BIODEGRADABLE PLASTIC CARRIER BAGS – SOLUTIONS THROUGH INNOVATION

Aquapak – Lot 1

WEO111 SBRI

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Contents

Figures

Introduction

The Defra SBRI call *Biodegradable Plastic Carrier Bags – Solutions Through Innovation* set the challenge of finding solutions and/or modifications that will enable the improvement of carrier bag manufacture, use, collection, separation, recycling and end-of-life processing. In particular it sought new ideas for quicker biodegradation of carrier bags in different natural environmental conditions.

The aim of Aquapak Polymer's work across both Lots 1 and 2 was to prove their polymer (part of the AP family of products) was biodegradable and recyclable as a flexible film. Whilst Lot 2 investigates the recyclability, Lot 1 focused on the biodegradability of the AP product in composting, anaerobic digestion and marine environments. The key point of this feasibility report is to demonstrate from the literature that the formulation blend used by Aquapak is biodegradable under various environmental conditions.

Consortium Partners

The consortium is made up of three companies whose expertise is considered to be one of the highest in the UK. In brief these companies are:

Adi Group Ltd (ADI): With mechanical & electrical engineering expertise, as well as process control and software engineers, their technical resource will significantly help integrate new detection & separation processes into existing waste management plants.

Aquapak Polymers Ltd (APL): This is the R&D company who have developed the hydrophilic polymer technology around flexible packaging from a blown film technique. Their patented process is being developed further for automation Gluco Technology Ltd.

Euro Packaging Ltd (EPL): Euro Packaging is a uniquely integrated sales, distribution and manufacturing operation with significant expertise in a range of paper and plastic based packaging products.

Work Packages

The feasibility study into the biodegradability and functionality of the AP product has been delivered in two distinct work packages. The first is a scientific work package; it focuses on the rate and extent the AP film's biodegradability in various environments. The second, a technical work package, focuses on the functionality of using the Aquapak product for the manufacture of carrier bags.

Scientific Objectives

Objective	
1	Scientific literature review investigating the biodegradability of the AP product under natural and waste treatment environments
2	Understanding of the AP film biodegradation rates in sea water using an established marine test. Examine marine life digestive system responses to ingested AP film.

Technical Objectives

Objective	
1	To understand any issues with bonding and sealing of the AP film to form bags.
2	To introduce colour using dyes and pigments into the formulation to satisfy the brand identification.
3	To identify printing inks suitable for AP films taking into account the need for an acceptable end-of-life disposal method.

Biodegradability of AP Films

Biodegradable polymers can be divided into two main categories: petroleum-derived and microorganism-derived biodegradable polymers. The AP film is currently petroleum-derived and is used extensively in aqueous solution for film casting, textile coating and as a binding agent in the paper industry. The AP films can also be derived from a renewable source such as sugar cane, however the costs for such a process haven't yet been introduced as a feed stock for the AP films.

The biodegradation of plastics in the environment and waste treatment processes is controlled by two factors: (1) exposure conditions and (2) polymer characteristics (Figure 1)

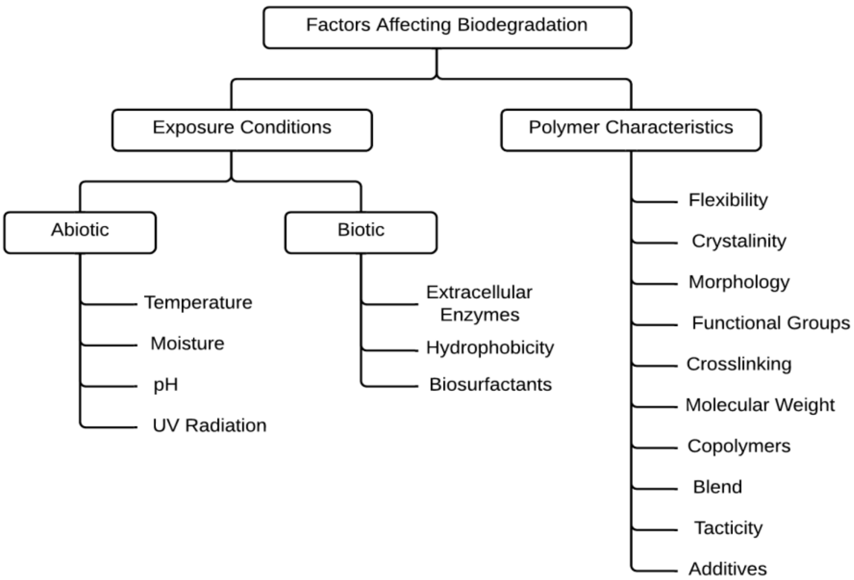

Figure 1 Factors affecting biodegradation. Diagram based on Kijchavengkul, T. and Auras, A. [1]

The base material of the AP film is regarded as one of the truly biodegradable polymers in the environment. It is manufactured in fully or partially hydrolysed form and is one of very few vinyl polymers that are hydrophilic and soluble in water[2, 3] thus making it susceptible to biological breakdown in the presence of the correct microorganisms. Those microorganisms however appear to be associated with hydrophilic contaminated sites and/or very specific environments such as paper mill and textile effluents[3-6.]

The first reports of biological mineralisation of the hydrophilic material were in the 1930's where Nord[8] demonstrated hydrophilic breakdown by the fungi *Fusarium oxysporum f.sp. lini*. More recently, numerous (>50) microbial organisms have been successfully identified[9, 10] as capable of hydrophilic degradation. For the most part these organisms are Gram-Negative bacteria, such as *Alcaligenes spp* and *γ-Proteobacteria,* which are all prevalent in the natural environment. Some Gram-Positive bacteria (e.g. *Bacillus spp Paenibacillus spp*) that can be found in thermophilic microbial communities in solid-waste composting systems[11] have also presented hydrophilic degrading characteristics. Enzymes secreted by fungi also appear to play an important part in biodegradation under composting conditions[12]. Fungal strains such as, *Apergillus niger, Pycnoporus cinnabarinus, Fusarium* and *Phanerochaete chrysoporium,* have all been reported to change the surface texture/roughness of the hydrophilic film, thus facilitating further microbial activity[13, 14].

The mechanisms involved in microbial degradation of hydrophilic film are dependent on the oxidation of one or more of the polymer's chemical/physical bonds. This process is enzyme specific and influenced by temperature. Kim, et al.[15] suggest the optimal temperature and pH for enzymatic decomposition of hydrophilic film is between 30-35°C and *c*. pH 8.0 respectively.

Aerobic Composting

There has been limited scientific investigation regarding the biodegradability of hydrophilic film under composting conditions. The work that has been undertaken shows that it might degrade slowly in this environment. For example, Chiellini, E. et al.,[7] reviewed the scientific evidence up to 2003 and cited experimental work, including their own[16], that showed limited mineralisation under compost conditions, e.g. 7% in 48 days within stabilised compost taken from urban solid waste. Alternatively, Jayasekara, R.[18] tested (BS EN ISO 14855) the biodegradability of several starch/hydrophilic polymer/glycerol polymer blends over 45 days and found that all the blends degraded to leave the hydrophilic polymer component virtually intact. There is a clear need for further investigation in this subject area.

Anaerobic Digestion

There are only a few reports published on the biodegradability of hydrophilic film under anaerobic conditions. Matsumura, S. et al.,[20] tested the biodegradability of the AP base material with molecular weights of 2000 and 14,000 in anaerobically pre-incubated activated sludge and river sediments. Biodegradation of the low molecular weight sample within the river sediment equalled *c*. 75 %, whereas the high molecular weight reached 50-60 % after the same incubation period (at *c*. 125 days of experimentation). Biodegradation rates of hydrophilic film within the anaerobically treated sludge equalled 45-50 % and 35-40 % in the high and low molecular weight respectively, after the same time period. However, in contrast to these positive indications of biodegradability, Gartiser, S. et al.,[21] only found between 0 and 12 % biodegradation in 77 days using ASTM D 5210-91 and ISO 11734 test methods.

Although scientific studies suggest that hydrophilic film could be biodegradable under anaerobic conditions, it is evident that more experiments are required to test how molecular weight, the anaerobic environment and the polymer blend influence the degree and rate of biodegradation.

Biodegradation in the Natural Environment

A scientific literature search using a combination of the words “hydrophilic, marine and seawater” returned no scientific articles by the Web of Science search engine. To provide an indication of marine biodegradability The Open University conducted a sea water inoculum experiment as part of this study. A standard method (ASTM D6691) for determining aerobic biodegradation of plastic material in the marine environment was used as the basis of the experiment. In this method, biodegradability is assessed by determining the proportion of polymer-C converted to biogas-C. Percentage mineralisation is calculated as a fraction of the measured versus the theoretical carbon content of the test material. The test was run for only five days but an encouraging 9% mineralisation was measured. This measured biodegradation rate is higher than those reported for terrestrial environments, which may be explained by the solubility of the plastic in water and subsequent bioavailability to microorganisms.

This quick scoping experiment showed that the AP film is potentially biodegradable in sea water. This study needs replicating and expanding to fully understand the behaviour of AP film in this type of environment. In particular, the impact of changing temperature on the AP film degradation rate should be examined.

Marine life Impact

The AP base material has been used as a method of drug delivery for many years now and has been deemed medically safe as the unhydrolysed polymer easily dissolves in aqueous solution[31]. However, the process of hydrophilic dissolution is not the same as hydrophilic decomposition[32]. There is a paucity of knowledge with regard to the effects of dissolved hydrophilic film on aquatic fauna and flora. The effect of dissolved hydrophilic film on whole organisms has yet to be investigated for species other than humans.

Summary

Based on the literature review it is clear that hydrophilic film in both natural and waste treatment environments has shown varied degradation rates. The findings (apart from the OU’s marine test) are based on standard hydrophilic film and not the AP-60 class proposed by Aquapak.

Recommendations:

- Using international standardised methods undertake a comprehensive analysis of the biodegradability of AP60 class material in a variety of different natural and waste treatment environments.
- Test the hypothesis that adding hydrophilic degrading organisms into waste treatment environments would enhance degradation of hydrophilic based materials.
- Investigate the impact of AP60 on marine life by performing a series of microcosm incubations, designed to emulate the natural microbiome of key marine organism's intestinal flora.

Using Hydrophilic Film

Achieving the required mechanical properties from the hydrophilic material is vital for its commercial success. A series of small technical objectives have been undertaken which aimed to prove that APL's AP60 can be used for carrier bag manufacture.

The major users of carrier bags are supermarkets and retail chains that normally take every advantage for advertising or to re-enforce brand image. It is already known from in-house trials that AP60 accepts standard printing inks and since hydrophilic fibres have been in use for many decades it is also known that the polymer accepts many dyes and pigments. The main issues to be resolved are (a) the matching of the colour schemes of the main end users of carrier bags, (b) ensuring that the colouring agents are not only compatible with a hydrophilic film but that they do not destroy the desirable environmental properties of the material, and (c) the colourant has little or no impact on the physical properties of the hydrophilic derived carrier bags when in use.

Polyolefin-based masterbatch materials commonly used for plastics such as PE are thermodynamically incompatible with hydrophilic polymers. One potential alternative is to use dyes for colouring the hydrophilic film. It is however important to select the right class of colorant for any particular end-use and to ensure that the colours selected have no deleterious effect on either the intrinsic properties of the hydrophilic polymer or the processing methods used for the manufacture of hydrophilic film. The same is true for the printing of the carrier bags.

Having the ability to communicate to consumers via printing on a bag is a 'must have' for many leading brands. Whilst it can be argued that the type of ink used on packaging does not overly affect its biodegradability (due to the comparative small amounts), there is a need to identify and test more sustainable and natural sources of ink to eliminate any potential of (ink) contamination at the product's end-of-life disposal.

Two potential alternatives to solvent inks have been identified:

1. Water based ink
2. Soy/Vegetable based ink

Based upon an understanding that there is no need to pre-treat hydrophilic film prior to any printing process, a preliminary printing trial using both Rotogravure and Flexography printing equipment on non-Corona treated film (both in the UK and Malaysia) was commissioned.

Initial observations concluded that the ink adhesion is excellent, with no signs of ink lift, even immediately after the ink has been applied to the film (determined using a manually applied adhesive tape lift test). The trials have therefore additionally proven the initial feasibility of running hydrophilic film through mass manufacture printing equipment. From the initial solvent based print trials already completed (using a number of retail style print designs), it was possible to establish that ink intensity and spread is excellent on hydrophilic film, as is print definition and edge clarity. There were also no signs of ink streaks or bleed.

Lastly it was vital to determine the ability of APL's material to be formed into a bag. As such an automated seal process using the hydrophilic film was commissioned. The test was designed to tackle three key variables, namely:

- Temperature: At what temperature should the seal bar be set at in order to melt the polymer and create a seal?
- Time: How long should the seal bar be held in position in order to create the right seal?
- Pressure: What pressure should the seal bar apply in order to generate heat transfer across the thickness of the film?

The results from the practical tests were conclusive and provided the required information on sealing temp, machine speed and residence time, from which the conclusion of a ‘very good seal’ was achieved.

Some of the properties not discussed in this report but warrant being highlighted are:

- High strength, tear and puncture resistance
- Anti-Static properties which will protect sensitive electronic components
- Solvent, Oil and Gas inhibitor – significant offshore oil application
- Hydrophilic – breathable membrane which extends fresh food shelf life
- Can be processed with biodegradable and/or water soluble colours and inks

Conclusion for Lot 1 – Phase 1

The project set out to prove that a hydrophilic formula used to produce the AP60 variant by APL is a biodegradable and recyclable flexible film. The literature review has identified from historical papers that hydrophilic film has some inherent biodegradable characteristics. However it is unclear at this stage the exact rate and extent of biodegradation which can be achieved and whether AP60 might offer enhanced results.

If successfully proven a fundamental property of AP60 would be its ability to be biodegradable in seawater. The test carried out by The Open University offer a positive starting point towards this. Furthermore the suggestion that the film could be harmless to the fish digestion system should also warrant further research. Another opportunity which hydrophilic film offers is the ability to ink and colour the carrier bag using biodegradable and/or water soluble pigments and dyes not achieved previously for PE.

There is clearly a lack of primary data needed to address the questions around hydrophilic polymer’s biodegradability, but with a comprehensive testing regime this is achievable and the case for AP60 can be made.