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The Performance of Degradable Polymer Bags

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Summary: 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. This 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. 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 open windrow compost conditions.

Keywords: biodegradable; polyethylene (PE); scanning electron microscopy; waste

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 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.

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Biodegradable Polymers

Biodegradable polymers can be divided into three broad 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 concluded that degradation of PE occurs at a rate of approximately 0.5% of weight per annum[4] even though 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 be said to be degradable.

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 characteristic has been evident during this research, where starch based bags filled with organic wastes have been significantly more attractive to macro-organisms than the PE based product.

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 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. As micro-organisms need food (nutrients) the rate of nutrients available 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. Scanning Electron Microscopy (SEM) techniques have highlighted the differences in surface texture of different degradable materials. Starch based polymer films have rougher surface textures than the PE based film.

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 storage, collection and transport stages.

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. Biodegradable plastics have great potential for the kerbside collection of organic wastes from some households and small organic waste producers as they can be produced to be transparent, allowing collection operatives to easily ascertain any contamination. Bags can be produced in a wide variety of different sizes to correspond with different capacity requirements. (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) and 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.

Pilot Study

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

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

It was essential that the compostability of the bags corresponded 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.

Measurement of Polymer Weight Loss

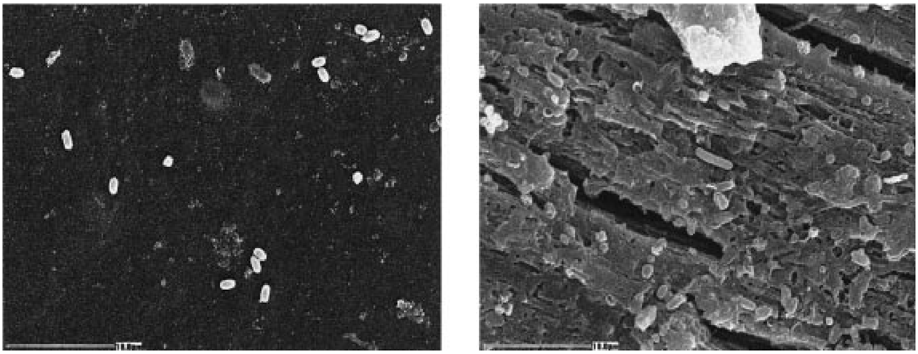
Measuring weight loss in a polymer sample is a cheap and easy way to establish a rate of degradation. However, it is not always accurate. For polymers that have been 'incubated' for a period of time there may actually be a weight gain as a result of micro-organisms colonising the polymer. Degradation 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 deep 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 300 mm. Each polymer sample was then weighed to two decimal places in laboratory conditions before being contained within a mesh bag.

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 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.



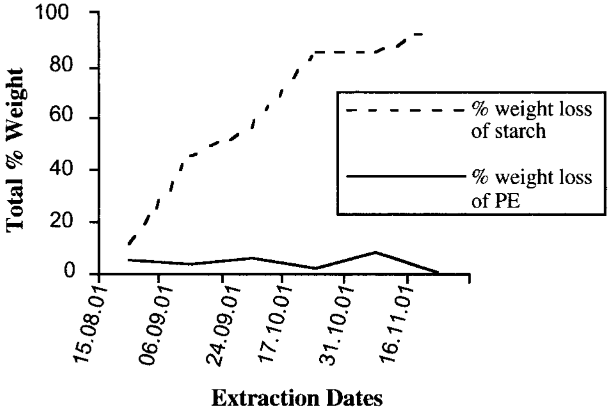
Polyethylene **Starch**

Plates 1 & 2: Scanning Electron Microscopy (SEM) images of degradable PE and a degradable starch film product after 28 days within an open windrow

The 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 differences in the surface texture of the polymers is also clearly defined. The textured surface of the starch based product making it more susceptable to microbial and fungal attachment.

There is also a 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 later phases of the composting process.

Graph 1 shows the percentage weight loss results obtained for two different degradable polymer samples on the UK market.

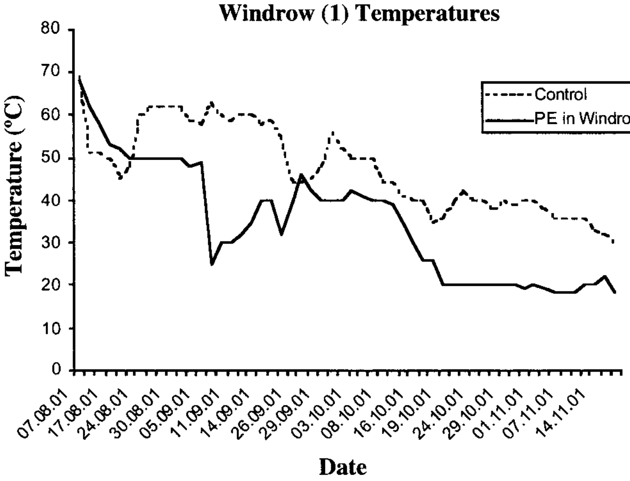


Graph 1: Percentage polymer weight loss over time

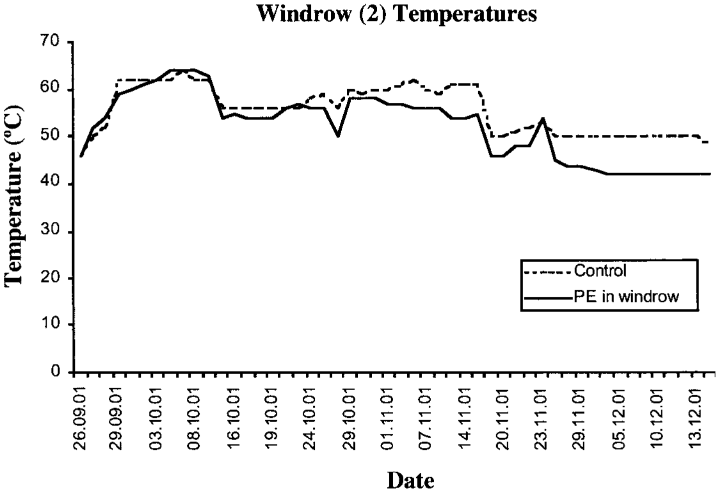
The weight losses contained within Graph 1 were calculated as percentage weight loss values and statistically analysed using the Wilcoxon matched pairs design, with the resulting probability of 0.028, which is significant at the 5% level. Thus the percentage weight loss experienced by the starch product 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.

Monitoring of Windrow Temperatures

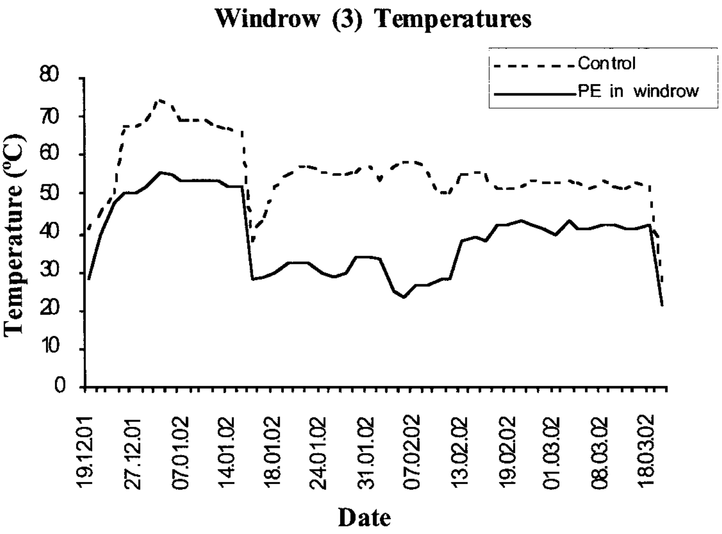
A good compost windrow temperature profile is essential to demonstrate that the composting process has been effective in both degrading the organic matter content to a stabilised and useable product, but also ensuring that sterilisation/pathogen kill has been achieved. Monitoring of windrow temperatures is undertaken daily by the site operator. Graphs 2 to 4 show the temperature profiles of the windrows containing the PE in addition to the temperatures of green waste windrows composed of the same feedstock.



Graph 2: Windrow temperature profile of the first set of windrows within the trial



Graph 3: Windrow temperature profile of the second set of windrows within the trial



Graph 4: Windrow temperature profile of the third set of windrows within the trial

Temperature graphs 2 to 4 show that the temperatures achieved within the windrows containing the PE are consistently lower than the temperatures achieved within the control windrows. The control windrows are composed of kerbside collected green waste from residents using 140 litre wheeled bins for collection and storage of green wastes as opposed to PE bags.

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 bin collected organic waste windrows that contain 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, vegetable and garden waste) and treatment on-site of the two windrows is the same.

A waste audit of the feedstock materials conducted during April 2002, noted that there was a notibly higher proportion of kitchen waste to garden waste within the polyethylene bags as opposed to the kerbside organic waste collected using a wheeled bin collection system. Sub-sampling of the separated kitchen and garden wastes from the PE bag and wheeled bin collection rounds was undertaken with the sub-samples subjected to chemical analysis. The chemical analysis showed that the C:N ratio of the organic kitchen wastes was significantly higher than C:N ratio of the organic garden waste. This was an unexpected result as garden waste typically has a higher C:N ratio that domestic kitchen waste. However, the amount of carbon present for both the kitchen and garden waste was similar, but the nitrogen levels within the garden waste were considerably higher. The high nitrogen levels of the garden waste was attributable to the large proportion of grass clippings, which comprised of a large percentage of the garden waste at the time of the audit.

The C:N ratio of the finished compost from the PE bag collected waste has been continually higher than the C:N ratio of the bin collected waste for the duration of the trial. Other factors affecting the C:N ratio may be as a result of the lack of mixing that the organic material contained within the PE bags receives.

The organic waste is also 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 contents 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 currently tested using gas analysis of the conditions within the PE bags containing organic wastes. Gas analysis of the windrows containing the shredded PE bags is also being undertaken. The results are being compared with open windrows containing kerbside collected organic wastes using 140 litre wheeled bins.

The waste audit also revealed that the PE bags comprised of approximately 1% of the total weight of organic matter collected. However, by completion of the composting process, screened samples indicated that the PE comprised of 4-6% of the total weight of organic matter. Contamination levels fluctuated between the PE bag and bin collection systems. The highest level of contamination recorded during the duration of the waste audit was for an area using the PE bag system. The single largest contamination materials within the organic waste was paper (absorbent paper towelling) and cardboard. Most of this type of contamination can be attributed to kitchen generated waste arisings. Although small quantities of organic paper materials do not pose a negative effect on the composting process, large amounts can pose a litter problem on open windrow composting facilities and can cause additional odour.

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 reducing temperatures within the windrows.

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 requires fine 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 it's containment within the PE sacks and householder participation surveys. The weights and quality of the incoming kerbside collected organic wastes from the pilot areas using the PE bags are also monitored and compared with areas using alternative kerbside collection receptacles such as wheeled bins.

This research, when brought together, seeks to answer the question of the appropriateness of using degradable polymers for the kerbside collection of organic wastes. Currently, the main barrier to wide-spread adoption of degradable sacks for the kerbside collection of organic wastes within the UK is cost. The cost of degradable sacks is viewed by many authorities as being unsustainable, particularly against alternative collection vessels such as bins. This is due to the higher purchase costs of degradable bags and the additional frequency of distribution in order to deal with the issues surrounding the limited storage life. Additional shredding and screening processes during composting also make degradable sacks more expensive than bin collection systems during the recycling phase. However, a sack collection system is more cost-effective during the collection phase than a bin system due to higher fuel efficiency brought about by not operating a bin lifting mechanism.

In order for the degradable polymer sack to be successful for the collection and treatment of organic wastes, it must provide problem-free use by the householder whilst providing problem-free processing at the compost plant. 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 (for example, bins) within the waste management industry for the kerbside collection of organic wastes.

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