injection moulded polypropylene flipper.

<u>Third iteration tooling</u>

In the third iteration stacking station the pillar of the pusher unit was redesigned to further reduce the weight of the pusher. Using design innovation developed in this project the tool pillars have now been transformed from solid steel bar to extruded aluminium section to reduce the overall pusher weight while maintaining critical tool strength (Figures 16). The pusher weight was reduced to approximately 25 kilos and allows for the pusher to run smoother at higher speeds without causing strain on the machine. The reduction in pusher tool weight from 50kg to 25kg due to the innovation in this project has for the first time allowed for a SMED (Single Minute Exchange of Die) system to be introduced for tool changes

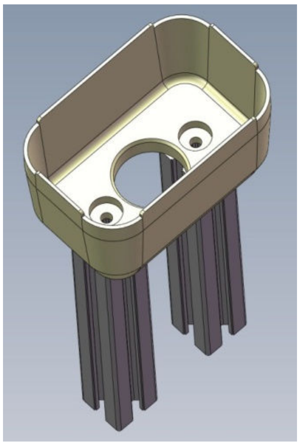

Figure 16: *Individual pusher locator with lightweight, high mechanical strength extruded aluminium pillars*

The injection moulded polypropylene flipper, developed in iteration 2 was prone to regular failure at high thermoforming speeds, which required replacement of the flipper and significant downtime. For the third iteration tooling a second innovative flipper design was developed and trialled. The flipper for the catcher was re-designed to a highly innovative concept, an extruded aluminium 2 part mechanical flipper with the moving parts enclosed in a casing and sprung loaded. (Figures 17). The prototype extruded mechanical flipper is light weight, yet it retained a high degree of mechanical strength. When integrated it reinforces the strength of the catcher plate allowing reduction in catcher plate thickness and light weighting of the catcher plate assembly. The design of this prototype mechanical flipper provided technological challenges as the two parts of this flipper had to be manufactured to extremely high tolerances (± 0.1mm accuracy) as early versions of the prototype flipper stuck in the closed position. In addition, it was noted in early trials that the prototype mechanical flipper could shift the stacked trays out of position as the moving component returned to the open position. Thus a prototype sprung loaded dampening mechanism was designed to efficiently hold stacked rPET trays in place. In prototype rPET thermoforming trials this innovative design flipper was highly effective in catching trays in the stacking process at high speed (up to 40 cycles per minute in an A-B-C stacking process). The advantages of this innovative prototype design in thermoforming of rPET are as follows. 1) it has a larger landing area, giving increased stability, 2) improved slide from location A to B, 3) the complete moving mechanism is protected inside the plate and 4) the prototype tool components are anodised for extended life.

Figure 17: Prototype extruded aluminium mechanical flipper

Potential impact and main dissemination activities and exploitation results

Overall business plan for exploitation of project results

The RPET-FC project has no only achieved all the planned deliverables set out in the project DOW, it has also achieved a number of developments in rPET material and thermoforming technology that were not originally envisaged such as the development of antimicrobial and antioxidant rPET packaging and the development of tag-less cutting during the rPET thermoforming process.

The range of material developments that have been delivered during the project include High IV 100% PCR rPET material, Enhanced Seal Formulation (ESF) rPET, high barrier rPET and antimicrobial and antioxidant active rPET. Thermoforming tooling developments include individual cooled flange clamping, floating cutters with heated blades, tag-less cutting, mechanical flippers and base tools with moving/rotating denest innovations.

Post project completion it is envisaged that the consortium will seek support funding under the Research for SMEs 'Demonstration action' to demonstrate the innovations in tooling and materials in high volume production trials to verify the commercial potential of the prototypes developed in the RPET-FC project. In order to demonstrate of the full commercialisation potential of the project, high volume, high speed, multi-cavity thermoforming tooling incorporating the innovative aspects of the prototype tools developed in the RPET-FC project will need to be manufactured in a wide range of tray profiles. This tooling will be used in full production trials to manufacture high volumes of the various innovative rPET formulations developed during the RPET-FC project, which will then be trialled by a number of selected major end users in the food industry throughout Europe. The following end users are aware of the innovations delivered in the RPET-FC project and have agreed to conduct full production trials with rPET prototype formulations, as soon as they can be delivered at the required high volumes at no cost to the end user other than overheads for production trials. Major potential end user of innovative rPET packaging developed in RPET-FC that have already expressed a keen interest in exploiting the research results include Moypark, Fernholtz, Cranswick, Monaghan Mushrooms, PSG, Tesco, Marks and Spencer, Albert Heinz and Muller. Once the innovative features of the rPET trays have proven successful for high speed, high volume automated food packaging process lines the consortium have received commitments from these end users to discuss long term contracts for the supply of innovative rPET packaging, which will help meet the carbon footprint reduction goals set by these companies.

Major end users in the British market have informed the consortium that post successful high volume production trials in their individual facilities, these end users are firmly committed to switching from their current industry standard virgin polypropylene food trays to innovative rPET formulation as this will ensure they not only achieve but surpass their environmental commitments, as signatories to the Courtauld Commitment on the use of environmentally packaging with increased levels of recycled content and lower carbon footprint.

Following demonstration of the wide range of potential product offering on offer from the innovative research conducted in the RPET-FC project to end users, the consortium will be in a much better position to widen the commercial scope of rPET to include modified atmosphere packaging application, packaging where uniform sealing is of critical importance and packaging where food shelf life is an issue.

Innovative rPET packaging supplied to selected end users during demonstration activates will include novel de-nest feature to facilitate highly automated de-stacking and packing process that are widely employed in end user food packing facilities. This will dramatically reduce, if not altogether eliminate material wastage and downtime at both thermoforming and end user facilities associated with poor release qualities of current state of the art rPET food trays.

Contribution of the individual SME partners to exploitation of project results

Based on the overall performance of the RPET-FC project, Holfeld Plastics have invested a further €2 million of their own money to purchase an FDA approved, EFSA compliant extruder with production capacity for 8,000 tonnes post consumer rPET with full contact approval. This will increase Holfeld's capacity from 10,000 tonnes to 18,000 tonnes and running at full capacity has the potential to increase turnover from €19 million to €34 million. Initial interest in the rPET prototypes trays developed has been very positive from leading end user in the food industry such as Moypark (northern Ireland), Cranswick (UK), Monaghan Mushrooms (Ireland), Fernholtz (Germany), LSG (Germany), Berryworld (UK), Berry Gardens (UK) Marks and Spencer (UK), Tesco (UK), Albert Heijn (The Netherlands).

Based on the initial feedback from end users Holfeld have secured interest in significant orders for new innovative material post successful demonstration of the versatility of the rPET trays developed. However, in order to meet the wide variety of food trays demanded by the market in the immediate future the consortium SME partners will have to invest a further €3-4 million in further research (€1-1.5 million) and demonstration activities (€2-2.5 million), in addition to the €2 million already committed by Holfeld Plastics in procuring processing equipment capable of converting an additional 8,000 tonnes of post consumer rPET material. This further investment will allow Holfeld to move from a relatively small niche market player in the European food packaging industry to the market leader in manufacturing of innovative rPET food trays in Europe.

Based on the success of the RPET-FC project, RecycleNet, one of the SME partners, has received full planning permission from the Irish government for the construction of a 20,000 tonne post consumer PET bottle recycling facility on the Holfeld manufacturing site in Arklow, Ireland which will come online by mid 2013. In so doing the site in Arklow will become the only one in Europe containing the full suite for postconsumer PET collection, sorting, washing and conversion back to food contact approval packaging and will become the first closed loop site for rigid rPET food packaging in Europe.

From project beginning to project end Holfeld plastics have increased their sales by 23% (€15.5 million to €19 million). This increase in sales has allowed Holfeld to purchase new equipment to increase manufacturing capacity by 80% (10,000 to 18,000 tonnes) in order to better meet the expected demand based solely on the limited number of prototype trays developed in the project, not considering the huge potential following demonstration of the full range of product offerings needed by the market place in the as yet untapped red/white meat, fruit, vegetable, fish industries.

Cumapol BV will provide speciality polyester materials to Holfeld to manufacture innovative rPET food trays with enhanced sealing and gas barrier performance. This partner will be heavily involved in demonstration activities with Holfeld plastics in proving the enhanced seal and high barrier rPET materials in the market place and will also invest further significant fund to achieve this.

Spiegelberg and Zinke GmbH – This partner continues to open up lines of communication with potential end users on continental Europe, especially in Germany, Austrian, The Benelux countries and France. Spiegelberg have identified the fresh red meat and yogurt sectors as markets with significant potential for high barrier and enhanced seal rPET trays. This market are currently utilising 100% virgin polypropylene trays which have higher carbon footprint, more weight and have poor barrier performance and are not currently recycled. The fresh meat food tray sector in Germany alone accounts for €500 million annually and is ripe for conversion to rPET trays as soon as trays with the correct specifications can be demonstrated to this sector. Major end users in this sector in Germany especially are very aware of their environmental responsibilities and anxious to switch to light weight, low carbon footprint alternatives with high barrier and enhanced sealing properties that can now be achieved with rPET. Spiegelberg has already secured commitments from major end users such as Fernholtz to switch to rPET trays developed in the rPET-FC project provided that the enhanced features of these trays can be fully demonstrated in large scale production runs in the high automated end user food packing and sealing lines.

The Label Company – This SME partner has developed a range of top films that will seal to rPET tray prototypes developed during the RPET-FC project. In combination with the innovative rPET trays these top films offer a complete product solution to end users and will be used in all future demonstration actions. This top film supplier will remain a strategic partner for Holfeld plastics and will benefit from the initial licensees that will be approved by the SME partners.

Three to five years following rPET-FC project completion, having successfully demonstrated the wide variety of tray product offerings required by the market place it is a certainty that the SME partners in the project will not be able to meet the huge increase in manufacturing capacity demand utilising their own resources. To address this problem the SME partners have agreed to licence their intellectual property to a number of carefully selected tray manufactures strategically located across the European Union.

Following successful demonstration and exploitation of the RPET-FC project results the consortium has employment targets for an additional 105 high tech jobs within the SME partners. This will include, Holfeld Plastics 35 addition staff, RecycleNet Ireland limited 55 additional staff, Cumapol BV, 5 extra staff, The Label Company 6 additional staff and Spiegelberg and Zinke GmbH, 4 additional staff.

Target for exploitation of each individual rPET material formulation:

100% PCW high IV rPET – Targeted at sectors of the food packaging industry which do not require consistent sealing to top film in their applications. E.g. Fruit, vegetables, mushrooms,

ESF rPET - Targeted at sectors of the food packaging industry which do require excellent consistency of sealing to top film even under potential food contamination of the tray sealing rim. E.g. Fresh red meat and poultry

High barrier rPET - Targeted at sectors of the food packaging industry which require trays with excellent gas barrier properties. i.e. Modified Atmosphere Packaging

Antimicrobial and antioxidant active rPET: Targeted at sectors of the food packaging industry where microbial contamination presents food safety and shelf life issues such as Poultry packaging. Sectors where oxidation of the packaged food is an issue for food aesthetics and taste such as the cooked meat packaging sector.

Target for exploitation of prototype thermoforming tooling developed during the RPET-FC project:

The following thermoforming tooling innovation have been delivered during the RPET-FC project, Flange clamping, Floating cutter, Tag-less cutting, Mechanical flipper and Rotating denest. These innovations will be protected by the consortium through a combination of patent and secret knowledge. Post high speed, high volume demonstration of the exploitable results of the RPET-FC project with selected major end users.

Upon successful demonstration of the actions envisaged, the consortium is convinced that their capacity to meet the future demand will not suffice. Consequently, the consortium have agreed to franchise the patent and secret knowledge built up during the RPET-FC project on thermoforming tooling and innovative rPET formulations to a number of strategically located thermoforming processors across the European Union.

Main dissemination activities

The consortium has conducted 21 separate dissemination activities in the course of the RPET-FC project. These included:

- Establishing a project website broadcasting the project to the general public and internally disseminating progress and project results to all members of the project consortium
- Presenting stands at 8 national and international food packaging and thermoforming tooling trade shows publishing the potential for the prototypes being delivered in the RPET-FC project
- Publications of 6 articles in scientific peer reviewed publications and technical magazines
- 1 article published in national newspaper in Ireland
- 1 presentation to industrial SME group on progress of RPET-FC project and benefits working in FP7 research for benefits of SME's programme
- 1 academic Masters (M.Eng) thesis to be published in January 2012 on work conducted by the student on the carbon footprint benefits associated with the RPET-FC project