COMMENTARY

Biodegradability of plastics: the pitfalls

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Abstract: Biodegradation of plastics as a research topic has received increasing attention due to their recalcitrant nature and large quantities, but little progresses and new information have been made available recently in the literature. In this context, plastics properties as a substrate, microorganisms responsible for degradation, assessment techniques and degradability are discussed critically to summarize the basic requirements for proper biodegradation testing and also the interpretation of the results for a meaningful presentation. New directions in this area of research are also presented to individuals working on this topic to advance the research.
Keywords: biodegradability, plastic pollution, ocean pollution, landfill pollution, platicizers

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1. Introduction

Plastics, as an innovative material with high durability and performance, have many negative drawbacks to the environment. One apparent sign of human impact on the whole ecosystem is the abundance of anthropogenic materials that can be found in the different types of ecosystems, on land and in water. Chemical pollutants occur and migrate, but they are mostly invisible. Man-made materials with increasing strength and durability were magic and wonder of civilization in terms of the improvement on the quality of life. This is very well illustrated by the first availability of Nylon materials, especially in the fashion industries. The once natural silk-made wears were quickly replaced by the much inexpensive ones, and higher quality and durability of the petroleum-based ones to be affordable to many people. With increasing consumption of plastics, especially in daily consuming products and packaging, disposal of them after use is a major issue to many cities and countries due to the limited space of landfill and contamination of landfill leachate to groundwater.

The contradiction between durability during service and quick degradability after disposed of is not a simple problem to be tackled scientifically. When in applications, durability is a desirable property sought, but the opposite is preferred after use. Biodegradability of plastics has been the central topic for discussion publicly, but many of the new investigations and published results have failed to address the fundamental issue scientifically and vigorously. As a result, a large portion of them has major pitfalls in the experimental design, analysis or interpretation, and sometime misleading conclusions. With this in mind, I would like to offer a discussion on this topic and try to illustrate my arguments through several important issues listed below.

2. Plastic Materials as A Substrate

In any scientific investigations, the chemistry of the materials has to be known and documented thoroughly, and this rule also applies to plastics (Gu, 2003; 2007; 2016). It is not common to see information on the chemical structure and also the molecular weight in a research report on plastic biodegradation even though polymers are polymerization products, and both the monomer and molecular weight are basic information to the description of a material type. For example, polyethylene has a chemical structure of -(CH_2-CH_2)$_n$-, its molecular weight will determine the degradability and degradation rate whether degradable or non-degradable. Furthermore, the purity of the materials in product forms is an unavoidable issue and critically important information, but many investigators used commercially available products rather than pure resin to cast or mold their specimens for research investigation without acknowledging the fact that products contain a range of chemicals, including plasticizer, filler and colorant etc in addition to the backbone polymers (Gu, 2003; Gu et al., 1993; 1996a, b). In this context, processing of polymers into products requires the addition of plasticizer, filler and molding chemicals so that the expected products can be made successfully. Without them, pure polymer resin cannot be converted into any quality products, so this process introduces chemicals into the finish products. Any degradation observed on the products cannot simply be due to the polymer/plastic alone. Few researchers pay attention to this issue, which affect the degradability claimed for utilization of them as the sole source of carbon and energy.

Commercial products also contain oxidants to enhance the destruction of the plastics, especially for packaging use. Because of this, the degradation observed is at least partially due to the oxidant in the formulation from production. Another factor, which is overlooked mostly, is UV radiation from the sun after disposal of plastics also contributes significantly to the disintegration of plastics in the open because of the availability and natural occurrence.

3. Test Methods

This is critically important because different products or polymers have very different physical and chemical properties, which lead to their persistence or degradation under the selective environments of testing. This issue on choice of the appropriate methods has been discussed previously in several publications (Gu, 2003; 2016; Gu and Gu, 2005). The methods can be chosen from the very sensitive electrochemical impedance spectroscopy for persistent plastics to use gravimetry or respirometry for easily degradable products (Gu et al., 1996a, b). Respirometry can yield mineralization of the plastic materials if properly handled with inoculation of microorganisms together with parallel controls in the same set of experimental set up (Gross et al., 1995; Gu et al., 1993).

Biodegradation is defined as the breaking down of polymerized materials to mineral products, including CO_2/CH_4, H_2O by (micro)organisms, including archaea, bacteria and fungi (Gu, 2016). The transformation steps involved for a selective plastic material of pure resin to mineralization products involve a series of intermediate biochemical reaction steps to achieve the complete degradation of the starting material (Gu, 2003; 2007). Based on this fundamental, degradation should be focused on mineralization of the polymers to minimize any negative impacts to the environment as the goal if possible.

Several misunderstandings are common in setting up degradation experiments and gathering research data in laboratory research, which leads to incorrect information and practices widely reported in the literature. It deserves the careful attention of beginners to fully understand these basics and make their experimental design effectively and meaningfully to achieve specific research objectives and advance development in science on this topic.

Weight loss is frequently used to monitor the weight loss of selective specimens under selective conditions. This gravimetric technique has a major problem that smaller pieces from fragmentation of the specimens cannot be accounted for in the weight loss, so the results generally overestimate the degradability and mineralization (Gu, 2003; 2007). Since this method does not account for mineralization as the final product, this drawback can be overcome by respirometry to measure the mineralization products, e.g., CO_2, to achieve the yield of substrate conversion from plastic carbon to CO_2 (Gu and Gu, 2005).

Fourier Transform Infrared (FTIR) spectroscopy is more frequently used in analysis to characterize the degradation reactions on plastics, but this method was not used properly when exposed to microorganisms or environments because of available natural biochemicals and biometabolites, which can adhere onto the plastics. It is a pity that no serious investigations have been made to evaluate the possibility to eliminate the interferences from environmental entities in biodegradation testing through measuring pure plastics, the ones under abiotic condition, with exposure to microorganisms, and different means of cleaning to document the validity of results through subtraction method. FTIR spectra of plastic film after exposure to cultural medium containing microorganisms cannot provide convincing evidences on biodegradation even though oxidized functional groups, -COOH and -OH, are observed due to the contamination issues.

Culturing media are a major issue in degradation research because many of the media used contain additional organic carbon (glucose as an example) or yeast extract or nutrient broth to promote the growth of the microorganisms. Such approach or manipulation of experimental systems can easily observe the active growth of microorganism, but does not allow the conclusion on that microorganisms are responsible for the 'degradation' observed, especially with FTIR.

4. Plastisizers and Additives

Plastics are products from polymers together with many additives, though minor in proportion to the bulk plastic, to produce a finished product. In this process, the additives can serve as a good source of carbon and energy to microorganisms (Gu et al., 1996a, b), resulting in growth observed, population, enzyme activities, and also functional groups from microbial metabolites. Commonly used plasticizers of the phthalate ester family are known to be degradable by a wide range of microorganisms, aerobic and anaerobic (Gu and Wang, 2013a, b; Wang and Gu, 2006). Degradation of them can be achieved with microorganisms from activated sludge, mangrove wetland and deep ocean sediments (Gu and Wang, 2013a, b; Li and Gu, 2007; Li et al., 2005a, b; Wang and Gu, 2006; Xu et al., 2005; 2006). It should be mentioned here that the initial hydrolysis of ester bonds to produce monophthlate ester and then phthalate in sequence, but monophthlate ester is more toxic than the parent compound or the further degraded one, phthalate.

5. Future Perspectives

The first fundamental in this research is that the target plastics under investigation are not the sole sources of carbon and energy for microorganisms because complex cultural medium containing some or all of the followings: glucose, yeast extract, and/or nutrient broth to enhance the growth of the microbial populations. Therefore, the basic rule in the practice is to use defined mineral medium with known chemical composition to achieve the goal of degradation by microorganisms capable of utilizing the test plastic as the sole source of carbon and energy (Gu, 2003; 2007; Gu and Wang, 2013b; Li and Gu, 2007; Yip and Gu, 2016). Secondly, the assessment methods must allow the evaluation of degradability of the polymeric materials to degradable intermediates or mineralization products. Careful selection of the available testing methods is a necessary step before sound scientific conclusions can be made (Gu and

Gu, 2005). Thirdly, the dynamics of both microbial population must be monitored and presented together with the plastics degradation in the results obtained. In addition, an abiotic control is a must in parallel to the biologically active treatments to confirm the degradation by microorganisms to eliminate biases from chemical transformation, e.g., hydrolysis (Gu and Wang, 2013b; Li and Gu, 2007). An additional control shall be included, but rarely used, is the pones with killed or sterilized inoculum to determine any possible effects from denatured proteins of the inoculum cells. With full consideration of these above, the experimental set up can obtain strong evidences on degradability of selective plastics by a pure culture or a consortium of microorganisms.

Overall, degradability of plastics is experimental easy in design, but the degradation of them can be time consuming due to the very slow degradation initial by microorganisms. On scientific ground, degradation tests must follow the necessary guidelines and requirements so that the data produced are sound and valid. With a better knowledge on the current pitfalls, future research on this topic can hopefully avoid these shortcomings to gain in-depth information to advance the scientific research on this subject.

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