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Degradation of some EN13432 compliant plastics in simulated mesophilic anaerobic digestion of food waste

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ABSTRACT

The research looked at the anaerobic biodegradation of 9 different bioplastics, all of which were commercially available and certified in Europe as compostable packaging material compliant with the biodegradation and other requirements of the EN13432 standard. A combination of testing strategies was used to assess the degree of degradation both under batch conditions, and in a simulation in which the plastics and food waste were fed daily to a digester for a period of 147 days. Two non-biodegradable plastics were used as controls, and verified the robustness of the sampling regime and the recovery of the plastic film, with errors of < 1% in the final balance. The simulation allowed quantification of the weight loss of the plastics and determination of a decay coefficient for the different materials, which was then used to estimate long-term degradation. Use of a biochemical methane potential (BMP) batch test allowed estimation of the conversion of carbon into gaseous products. There was no evidence that any of the plastic films inhibited the anaerobic digestion process when continuously fed to digesters, although some inhibition occurred when the most readily degradable materials were tested at higher concentrations in batch mode. There were some interesting differences between results from the various measures of plastic degradation in the batch and simulation experiments, with batch testing in most cases suggesting a higher degree of degradation than was achieved in a semi-continuous system at a solids retention time of 50 days. The exceptions to this were two plastics that appeared to show rapid weight loss in the simulation experiment. BMP test results confirmed this was not through biological conversion of the bioplastic to gaseous carbon products, and was therefore probably due to physical disintegration. It was concluded that, of the 9 bioplastics tested, only 4 showed substantial biodegradability under anaerobic conditions. Further evidence to support the mechanism of biodegradation was obtained by microscopy, and photomicrographs using different techniques are included to illustrate the process. Even the most degradable materials would not break down sufficiently to meet the physical contaminant criteria of the UK PAS110 specification for anaerobically digested material, if fed to a digester at 2.0% of the input load on a volatile solids basis.

1. Introduction

Plastic films are commonly used in food packaging as a means of protecting the food from contamination, both airborne and from manual handling; whilst at the same time allowing customers to see the contents of the package. These films may also have specific properties related to their permeability to moisture and gases, with the goal of improving the product's shelf life and its physical appearance. Other modifications include physical attributes that determine how the film can be applied and sealed. Although plastic films used in consumer-targeted food wrapping only represent a small proportion of the total plastic waste load, this fraction causes significant problems: it is particularly difficult to recover due to its non-uniform size and composition, to its presence in multi-material packaging, and to problems associated with mechanical separation in sorting plants. As a result, this material is not normally targeted by household waste segregation schemes, and is likely to be discarded in the general waste, or as a contaminant in source-segregated food waste streams. Similarly, supermarket products which are past the sell-by date are often disposed of with their packaging. It is the commercial food retailing and catering sectors that have therefore driven growth in the development and use of biodegradable biopolymers [28] as companies seek to meet sustainability goals.

The difficulty in recycling plastic films is compounded by the fact that they often consist of several layers of different compositions; when used in food packaging they are frequently contaminated with residual food; and they are commonly found as small-format items in heterogeneous recycling streams [42]. To overcome these challenges there has

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been considerable interest in developing biodegradable films designed for disposal via composting or anaerobic digestion. These plastics, generally referred to as 'bioplastics', can be produced from conventional petrochemicals or from renewable biological resources; in the latter case they are termed bio-based plastics. Bio-based plastics can be synthesised from bio-based chemical building blocks, e.g. lactic or succinic acids; through modification of natural polymers, such as starch, cellulose or chitin; or through fermentation to produce microbial polymers such as polyhydroxyalkanoates.

Anaerobic digestion is becoming increasingly popular as a means of processing food waste for energy and fertiliser recovery. The inclusion of biodegradable catering films, food wraps and card packaging in the feedstock stream would simplify collection and processing, and eliminate the need for a depackaging stage when the input materials include supermarket wastes and other packaged food materials. It is now recognised that the biodegradability of plastic films is dependent on process conditions, with significant differences reported between aerobic and anaerobic systems [13,22,27,29]. There are also disparities between methods for assessing biodegradability, leading to questions as to whether batch testing methods can adequately predict what will happen under real operating conditions in a full-scale bioprocessing plant [10].

Biodegradation of packaging materials via composting is covered by European standard EN13432 [16] which stipulates the requirements for packaging recoverable through composting and biodegradation: the standard requires testing in accordance with [17] for carbon conversion to CO_2, and in accordance with [18] to show visual disappearance. The US ASTM standard D5338-15 [6] covers the aerobic biodegradation of plastic materials under controlled composting conditions at thermophilic temperatures, and is based on carbon conversion to CO_2. Oxidative degradation is defined by CEN/TR1535 [12] as degradation resulting from oxidative and cell-mediated phenomena, either simultaneously or successively. It applies to conventional plastics that contain additives to speed up oxidative degradation. Oxo-degradable materials do not conform to the EN13432 and [6] standards, and are not considered compatible with composting processes. Anaerobic biodegradability of plastic materials is covered by Ref. [7] and by Refs. [23–25]. All of these consider conversion of carbon in the sample to a gaseous form in batch tests, and thus do not necessarily represent degradation behaviour in continuous systems over extended periods where accumulation, leaching and/or acclimatisation may occur. These tests have a number of other limitations related to the types of inoculum used, the mixing conditions and the operational temperature and do not allow consideration of interaction with any co-substrates.

The aim of the research was to assess the extent to which selected bioplastic films were broken down under anaerobic conditions in a mesophilic digester treating food waste. In addition to the bioplastics, card packaging was added as part of the digester feedstock, to simulate the case where a biodegradable composite packaging is co-digested with food residues in a bio-treatment process. The feedstock in the trial was formulated to contain food waste, card packaging and bioplastic at volatile solids (VS) ratios of 80:18:2 based on a likely composition for segregated waste streams arising either from homes, or from supermarkets if biodegradable packaging is included at source. The nine bioplastics used in the study had all been certified as compliant with the composting standard EN13432, and were therefore recognised as biodegradable in bio-based waste treatment processes in the EU. Their anaerobic biodegradability, biogas production potential and whether the resulting digestate would meet relevant quality standards for use in agriculture had not previously been tested. A simulation trial was chosen in preference to batch testing, as this allows acclimatisation of the inoculum; it also offers less stringent conditions, since co-digestion provides the primary carbon source as well as potentially increasing the supply of 'metabolic' co-factors that may be important in stimulating and promoting biodegradation. The drawback of this type of simulation is that it is difficult to quantify carbon conversion from the polymer alone into a gaseous form: this is recognised as the definitive means of assessing ultimate biodegradation, as opposed to primary biodegradation where the material is no longer detectable by the original analytical approach but may not have been fully mineralised. Testing of ultimate biodegradability is therefore typically carried out in batch assays although, as with aerobic testing, care is required to ensure comparability of results from different methods [10]. To complement the results from a continuous co-digestion trial, where degradation was assessed by gravimetric methods, a batch degradation study was therefore carried out in which production of biogas and biomethane from the polymer was quantified in a biochemical methane potential (BMP) test, and compared with the theoretical value based on substrate elemental composition. A number of variants of the BMP test are available to simulate different conditions [20]: the technique has frequently been used for assessment of degradation, and forms the basis for the now-numerous batch testing strategies that have been proposed specifically for assessing the anaerobic degradation of plastic polymers. The results of the study were intended to provide comparative information on the degradation of selected biopolymers under anaerobic conditions, and to inform stakeholders on whether anaerobic digestion (AD) is a suitable treatment method for a waste stream containing packaged food material that includes carton and renewable plastic film. Although previous studies have considered the biodegradation of plastic polymers under anaerobic conditions in landfill [1,2,8], and numerous batch digestion tests have been carried out [14,19,32,37], this is the first reported study on degradation kinetics in a co-digestion study with feed addition and removal designed to simulate practice in a commercial AD plant.

2. Materials and methods

2.1. Feedstock components

2.1.1. Bioplastics

These were provided by the manufacturers, and had been certified as EN13432 compliant by an independent body after testing in an accredited laboratory, issued with packaging product certification numbers and awarded the right to carry the scheme's certification logo. They were tested alongside non-biodegradable controls of an uncoated polypropylene (PP) film and a plain low density polyethylene (LDPE) film. All of the bioplastics were in sheet form, with the exception of a Polylactic Acid Blend (PLAB) in pelleted form. Each sheet material was measured and weighed and then accurately cut into 1 × 1 cm squares ('tokens'), the average weight of which is shown in Table 1. PLAB was used as supplied, with the average dimensions and weight of each pellet as shown in Table 1.

2.1.2. Food waste

To be certain of avoiding contamination with non-targeted plastic films, the trial used a synthetic food waste (SFW), formulated as described in the Data in Brief article, using food materials purchased in a supermarket. All packaging was removed and the materials were roughly chopped and fed through a macerating grinder (S52/010 Waste Disposer, Imperial Machine Company (IMC) Limited), then packed in 4-L containers and stored at −20 °C. When required the SFW was allowed to thaw, stored in a refrigerator and used within 7 days.

2.1.3. Card packaging

To avoid any potential contamination from plastic films, unprinted card (GK unlined grey machine board 70–100% recycled fibre with bulk 1.4 $cm^3\ g^{-1}$) was obtained from A Stevens & Co Ltd Yeovil, Somerset and shredded in an office-type cross-cut paper shredder to a particle size of ~2 cm^2. The card packaging (CP) was then macerated with water, frozen and stored until use as above.