

The performance of degradable polymers within wastes management

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Abstract

The use of degradable polymers for the collection and composting of organic wastes is explored within this paper. With reference to one trial where the performance of a 'degradable' polyethylene based sack for the kerbside collection of organic wastes was investigated. Areas for consideration were the impacts of the degradable polymer on the composting process and the quality of the finished product.

The above trial also included a comparative study of two different types of 'degradable' polymer sacks currently on the European market (polyethylene and starch). A number of quantitative tests were conducted on the different polymers to assess the mechanisms of degradation and how this affected their suitability for the treatment of organic wastes. In this comparative study, a designated number of samples of the different polymers were contained within a 'mesh bag' and buried one metre into an open windrow comprised of green waste. The samples were extracted and weighed at given intervals.

Provisional results have indicated that the polyethylene (PE) sacks are not degrading as anticipated within open windrow conditions, adversely affecting both the composting process and the quality of the finished compost product. Whilst the degradable starch based sacks appear to actively degrade within compost conditions.

1 Introduction

In the UK, the proportion of compostable organic garden waste fluctuates both seasonally and geographically and is highly dependant on other factors such as types of housing, proximity to bring sites and other recycling initiatives [1]. Data collected via waste auditing conducted by the Organic Resource Agency suggests that garden waste can make up between a fifth to a half of the total weight of household waste generated.

The implementation of the European Landfill Directive in July 2001, limiting the amount of organic waste going to landfill, and the forthcoming Directives on Composting and Biodegradable Wastes, means that an increasing number of UK Authorities have begun implementing kerbside collections of household organic waste to fulfil their regulatory obligations.

The work reported within this study is based on a pilot study conducted within the UK to assess the performance of degradable polymers for the kerbside collection of organic wastes.

2 Biodegradable polymers

Biodegradable polymers can be broadly divided into three categories[2]: -

- Natural Biodegradable Polymers
- Synthetic Biodegradable Polymers
- Modified Natural Biodegradable Polymers.

Polymers have been purposely designed to resist degradation. The challenge is to now design polymers that have the “necessary functionality”[3] during their use and then degrade under specified environmental conditions.

Substantial work on polyethylene (PE) degradation has been conducted in Sweden by Prof. Albertsson[4]. She concluded that degradation of PE occurs at a rate of approximately 0.5% of weight per annum. PE is a chemically inert polymer[5]. The biodegradation of PE is primarily effected by irradiation from a UV source and other factors such as molecular weight, additives and surface area[5], whilst micro-organism attack on PE is a secondary process[6]. Fungi and bacteria in their metabolism use carboxylic acids formed in biodegraded PE, but this has no effect on the rate of degradation observed[7]. Further studies [8] have categorically stated that “Polyethylene is not readily metabolised by living organisms and so must be considered for all practical purposes as non-biodegradable”. Polyethylene, however, will degrade over a period of time and thus could said to be degradable.

3 The degradation process

The word degradation implies a loss of properties. The trigger for degradation could be a “microbially, hydrolytically or oxidatively susceptible linkage built into the backbone of the polymer” or alternatively “additives that catalyse breakdown of the polymer chains”[3]. This ‘trigger’ can be specifically designed to ensure degradation does not occur within the ‘in-use lifetime’ and to also ensure that degradation occurs upon disposal within a given environment. Degradation will ultimately depend on several factors such as the microbial activity of the environment, the surface area of the polymer, temperature, pH, molecular weight and polymer crystallinity.

Polymers can degrade in a variety of ways through reacting with: -

- Sunlight (photo-oxidation)
- Bacteria (presence of species-correct micro-organisms)
- Chemicals (oxidation processes, including moisture, including or excluding oxygen)
- Macro-organisms (invertebrates and insects)

Degradable polymers can be made more attractive to macro-organisms by incorporating “feeding stimulants”[9] such as starch, as starch is a natural food to many insects possessing amylase digestive enzymes. This trait has been evident in our research to date, where starch based bags filled with organic wastes have been significantly more active with macro-organisms than the PE based products.

The most aggressive degradation processes in the ‘outdoor’ environment are photo- and thermo-oxidation. Within a composting environment thermo-oxidation plays the dominant role in degradation, since temperatures can easily exceed 60-70°C for a prolonged period of time even during the UK’s colder months. Ageing and weathering are also important factors.

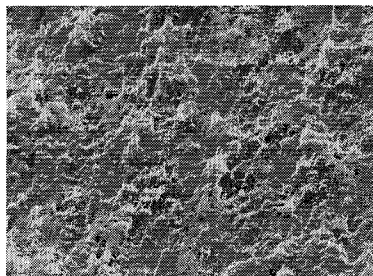
Biodegradable plastics are attacked and disintegrated by enzymes from naturally occurring micro-organisms (such as bacteria and fungi) encountered under specific conditions found in soils and composts. The micro-organisms digest the small fragments of the macro-molecules. The end products of this metabolic process are then excreted and become part of the natural cycles of materials. Micro-organisms need food (nutrients); thus the rate of nutrients available also has a direct influence on the rate of degradation. Moisture is also an important factor affecting microbial activity in composting and ultimately the rate of degradation. Too much moisture will create anaerobic conditions, whilst if too dry, the microbes will dehydrate.

In order for micro-organism degradation to take place, the micro-organisms need to be able to adhere to the surface of a polymer. Thus polymers that have a rougher surface finish will be more prone to microbial attack. The following Scanning Electron Microscopy (SEM) images highlight the differences in surface texture of different degradable materials. Both images are from the film manufactured into the sacks used for the kerbside collection of organic materials.

The starch based polymer film has a much rougher surface texture than the PE based film.



Polyethylene



Starch

Plates 1 & 2: SEM Images of degradable PE and a degradable Starch film product. Magnification X500.

4 Degradable polymers for the kerbside collection of organic wastes

Degradable polymer bags can help facilitate hygienic and sanitary collection of organic wastes from households. They can help control the release of odours and can limit insect infestation during the collection and transport stage.

Polymer bags also reduce the requirement for washing collection receptacles by acting as a liner. They can also (if properly sealed) control the release of liquids from the waste during the transport phase. This can effect the type of vehicle used for the collection, the frequency of the collection, as well as reducing the contamination of other recyclables within the domestic refuse stream. It is felt that biodegradable plastics have great potential for the kerbside collection of organic wastes from some households and small organic producers because:-

- Unlike bins and other receptacles they can be produced to be transparent, thus allowing collection operatives to easily ascertain any contamination.
- Bags can be produced in a wide variety of different sizes to correspond with different needs. (For example, tenants living in a high rise block of flats would not require the same organic collection capacity of a householder with a garden).
- Bags are more 'collection friendly' for some applications
- Bags will not require any changes to collection vehicles, such as the addition of bin lifting equipment, where the residual waste is collected using a bag system.

5 Trial conditions

The trial consists of organic garden and selected kitchen waste being collected from 2500 households using a degradable PE sack. The filled sacks are collected fortnightly from the householders and then composted using the open windrow method. The waste collected via the PE sacks is kept separate from any other wastes to ensure there is no cross contamination.

Monitoring of the composting process and the resulting compost products is essential to ensure that the degradable sacks did not have a detrimental effect on either the composting process or the compost product.

It is essential that the compostability of the bags corresponds to the composting technology employed at that site. In practical terms this means that the bags (and all bag material), must have visually disappeared through decomposition within the composting time-frame which is 8-12 weeks for most open windrow composting techniques employed within the UK.

5.1 Measurement of Weight Loss

Measuring weight loss in a polymer sample is a cheap and easy way to establish a rate of degradation. However, it is not always accurate. For polymers that have been 'incubated' for a period of time there may actually be a weight gain as a result of micro-organisms colonising the polymer. Degradation is initiated at the surface of a polymer, thus weight loss is proportional to the surface area[5], and is therefore calculated as weight loss per surface area rather than percentage weight loss. However, for the starch based samples that experienced severe degradation throughout their matrix, percentage weight loss was considered to be an appropriate measurement.

To accurately assess polymer weight loss over a controlled period, pre-weighed polymer samples were secured in mesh bags. A series of these samples were then buried one metre into an open windrow of the collected organic waste. Individual samples were then removed periodically, and re-weighed to establish weight loss and visual degradation over time.

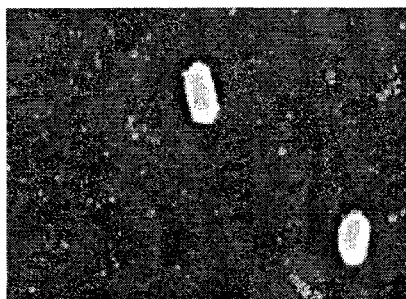
The polymer samples within the mesh bags had been cut from 'compostable' sacks supplied by the relevant companies, into a single ply sheet of approximately 200 by 300mm. Each polymer sample was then folded in half (to limit the amount of detritus on each sample) and then weighed to two decimal places in laboratory conditions before being contained within one of the mesh bags.

It was essential to ensure that the degradation process ceased upon removal from the test environment so that the results were not invalidated should there be a delay before analysis. To ensure degradation ceases, it was necessary to carefully brush and/or wash the degradable polymer sample with a soap solution and then carefully dry it before analysis in order to remove any detritus and micro-organisms. Some biodegradable polymers are sensitive to moisture, particularly those from starch sources (as starch is hydrophilic). Due to the low

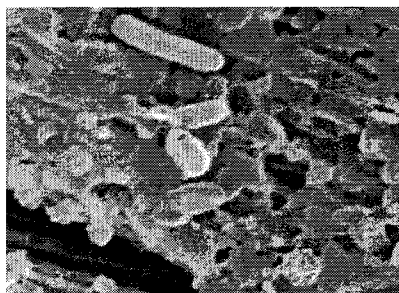
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initial weights of the samples the smallest amount of detritus could impose a large degree of error.

To visually quantify the amount of degradation experienced by the polymer samples, the experimental procedures were repeated using the same polymer and the extracted samples were subjected to SEM analysis. To obtain detailed and accurate SEM images, the samples had to be left unwashed and analysis took place within 24 hours from removal. SEM also provided a good indication of micro-organism and fungi activity.



Polyethylene



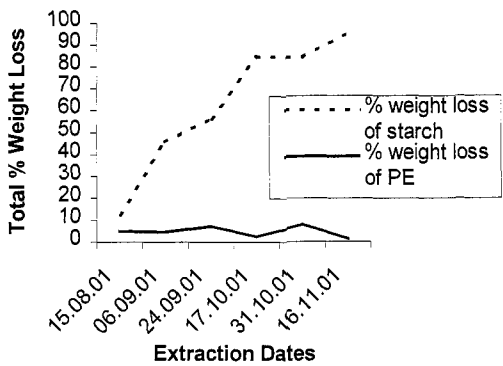
Starch

Plates 3 & 4: SEM Images of degradable PE and a degradable starch film product after 28days within an open windrow. Magnification X3000.

The previous SEM images contrast the different rate of degradation of the two polymers after 28 days exposure within open windrow conditions. The first image clearly shows that the surface of the PE sample does not show any signs of degradation. Whilst the second image of the starch based product clearly shows the breakdown of the integrity of the film.

The SEM images also show the strong contrast between the amount of microbial activity on each of the materials. Throughout the trials, the SEM analysis has consistently demonstrated that the number and variety of species of micro-organism on the PE samples is more limited than those found on the starch based product. Also no fungus spores have been detected on the PE samples. Fungus is an important organism in the degradation of organic matter during the composting process.

The graph overleaf shows the percentage weight loss results obtained for two different degradable polymer samples on the UK market.



Graph 1: Percentage polymer weight loss over time

The above weight losses were calculated as percentage weight loss values and statistically analysed using the Wilcoxon matched pairs design, with the resulting probability of 0.028 which is significant at the 5% level. Thus the percentage weight loss experienced by the starch product over 15 weeks is significantly greater than the percentage weight loss experienced by the PE product.

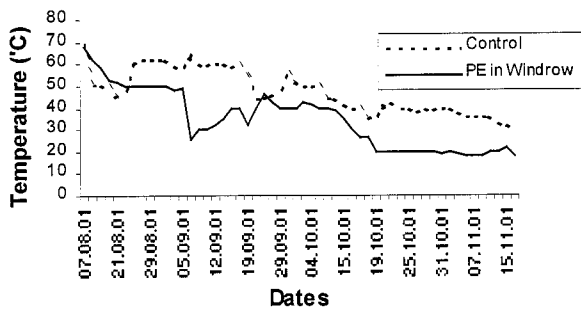
No ‘visible’ degradation had occurred to the PE samples, yet the slight weight loss implied that some degradation had taken place. The SEM images of micro-organisms attached to the surface of the PE could indicate that the surface of the polymer was being degraded, though no visible evidence of this could be ascertained during the SEM process.

5.2 Monitoring of Windrow Temperatures

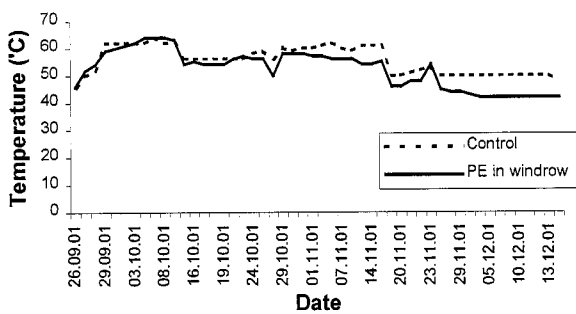
A good compost windrow temperature profile is essential to demonstrate that the composting process has been effective in both degrading the organic matter content to a stabilised and useable product, but also ensuring that sterilisation/pathogen kill has been achieved.

Monitoring of windrow temperatures is undertaken daily by the site operator, with temperatures being recorded onto specialised forms. These forms also record the windrow turning frequency data. The graphs overleaf show the temperature profiles of the windrows containing the PE in addition to the temperatures of green waste windrows composed of the same feedstock.

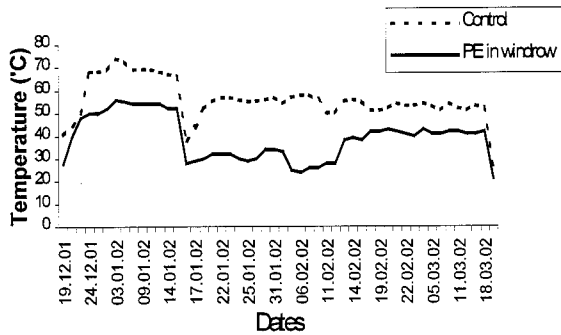
Windrow (1) Temperatures



Windrow (2) Temperatures



Windrow(3) Temperatures



The previous temperature graphs show that the temperatures achieved within the windrows containing the PE, are consistently lower than the temperatures achieved within the control windrows containing only kerbside collected green waste.

5.3 Chemical Analysis of Composts

One of the methods used to assess the impact of the PE on the finished compost product is to conduct chemical analyses on a representative sample of the compost matrix. The chemical analysis includes parameters related to the progress of the composting process and suitability for the final use of the compost, such as the carbon to nitrogen ratio (C:N), pH and electrical conductivity. Other parameters are associated with levels of metal contaminants such as lead, mercury, iron and cadmium. Metals tested within the chemical analysis also included the constituent metals present within the PE in order to facilitate its' increased degradation.

Chemical analysis conducted to date has shown that the C:N ratio of the windrows containing the PE are higher than the C:N ratio for the green waste windrows containing no PE. A low C:N ratio is desirable as it shows that the soluble carbon is being degraded and released as carbon dioxide, thus causing a decrease in carbon relative to nitrogen, decreasing the C:N ratio. The feedstock (kerbside collected uncooked fruit and vegetable waste and garden waste) and treatment on-site of the two windrows is the same. The only difference is that the organic waste is contained within the sealed PE bags until the shredding process. It is hypothesised that the period of containment for the organic waste is causing the conditions within the sealed PE bags to turn anaerobic. Anaerobic conditions would inhibit the aerobic composting process, resulting in a reduction in achieved composting temperatures. This hypothesis is being tested using gas analysis of the conditions within the PE bags containing organic wastes.

Other factors affecting the C:N ratio could be the lack of mixing that the organic material contained within the PE bags receives or the composition of the waste. A waste audit is to be undertaken to establish the ratio of kitchen to garden waste to include sub-sampling of this waste for chemical analysis.

6 Conclusions

The research to date has indicated that degradable polyethylene products marketed for the kerbside collection of organic waste may not be suitable for open windrow composting. Early indications from the research undertaken demonstrates that the polyethylene negatively impacts on the open windrow composting process by substantially reducing temperatures within the windrows and also negatively impacting on the end compost product. The PE within the windrows is highly visible, even after the complete twelve week composting phase.

There has been a noted increase in the volume of polymer throughout the composting process, due to a reduction in the volume of green waste of up to 60% but a markedly smaller reduction in the amount of PE. This has resulted in finished compost with a visibly high proportion of polymer that will require screening prior to marketing.

On-going research into this trial includes tensile strength testing of the PE and starch based product throughout its in-use life-time, gas analysis of the organic matter throughout its containment within the PE sacks in addition to householder participation surveys. This research when brought together seeks to answer the question of the appropriateness of using degradable polymers for the kerbside collection of organic wastes.

In order for the degradable polymer sack to be successful for the collection and treatment of organic wastes, it must provide problem-free processing at the compost plant, whilst providing problem free use by the householder. There is a delicate balance between a reasonable service life and the requirement for rapid degradation upon composting. It is essential that the trials conducted as part of this ongoing research and comparable trials conducted elsewhere, demonstrate beyond doubt that degradable polymers have a beneficial and unrivalled application within the waste management industry for the kerbside collection of organic wastes.

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