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Comparative Biodegradability Assessment of Different Types of paper

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Abstract

Production and use of paper materials are excessively increasing with the development of civilization thereby making its disposal challenging. It is very important to have an accurate indication of the rate of different types of paper decay which would ultimately assist the waste management sector. The study investigates the rate of biodegradation of four available grades of paper in a captive compost environment. To investigate this, the papers were cut into strips according to the test specification and buried into the compost soil to let them biodegrade. Sampling was done periodically at certain sampling points to measure the extent of biodegradation by measuring tensile strength with a "tensometer". The tensile strength data of the experimental strips was compared with the same of controls (unburied) and also among the paper types by using different statistical methods. The result demonstrated that the recycled paper degrades more quickly followed by glossy papers, which take some more days to degrade utterly. The higher rate of biodegradation of recycled paper might have occurred due to its chemical pulping where chlorine is normally used as bleaching agent. The glossy paper also degraded promptly at its 1st and 3rd day of burial but took some more days to degrade completely. The reason may be the starch coating has accelerated the biodegradation at initial stage. The newsprint with ink did not fully biodegrade even after 21 days while newsprint without ink take 16 days to vanish. It is assumed that the lignin and ink content of newsprint without ink and newsprint with ink respectively may have inhibited biodegradation. To sum up, composition of principle raw materials and processing style contributes significantly in biodegradability of paper products. Composting, an eco-friendly option can solve the paper disposal problem which reduces the landfill cost and at the same time produces good quality marketable compost.

Keywords: Biodegradability Assessment; Biodegradation; Composting; Waste Management.

1. Introduction

Paper is a renewable, plentiful and versatile material which is used for writing, printing and packaging worldwide. The UK consumes more than 11 million tons of paper and cardboard every year where about 26% raw materials are imported from Canada and Scandinavia [1] and less than half of the paper used is recycled [2]. However, over five million tons are dumped at different landfill sites causing mounting waste disposal problem [3] which may cause potential damage to environment [4]. Moreover, pulp and paper industry which is currently amongst the most important industrial sections in the world are

also facing challenges in managing their effluents since they have to consider both the environmental criticisms and enduring legal requirements [5]. Therefore, the pulp and paper industry has been remodelling their pulping, bleaching and effluent treatment technologies to reduce the environmental footprint [6].

Biodegradation is the process whereby a compound is decomposed by natural biological activity. Paper, which is biosynthetically composed of cellulose, hemicelluloses and lignin of plant cell [7] is also subject to ageing since it is produced from organic substances [8]. The relative amount of cellulose, hemicellulose and lignin can vary among different grades of paper due to diverse pulping and bleaching processes [9]. Different papers have different biodegradability level as they maintain different processing styles. Some of them are easily bio remediable whereas some show a long-term presence even in the compost or landfill environment. In the paper production process, the pulp is made thinner with at least 99% water and several chemical substances such as mineral filler, china clay, titanium dioxide or chalk, and some water-soluble substances are added such as optical brighteners and polyvinyl alcohol [10]. Thereafter, some additives might be needed to be incorporated in the diluted pulp. Additives are used in order to aid the paper and pulp production process and to obtain desired properties in its products. They can be organic, inorganic, mixed or both [11]. Moreover, dyes, coating materials or preservatives can be found to be incorporated at some points of the manufacturing process for producing required grades of paper [10].

Newsprint is cheap, off white and non-archival type of paper which is mostly used in printing newspapers and other advertising materials. It is made from mechanical pulping that contains all of the initial lignin [9, 12]; therefore, it is rough to touch [9]. Nearly all newsprint is made of recycled paper so it should be biodegradable. However, in the composting plant it was found in the final product. The causes behind this may be lignin content of this type of paper and organic content of ink used in printing [13]. Because of the defensive nature of lignin, paper biodegradation with the presence of lignin is more intricate process. It requires the synergic activity of a series of enzymes such as laccases, pyroxidases, and also cellulases and hemicellulases [14]. However, when the comparative biodegradability of these three constituents of paper was studied, it was established that humus is mainly formed from lignin and is not totally mineralized during composting [15]. On the other hand, the high acidity in inks that are used for printing newspaper and other forms of paper may affect the biodegradability of the paper [16, 17]. Inks generally contain large amount of iron and copper which may inhibit localized degradation [9]. Therefore, few researches were found to be investigating if there is any negative effect of ink content of paper on its biodegradability.

Sometimes, wax, including paraffin, microcrystalline and polyethylene are used to coat glossy papers and cardboards to enhance mechanical strength and also to make papers impermeable to moisture [9]. A study was conducted to examine the biodegradation rate of waxed paper, polythene-coated paper and uncoated paper which are usually used as packaging materials in quick-service restaurants. The research demonstrated that comparing to the uncoated paper, the waxed and polythene coated paper showed only a little lag in degradation therefore the wax coated papers were proved to be readily biodegradable and was believed to provide the microorganisms a good metabolic energy source [18].

Recycled paper is made from chemical and mechanical pulping of waste papers which constitute a major paper source in UK. It is biodegradable and suitable for further recycling. Recycled paper is a significant source of cellulose fibre for several paper and board grades such as corrugated paper, newsprint etc. [10]. Literature indicated that almost half of all recycled fibres are used in the production

of corrugated board, and about 12% is used in newsprint manufacturing [19]. On the other hand, a huge portion of recycled paper are made from newsprint, cardboards, packaging waste, and also office waste including unprinted writing and printed paper [9].

The chemical resistance of the materials and the effect of external factors determine the permanence of the paper whereas the paper durability depends on physical and mechanical characteristics of dominant raw materials, additives and contamination by ions from the environment, the activity of light, humidity and microorganisms [8]. A variety of microorganisms are involved in degrading each of these polymers by producing a battery of hydrolytic and oxidative enzymes which work synergically [2]. It was found that the thermophilic micro-fungi are important lignin degraders in the compost environment [15]. However, some literature suggests that temperature is the factor which affects microbial growth mostly since it can influence biological reactions in two ways such as by working upon the rates of enzymatic catalysed reactions and by modifying the rate of diffusion of substrate to the cells [20]. Permanence of different grades of paper was investigated by Zou et al. using accelerated aging process and it was found that most chemical reactions rises up when temperature is increased and these chemical changes affects the physical properties of paper materials [21]. On the other hand, if the moisture content becomes lower than the critical limit, microbial activity will decrease. Oppositely, higher moisture level may cause lack of aeration and the leaching of nutrients.

An increased amount of low carbon and domestic sources of energy is necessary since we are heading some environmental issues such as climate change and scarcity of energy supply [22]. Sometimes, waste is used as a resource for energy production to save money; however, it is more efficient to reduce waste at the point of its origination [23]. Most of the developed countries, especially the European countries have endorsed a hierarchical manner (Figure 1) to solid waste management which says waste should be reused, otherwise recycled, next incinerated, only if no other option could be followed then it should be landfilled [24-26].

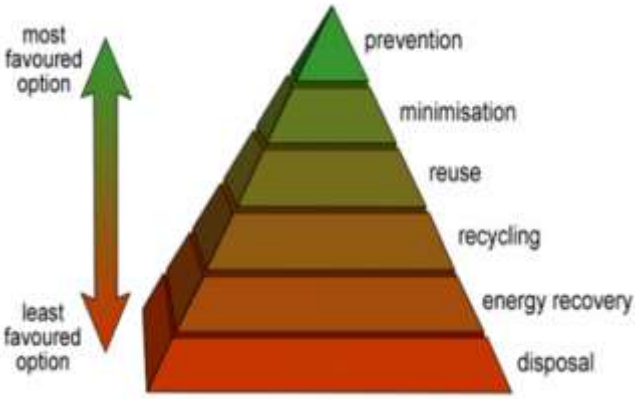

Figure 1. The Waste Hierarchy endorsed by developed countries [23].

In recent years, a sub-focus of waste management has been initiated both to reduce the effects of waste materials on natural environment by conserving raw materials used and to recover resources from wastes, i.e., recycling [23]. Recycling of paper has two main advantages such as the amount of waste going to landfill will cut and less vegetation will be vanished. However, recycling of paper is sometimes criticized both as a product and as a process since it consumes more energy than virgin paper production

[3, 27]. Since paper contains very low levels of contaminants so it is quite suitable for composting [18], a process which involves the interaction of different organisms at various level of the food chain [24] and is a complicated series of chemical and microbiological reactions is set in motion [28]. The composting process delineates an influential strategy in switching waste streams from landfills and re-establishing organic content to soils. Although it does not restore the material value like closed loop recycling, it is an appealing alternative where organic materials are intimately mixed with putrescible [18].

Composting can be a solution to our current state of waste pollution. According to Peigne and Girardin (2003) "Composting is an aerobic process of decomposition of organic matter into humus like substances and minerals by the action of microorganisms combined with chemical and physical reactions" [29] During composting, carbonaceous and nitrogenous compounds are converted by the activities of consecutive microbial populations into more durable complex organic forms which are similar to humic substances when observed chemically and biologically [30]. In addition, carbon dioxide (CO2) and water are originated in the form of gas and vapour respectively [30].

The generalized equation of composting is

Fresh organic matter + O2 →Humus-like substances + CO2 + H2O + Energy (heat) + mineral products [29].

Composting process recycles manures and organic wastes to produce soil enhancers; therefore, it has become a popular method. Moreover, it reduces environmental pollution and soil deterioration with reducing the amount of landfill wastes and greenhouse gas emissions [30]. Furthermore, it absorbs free water from wet compostable food materials, reduces the odours and provides a source of carbon which has a beneficial effect on soils that are deficient in organic matter [31]. Composting could contribute a better environmental outcome compared with substitutes such as landfill. There is a growing interest in the use of combined composting systems designed to comply with legislation and to achieve some definite technical objectives, such as producing high specification composts [32].

Although several previous researches have focused on the biodegradation of the typical municipal solid waste in bioreactor landfills, comparatively insufficient attention has been given to the biodegradability of individual refuse materials [33]. Considering the issues mentioned above, this research is aimed to investigate the extent of biodegradability of different grades (newsprint without ink, newsprint with ink, recycled paper and glossy paper) of paper in a compost environment with comparison.

2. Materials and Methods

2.1 Collection of different grades of paper

Four types of paper namely, newsprint without ink, newsprint with ink, recycled paper and glossy papers were selected (Table 1) for the experiment of the study. These papers were collected from different sources and were cut into strips according to test specification (20 cm in length × 25 mm in width). Control strips were also cut at the same size of the experimental strips.

Table 1. Grades of paper used in the experiment with their uses and sources of collection.

Type of Paper	Brief description of uses	Source of collection
Newsprint Without Ink	Printing newspapers and sometimes used for writing	Packaging paper used in "World Wide Fund for Nature"

Newsprint With Ink	Used in local and international newspaper	"Sunday Times" newspaper
Recycled Paper	Used for writing and printing	Printing paper of Learning Resource Centre of University of Hertfordshire
Glossy Paper	Used for advertising and packaging	Leaflets for the "Environmental Management" degree in the School of Life Sciences

2.2 Experimental Design

Hypothesis

Alternate Hypothesis HA = There is a variation in biodegradability among different grades of paper in compost environment.

Independent variable

Duration of exposure to compost environment (measured in days). For example, 9 durations were used in this experiment i.e. 1st, 3rd, 6th, 8th, 10th, 14th, 16th, 18th and 21st day of burial.

Dependent variable

Biodegradability of papers i. e. tensile loss (measured in Kilo Newton)

Control

10 strips of each category (Table 2) =40 strips

Constants

Temperature, moisture level, amount of compost soil in each bed

Table 2: Number of samples used for experiment

Categories of paper	No. of strips buried	No. of control strips used	total
Newsprint (with ink)	30 strips × 4 soil	10 strips	130
Newsprint (without ink)	30 strips × 4 soil	10 strips	130
Glossy paper	30 strips × 4 soil	10 strips	130
Recycled paper	30 strips × 4 soil	10 strips	130

12 strips were removed from each treatment (paper type) at each sampling point.

2.3. Preparation of biodegradation mixture

The biodegradation mixture was prepared by mixing commercial compost, garden compost and chicken manure together (Figure 2).

Figure 2. Mixing process of compost soil.

Commercial compost slowly releases nitrogen; therefore, the use of it establishes a better source of organic matter for the soil and augments potential N storages [30]. Commercial compost and garden compost were taken in equal amount for preparing single tray of mixture. Then half cup of chicken manure was added for each tray of the mixture. Significant researches have revealed that sequential addition of urea does not augment de-inking paper sludge composting; it only increases the concentration of free ammonia and soluble salt. Therefore, the initial pH and C: N ratio is crucial factors in the composting process [34].

2.3 Burying the experimental strips and sampling

Soil burial test procedure is an active and prompt method of verifying biodegradability [35]. The study was conducted with a consideration that four types of papers were the four treatments. For this experiment, the experimental paper strips were buried into the compost soil to accelerate biodegradation and then the rates of biodegradability of different grades of paper were observed and compared. To examine the extent of degradation, the buried paper strips were monitored by tensile strength measurements [36]. The control strips were kept in usual condition and their tensile strength were also measured in the same procedure of experimental paper strips.

The experimental strips were buried in "V" shape manure as shown in Figure 3 and Figure 4 to let the middle portion of the strip to degrade but leaving enough space (3-5 cm) at its two ends in order to keep it suitable for testing with "tensometer".

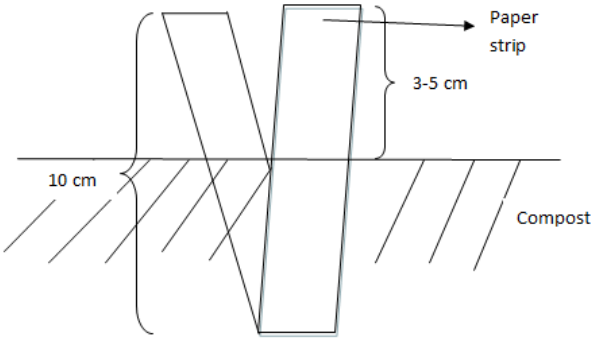

Figure 3. Burying procedure of paper strips which was followed in the experiment.

Figure 4. Paper strips buried in the compost box.

Figure 5. Unburied (control) and buried samples packed in aluminum catering foil before storing in freezer.

Paper strips were sampled at 9 sampling points such as 1st, 3rd, 6th, 8th, 10th, 14th, 16th, 18th and 21st day of burial. Upon unburying, the strips were picked up from soil very carefully. After that, the adjacent soil was cleared from the strips and was wrapped with aluminum catering foil with proper labeling such as date, paper type and number of strips (Figure 5). In addition, control strips were also wrapped in the same way at each point of sampling (days of unburying). Finally, the wrapped strips were kept in freezer to prevent further microbial activity.

2.4 Tensile strength test of the samples

Tensile strength test is used to measure the extent of biodegradation of paper and cardboards [37, 38]. In a tensile test, the maximum load at which the sample starts to tear apart is recorded by the device (tensometer) (Figure 6); thus, the attainable load that the sample can bear is obtained [37, 38]. Before testing the samples, the tensometer was set up according to the following specifications: speed: 10 mm per minute, force range: 50% and extension range: 50 mm.

Figure 6. Tensile load at break was recorded by using tensometer.

2.5 Data Analysis and Statistical Test

The forces needed to break the strips were collected from the tensometer and were incorporated into SPSS software for processing. For observing tensile strength loss of the paper strips over time, several multiple bar graphs (Figure 7 and 8) were produced.

To monitor the percentage degradation rate of different paper type over time, the force (KN) data were converted into percentage degradation data (%). The percentage degradation rate data were initially examined for normality (Estrada, Lutcavage & Thorrold, 2005) by looking at their histogram chart and therefore comparing the trend line with normal curve. The percentage degradation data were found to fulfil the assumption of ANOVA (Analysis of Variance); therefore, one-way ANOVA was performed ($\alpha = 0.05$) for each point of sampling and by considering four types of paper as four treatments (Table 3). The logic behind not using the original tensile strength data to perform ANOVA was that it would have given wrong idea as they were the reading of different grades of paper of different level physic-chemical properties.

3. Results and Discussion

In this experiment, the biodegradability of newsprint without ink, newsprint with ink, recycled paper and glossy paper was investigated in a compost environment. The changes in tensile strength as well as the percentage degradation of each grades of paper were analyzed to estimate the extent of biodegradation.

It was found that the newsprint without ink took 18 days to fully biodegrade in compost environment. Therefore, it was more biodegradable than newsprint with ink which did not fully biodegrade even after 21 days in compost environment. However, newsprint without ink was less biodegradable while compared with that biodegradability of glossy paper and recycled paper which took 14 days and 16 days respectively to degrade 100% (Figure 7 and 8, Table 3).

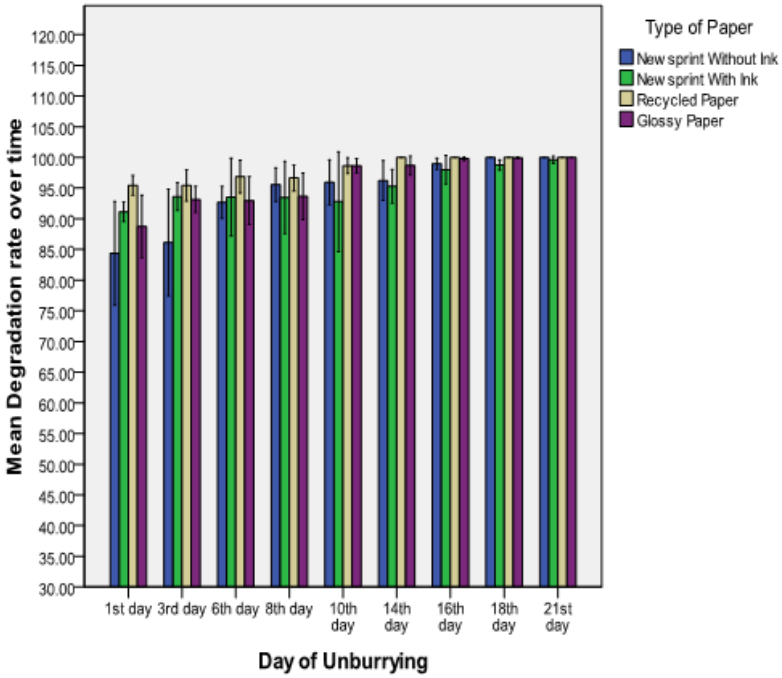

Figure 7. Comparison of tensile strength loss of 4 types of paper in compost environment over time.

Glossy paper degraded 98.63% (Figure 8) on the 10th day of burial, which was proved as more biodegradable for that sampling point than newsprint without ink (95.93% degradation) and newsprint with ink (92.78% degradation).

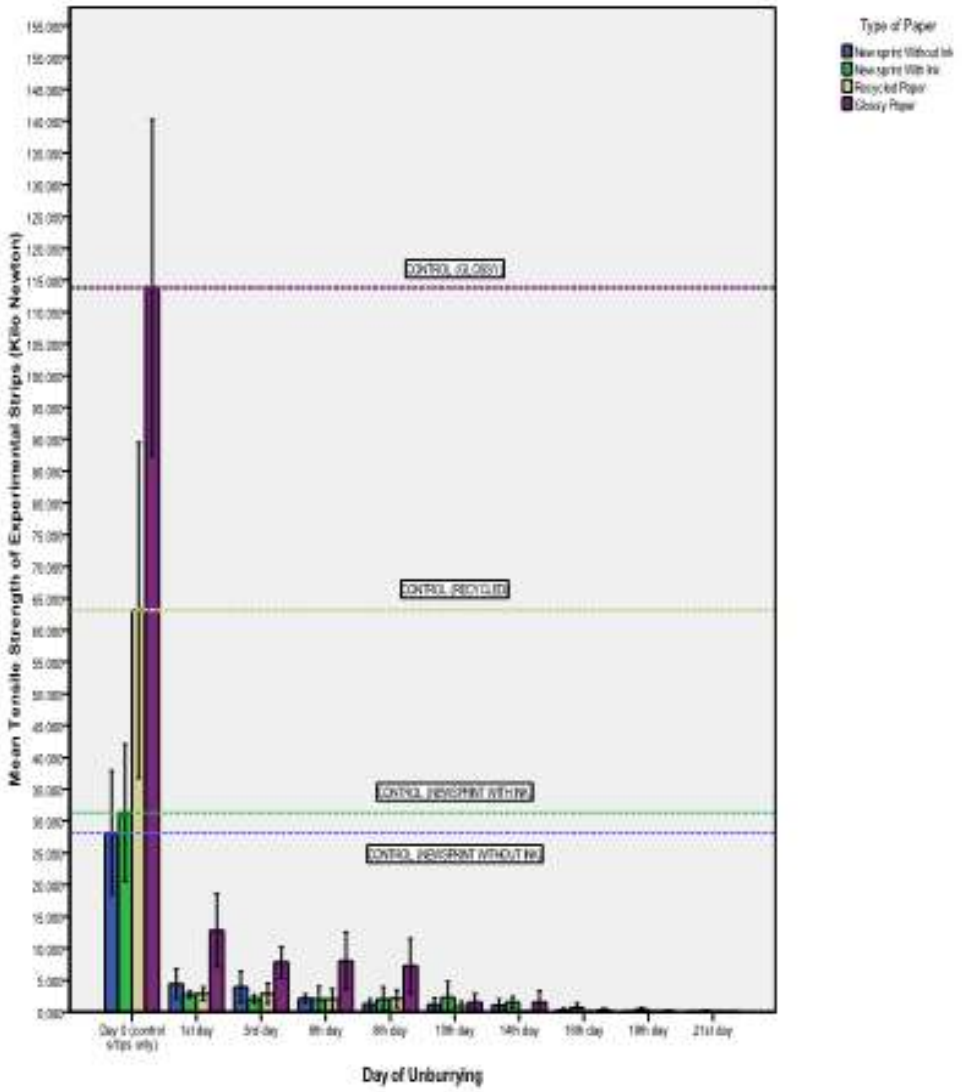

Figure 8. The percentage degradation of 4 types of paper in compost environment over time.

The ANOVA table (Table 3) represents the *p* values obtained from ANOVA tests when the percentage of degradation was compared between two treatments (types of paper) for a particular day of unburial. To produce the ANOVA table, several one-way ANOVA were carried out in SPSS at 95% confidence level. Therefore, if the *p* value is found to be less than or equal to .05, then the null hypothesis should be rejected.

Table 3. Levels of significance between treatments by using one-way ANOVA at 95% confidence level.

	Day of burial								
	1st day	3rd day	6th day	8th day	10th day	14th day	16th day	18th day	21st day
Treatments compared									
Newsprint without ink and Newsprint with ink	0.214	0.084	0.988	0.840	0.685	0.915	0.553	0.000	0.17
Newsprint without ink and Recycled paper	0.015	0.014	0.388	0.973	0.785	0.052	0.447	1.000	1.00
Newsprint without ink and Glossy paper	0.566	0.080	0.999	0.875	0.765	0.327	0.642	0.993	1.00
Newsprint with ink and Recycled paper	0.629	0.928	0.586	0.593	0.212	0.012	0.041	0.000	0.17
Newsprint with ink and Glossy paper	0.897	0.999	0.996	1.00	0.183	0.107	0.083	0.001	0.17
Recycled paper and Glossy paper	0.241	0.843	0.435	0.640	1.00	0.783	0.989	0.993	1.00

Newsprint without ink was and newsprint with ink were found to be less biodegradable than glossy paper and recycled paper. The causes behind this may be lignin content of this type of paper and organic content of ink used in printing [13, 39]. The lignin content of newspaper makes it insusceptible to biodegradation and less affected by environmental stress. These properties therefore reduce the water permeation across the newspaper fiber.

The buried newsprint with ink degraded at the slowest rate among the paper types; however, it became brittle and discolored due to exposure to heat and sunlight [37]. Researchers suspect that as inks contain large amount of iron and copper; the localized degradation may be inhibited due to the presence of ink. Moreover, the high acidity in inks that are used in newspaper and other forms of paper may affect the biodegradability of the paper.

Recycled paper is made from chemical and mechanical pulping of waste papers such as newsprint, cardboards, packaging waste and office waste [9]. Recycled paper was found to be readily biodegradable under suitable condition. Logic behind the higher biodegradability of recycled paper could be the higher fiber-to-fiber contact area. This attribute of recycled paper promotes better substrate accessibility for cellulases and other enzymes produced by microorganisms [37].

Glossy paper which looks strong and impermeable from outside, took only a little more time to fully biodegrade than recycled paper. The coating of the glossy paper is generally done with synthetic viscofiers (styrene- butadiene, latexes) and natural organic binder such as starches. Sometimes chemical additives are also used to make the paper water resistance and UV proof. Starch that is used in paper lamination is extracted from biodegradable and compostable plastic films. Therefore, glossy paper is much biodegradable than newsprint with and without ink due to its coating that attracts microorganisms.

4. Conclusion

In UK, the rapid growth in use of paper and paper product is causing disposal problem as the number of landfill sites are not enough in comparison with huge amount of paper waste and the management of these paper wastes has become the most exercised environmental issue today. Composting, an eco-friendly option can solve the paper disposal problem which reduces the landfill cost and at the same time produces good quality marketable compost.

The experiment has investigated the comparative biodegradability of four grades of paper (newsprint without ink, newsprint with ink, recycled paper and glossy paper) that are commonly found in UK landfill sites and highly used in our daily activities. The findings obtained from the experiment will therefore assist the waste management sector of UK government by introducing a reliable and eco-friendly waste management option and will help them in sorting out the suitable paper grades for composting purpose. Moreover, the research would guide the paper and pulp industries in making eco-friendly paper products.

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