



# **TESTING DISINTEGRATION OF PLASTIC PACKAGING MATERIAL IN LABORA- TORY SCALE COMPOST ENVIRONMENT**

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## **ABSTRACT**

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Testing disintegration of plastic packaging material in laboratory scale compost environment

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This thesis work was implemented as a part of PIHI project by Tampere University of Applied Science (TAMK). The PIHI project aims to create and establish a composting environment under controlled conditions for studying and testing material compostability. The objective of the thesis was to study the disintegration of a specific packaging material in a laboratory-scale composting environment according to SFS Standard EN 14045:2003. A bioplastic material was used as the test material and was received from VTT while a cellulose material was used as a reference material. Materials were mixed with compost media under controlled conditions. The experiment lasted for 12 weeks and included monitoring operations as well as visual inspection of the test and reference materials. At the end of the test, disintegration was assessed by sieving the compost and calculating the degree of disintegration.

The test material disintegrated in the compost media and the material retrieved was minor. To conclude, the test material was well disintegrated and had reached the requirement for disintegration stated by SFS Standard EN 13432:2000. However, to be categorized as a compostable material, other tests need to be performed to evaluate the biodegradability and compost quality. Also, the thesis study resulted in suggestions for future development of PIHI project.

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Key words: SFS Standard EN 14045:2003, compostability, biodegradability, disintegration

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## 1 INTRODUCTION

Plastic waste is one of the most severe environmental problems. The trouble mainly emerged from the fact that plastics were designed to resist degradation. As a consequence, plastics are accumulating in the nature, disturbing ecosystem and even killing animals. However, plastics are used and will be used for packaging for example in food industry. To solve the problem, both regulation and research, development and innovation operations are needed.

Plastics are composed of long chains of polymers. New polymers are innovated and developed to create more environmental-friendly plastics which are sufficient for the manufacture of various product such as film, packaging or hygiene paper products. Along with the development of plastics and polymers, testing facilities and standards are needed in order to evaluate the biodegradability or compostability of a plastic. To be labelled as compostable, the plastic material has to fulfil criterias like biodegradability and disintegration and not to leave toxic substances to the environment after the degradation process.

This thesis study is a part of PIHI project participated by Tampere University of Applied Sciences (TAMK), VTT, Ekokumppanit and nine Tampere Region enterprises funded by the Council of Tampere Region. The PIHI project aims to create and establish a composting environment under controlled conditions for studying and testing material compostability. The aim of the thesis was to test disintegration of a polymer material under aerobic composting condition. The test material was provided by VTT. Laboratory work was carried out in TAMK premises from June 6<sup>th</sup> to September 4<sup>th</sup> 2019 following SFS Standard SFS-EN 14045 for testing disintegration of polymer packaging material.

The first section is literature review focusing on biodegradability, compostability and compostable. The material and methodology part explains the experiment. The third section includes the results from the laboratory experiment following by the discussion and conclusion in the last section.

## 2 LITERATURE REVIEW

### 2.1 Definition of biodegradation

Contaminating waste is by far one of the most challenging environmental problem in the modern world. However, the conventional chemical and mechanical treating methods have shown to be quite feeble yet extremely costly. Therefore, the use of bioprocess in order to treat and destroy contaminant in hazardous waste has been studied and developed as a new solution. Biodegradation is a natural and effective way to break down organic matter and with that, unwanted contaminant can be significantly removed (Eskander & Saleh 2017,1.).

In addition, biotechnology has shown its unlimited potential for further development in the future (Eskander & Saleh 2017,1). Plastic, which was not designed to be capable of biodegradable (Mohee et al 2008), takes decades to be broken down (Ashter 2016, 61). As a result, the environment is tolerating the stress comes from the accumulation of nonbiodegradable plastic and packaging material. Fortunately, with new legislation and effort to reduce plastic and packaging waste, biodegradable plastic has swept the nation (Mohee et al 2008). The definition and basic of biodegradation will be reviewed in the following sections.

#### 2.1.1 Biodegradation

Biodegradation can be defined in various ways. Nevertheless, some specific mutual principles are always contained (Hamaide, Feller & Deterre 2014, 310.). According to the French norm NFU 52001 *Biodegradable materials in agriculture and horticulture – mulching films – AFNOR2005*, *biodegradation* is detailed as “The biodegradation of a material occurs via the succession of concomitant physical, chemical and biological phenomena, in all cases leading to the reorganization of biomass and the release of CO<sub>2</sub> (and/or CH<sub>4</sub>), water, energy (in the form of heat), eventually producing new organic molecules and possible inorganic residue.” In simpler words, biodegradation is a biological and natural decomposing process of organic substances into new and simpler compounds. In which, microorganisms such as bacteria shall play the main role in the transformation or

alternation. This process is essential as it turns toxic contaminant into substances which are nontoxic or less toxic to the environment (Eskander & Saleh 2017,3.). According to Alexander (1999, 4), in some cases however not necessarily, biodegradation converses C, N, P, S and some other elements from their original form into their inorganic forms. This process was termed mineralization or also known as ultimate biodegradation. In addition, aside from inorganic product, in ultimate biodegradation, carbon dioxide, water and mineral salts are formulated from the oxygen consumption of energy. There is as well the term “primary biodegradation”. In which, the microorganisms only eat the organic molecule partially. In contrast, the organic molecule is eaten completely in ultimate biodegradation (Eskander & Saleh 2017,3.).

Materials which are competent for biodegrading are referred as “bioactive”. The bioactive material is capable of breaking down to simpler compound such as simple sugar, carbon, oxygen or water. Vegetable, fruit, grains, ect. are good examples. Nonetheless, not every material is bioactive. In which, the most outstanding case is plastic as most of their kinds are not bioactive (Ashter 2016, 61).

Biodegradation can occur under both aerobic and anaerobic condition. In which, in aerobic condition, the microbial activity happens when there is oxygen presented (Eskander & Saleh 2017,4.). With the cooperation of oxygen, molecules are broken apart and the biodegradation process occur faster than under anaerobic condition (Ashter 2016, 61). On the other hand, in anaerobic biodegradation, the microorganisms break down substances in the absence of oxygen. Without oxygen, other substitutes are utilized as electron acceptor. Some commonly used are nitrate, sulphate and iron (Eskander & Saleh 2017,5.). There is another important distinction between aerobic biodegradation and anaerobic biodegradation. Under aerobic condition, in the final stage of the biodegradation process, oxygen is reduced and carbon dioxide is produced. Whereas, under anaerobic condition, methane and carbon dioxide are produced in the final stage. (Hamaide, Feller & Deterre 2014, 310.). In this, we focus on aerobic biodegradation as the composting test was implemented under aerobic condition in composting environment. Figure 1 demonstrates the aerobic biodegradation of organic substances (Mohee et al 2007).

According to Alexander (1999, 6), and Eskander & Saleh (2017, 6), there are a few requirements in order to let the biodegradation process happen:

- There must be opportune microorganisms present. In addition, the presented microorganism should contain requisite enzyme to engender biodegradation.
- Energy sources should be available for the maintenance and growth of cells.
- Carbon sources are as well essential.
- The microorganisms which have already had necessary enzyme should be able to access the substances or compounds that they are supposed to metabolize.
- An electron acceptor must exist. It could be either  $O_2$ ,  $NO_3^-$ ,  $SO_4^{2-}$ ,  $CO_2$  or any possible alternations.
- Nutrients such as nitrogen, phosphorus, calcium, magnesium, iron, trace elements.
- Appropriate environmental condition such as temperature, pH, ect.

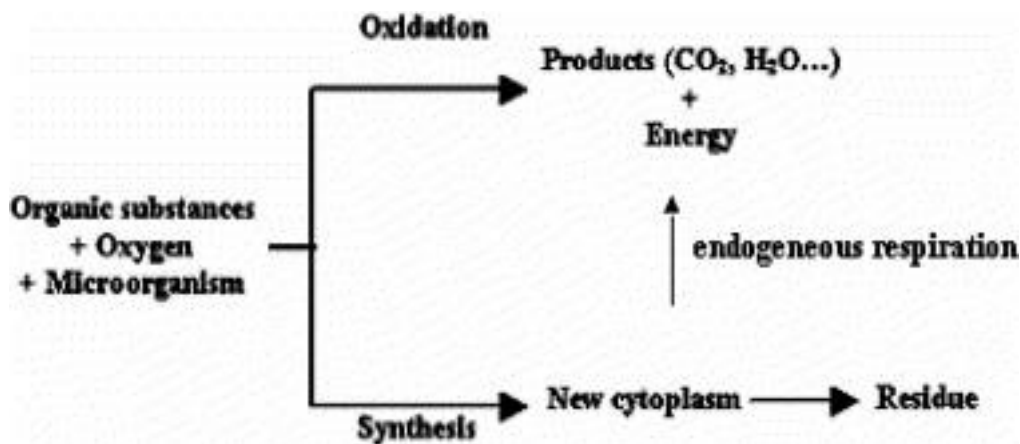


Figure 1. aerobic biodegradation of organic substances (Degli-Innocenti et al., 2000.)

### 2.1.2 Biodegradation of polymer material

In general, biodegradation could be summarized as the performance of microorganism which results in the recovery of carbon of carbon, the mineralization of



organic compound producing carbon dioxide, water and salt as well as the formation of new biomass (Lucas et al 2008.). According to Hamaide, Feller & Deterre (2014, 310), biodegradation of polymer material has three main successive stages. Nonetheless, the stages are likely to occur simultaneously. Although each stage is called with different names by different sources, they all indicating mutual context. The scheme of biodegradation is shown in figure 2.

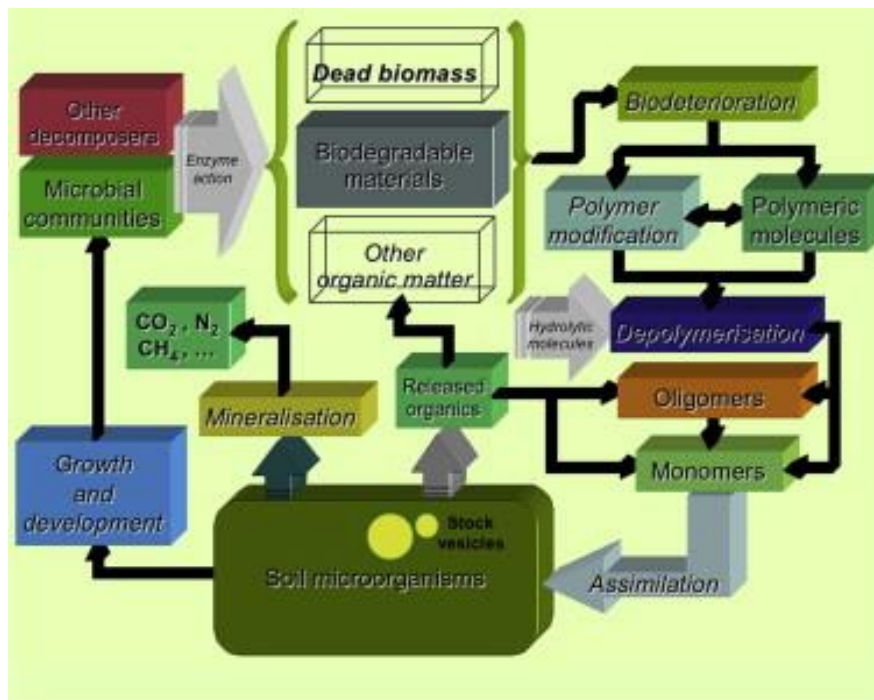


Figure 2. Biodegradation Scheme (Sources: Lucas et al)

The first stage is termed biodeterioration. In this stage, the biodegradable polymer material will be fragmented from its large form into smaller fraction (Lucas et al). This is the initial break down of the polymer material which could be resulted from either anthropogenic physical forces or natural biological forces. The physical forces could be from heating, cooling, freezing, wetting, ect. to severe erosion as long as it is capable of generating physical damage to torn or crack the polymer material (Eskander & Saleh 2017, 22; Hamaide, Feller & Deterre 2014, 311.). On the other hand, the biological forces are caused by the combination of the microorganism and/or abiotic factor to shred the polymer (Lucas et al 2008). According to Hamaide, Feller & Deterre (2014, 311), the small-fraction polymer after broken down could be range from decimeters to several millimeters and there should be no effect on the material physical or chemical properties.

In the second stage, complex polymer chains are broken down to obtain short-chain polymers. The stage is called depolymerization. The original form of polymer is normally too large and complex which make them unable to permeate the cellular membrane. To be more specific, the large molecular weight of original polymers with their low solubility decrease microorganisms' capability to attack and ingest through the cellular membrane, preventing further degradation by cellular enzymes (Eskander & Saleh 2017, 22.). Hence, in this stage, catalytic agents such as enzymes or free radical are excreted by the microorganism and taking part in breaking down long-chain polymers in to short-chain polymers. As a result, oligomers, dimers and monomers are generated (Eskander & Saleh 2017, 22; Lucas et al 2008). These polymers are low in molecular weight and small enough to penetrate microbial membrane and be further used as carbon and energy source (Eskander & Saleh 2017, 22). Both physical and chemical properties of the material are modified in this second stage and the process can be initiated by either biotic or abiotic hydrolysis (Eskander & Saleh 2017, 22; Hamaide, Feller & Deterre 2014, 312.).

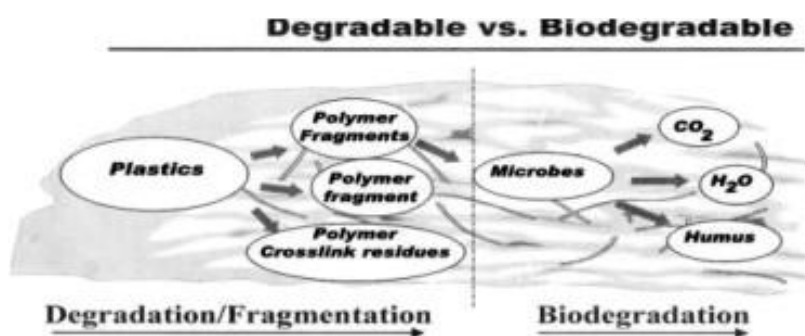


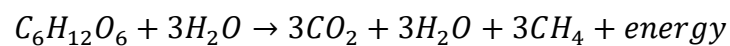
Figure 3. The difference between degradable and biodegradable (Mohee et al. 2008)

The third and final stage is called bioassimilation (Hamaide, Feller & Deterre 2014, 313). This is where energy, biomass, storage vesicles and various primary and secondary metabolites are generated as the results of conversing polymer systems (Lucas et al 2008; Hamaide, Feller & Deterre 2014, 313). According to Hamaide, Feller & Deterre (2014, 313), this is the beginning of degradation process. The process is termed mineralization when the final product, which are CO<sub>2</sub>, H<sub>2</sub>O or CH<sub>4</sub> and some salts, are released to the environment (Eskander & Saleh 2017, 22; Lucas et al 2008). This is the stage where the two term “degradable” and “biodegradable” are distinguished as only “biodegradable” materials are

consumed to produce the mentioned final product after being fragmented (figure 3) (Mohee et al. 2008). Under aerobic condition and oxygen is available, aerobic microorganism is active and break down the material to produce  $CO_2$ ,  $H_2O$  and biomass, which is described shortly by the following formula:



Whereas, when oxygen is absence and biodegradation occur under anaerobic condition,  $CO_2$ ,  $H_2O$ ,  $CH_4$  and biomass are generated:



## 2.2 Definition of composting

With the growing demand of shifting to another waste management approach other than waste ending up in landfills or incineration plants, composting most likely is the most potential option (Diaz 2007, 4). Composting is a natural solution to recycle organic waste, turning the waste into advantageous nutrient-rich compost which can be utilized in gardening, agriculture as it helps plants to grow (Ross 2018).

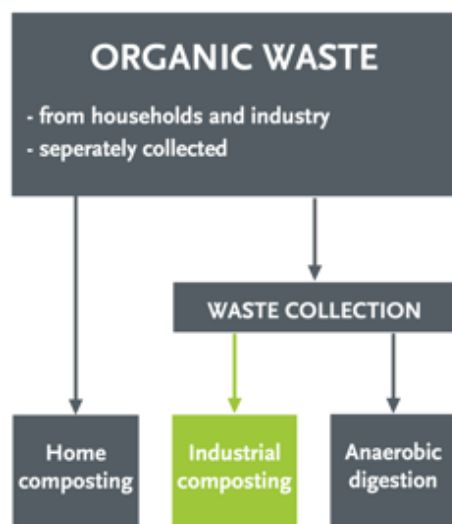


Figure 4. Options for organic waste management (European Bioplastic)

Figure 4 show the options for organic waste management. As it is indicated in the figure, the process can be arranged either in household scale or industrial scale

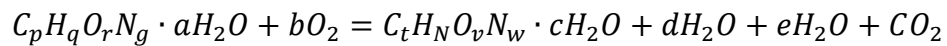
as long as the ideal condition is provided for the microorganism to be active (European Bioplastic 2015; Ross 2018). The term “compostability” refers to the ability of material to be “composable”. To be declared as composable, the material has to satisfy some specific requirements (Hamaide, Feller & Deterre 2014, 332). The definition, requirements and basics concerning composting, compostability will be reviewed.

### **2.2.1 Composting**

Speaking in general, composting is a biological process which occur under aerobic condition within 6-12 weeks duration (Insam & Bertodi 2007, 26; European Bioplastic Background 2015). The process is strongly relating with the activity of aerobic microorganism living when oxygen is available in order to break down complex organic matter into simpler substances which can be used as soil nutrient (Alvarez 2016, 123; Stanley & Turner 2010, 34). In nature, composting is termed rotting (Stanley & Turner 2010, 34). In this process, the microbial communities mainly bacteria, fungi are in charge of metabolizing organic substances into simpler matter (ecochem).

The controlled environmental conditions within the composting environment shall play a great role in contributing to the success of the composting process. The essential environmental elements include available amount of oxygen, moisture, temperature, material disturbance, organic matter and microbial communities' activity (ecochem.). Organic matter could be anything that can be found in your garden such as plants, manure, biowaste in general (University Of Illinois Extension). In our experiment for this thesis, biowaste was very important as it acts as composting media to decompose the plastic packing test material. The microorganisms grow on and metabolize the organic matter which eventually produce carbon dioxide, water, minerals and stabilized and sanitized organic matter as the final product and part of the energy is released to the environment (Insam & Bertodi 2007, 26; European Bioplastic factsheet 2009.). In which, the stabilized and sanitized organic matter is what we usually called compost and is known to be very advantageous for plant growth. In addition to carbon dioxide, ammonia and other volatile compounds are released to the atmosphere although in a very small amount compared to the emitted carbon dioxide and water (Epstein 1997,

20). The aerobic composting process is expressed under the form of chemical equation in the formula below by Wiley & Pierce (1955). According to Insam & Bertodi (2007, 26.), the first phase of composting process called decomposition is the beginning of the process as easily degradable organic matter start to be oxidized. Stabilization takes place as the second phase where not only slowly degradable substances are mineralized but other complex processes also occur. Whereas, the two phases were termed differently by Epstein (1997, 21), which is indicated in the figure below. According to the figure, the two main phases are high-rate composting phase and curing phase. Despite being named differently, they present the same order in which the process starts with breaking down the easily decompose compounds and the pathogen can be destroyed then the more complex compounds are broken down in the second phases. The process will be more carefully discussed in the next section.



In which,  $C_p H_q O_r N_g$  represents the input organic matter and  $C_t H_N O_v N_w$  represents the final compost.

Composting is a complex process which is in fact, thermophilic biodegradation (Alvarez 2016, 122). During this process, the energy is generated as heat which allow the biomass to increase in temperature (Alvarez 2016, 123; Insam & Bertodi 2007, 26). Occasionally, it is possible that the compost reach 70°C during fermentation. With the extensive amount of heat produced, it is absolutely a valuable source of energy (Alvarez 2016, 123.). The basic composting process is summarized in more simple way in figure 5.

The whole spontaneous composting process consist of four phases which will be carefully explained in the next section. During the phases, phytotoxin is temporarily produced. Surmounting the phytotoxin of fresh organic matter is therefore one objective of producing compost from fresh organic matter. Another aim is to minimize the risk of pathogenic agents such as parasites, fungi, viruses, bacteria to a level that it is considered to place no harm to health and environment. Last but not least, to produce organic fertilizer, soil conditioner and as the same time, biowaste and biomass are efficiently recycled (Insam & Bertodi 2007, 26&27.). In

addition, according to Cohen (2011, 113), from economical point of view, the product of composting is more economically beneficial as it cut down on disposal cost and even more environmentally friendly than conventional solid waste management.

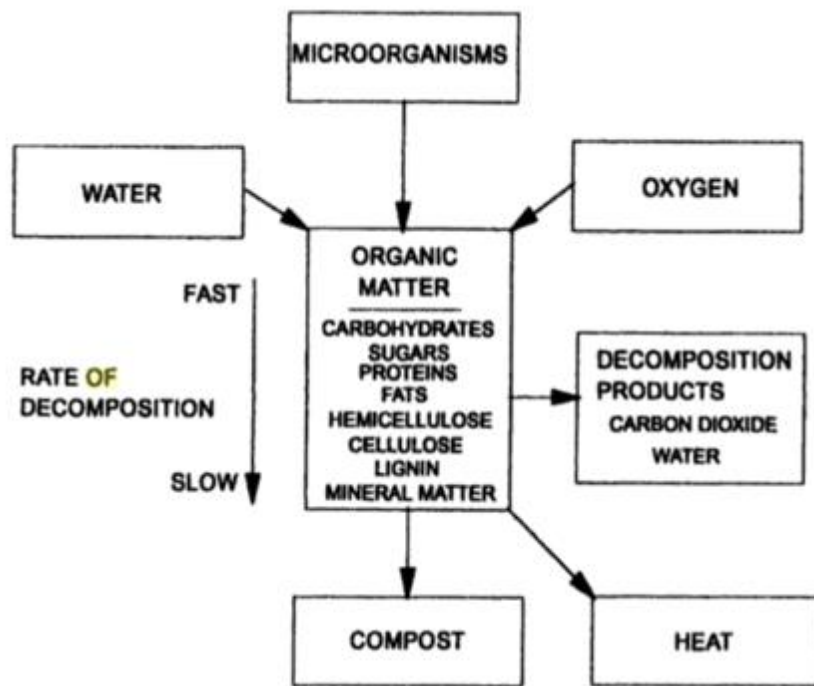


Figure 5. Composting process (Epstein 1997,20)

### 2.2.2 Process/ Stages

From microbiological point of view, biodegradation is similar to a continuous culture, where the external factors such as substrate quality, temperature or moisture are crucial. Whereas, because of the stable alternation in substrate composition and biochemical condition, composting process resemble a batch culture which consists of a sequence of continuous culture. Each of which possesses individual physical, chemical, biological properties and feedback effect (Insam & Bertodi 2007, 31.).

According to Epstein (1997,21) and Haug (1993), the composting system can be divided into two main phases, high-rate or active composting phase, and curing phase (figure 6). The phases again can be divide to sub-temperature zone which are mesophilic and thermophilic and in the end of curing phase is the stable and mature stage of the compost. Similarly, Insam & Bertodi (2007, 31) expanded the

definition by dividing composting process into four phases which are, mesophilic phase, thermophilic phase, cooling or second mesophilic phase and maturation phase.

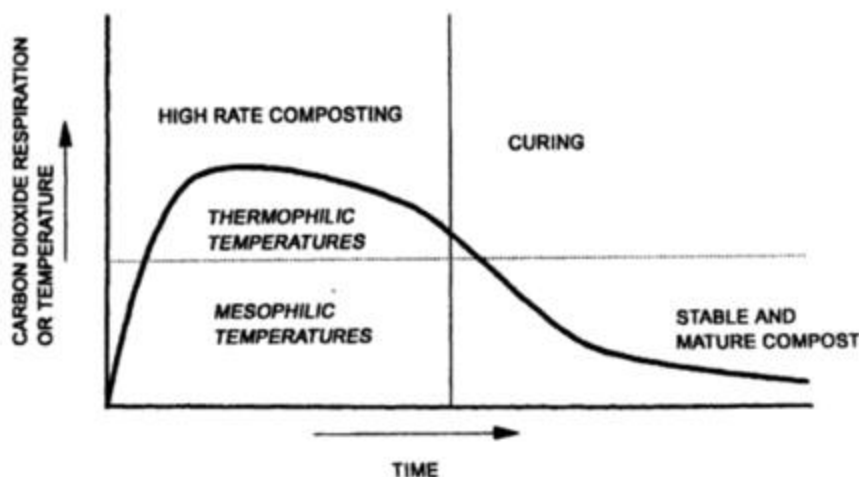


Figure 6. Phases during composting in relation to carbon dioxide respiration or temperature (Epstein 1997,21)

In the first phase, mesophilic phase, with the temperature between 10°C and 45°C, it is the functioning environment of mesophilic microorganism such as bacteria, fungi, actinomycetes, protozoa. As primary decomposer, these microorganisms initiate and degrade the available susceptible and easily decomposable organic matter such as sugar or protein. Mesofaunas such as mites, worms, millipedes, springtails also flourish and act mainly as catalyst. Their role in composting process can be either neglectable or considerable depending on the composting method. In addition, during this phase, the temperature is gradually raised due to the function of the primary decomposer oxidizing carbon compound, resulting in the take-over of thermophilic microorganism and the beginning of the second phase (Insam & Bertodi 2007, 32; Cooperband 2000).

The second phase, thermophilic phase, starts as the mesophilic microorganism are almost fully alternated with thermophilic microorganisms, which are capable of functioning within 45°C and 70°C temperature range. The dead mesophilic organism along with the remaining easily degradable compounds are digested by the microbe community. The decompose process accelerate and temperature continue to raise rapidly until approximately 62°C. This takes round 24 to 72 hours

and then the temperature is maintained for several weeks (Insam & Bertodi 2007, 32 & 33; Cooperband 2000). Normally, the rise in temperature is induced by microbial activities and the elimination of most microorganism should happen around 65°C. However, occasionally the temperature may raise up to 80°C which is possibly resulted from abiotic exothermic reaction. As the consequence, most mesophiles are erased and obstruct the recovery of the compost pile after the peak of temperature. The phase is very essential for hygienization that pathogen, weed seed and insect larvae are destroyed (Insam & Bertodi 2007, 33 & 34.). This phase, and the previous are called in general the active phase by Epstein (1997,21) and Haug (1993). According to Haug (1993), the phase can be summarized into a few main characteristics, high oxygen uptake, thermophilic temperature, high reduction in biodegradable volatile solid and higher odor potential. Regular aeration or turning is necessary in this phase (Cooperband 2000).

The third phase is cooling or second mesophilic phase. It is as well the beginning of curing phase according to (Cooperband 2000) as the temperature start to decrease which is described in figure 6. The decline of temperature is resulted from the surcease of thermophilic microbial activity due to substrate shortage (Insam & Bertodi 2007, 34). The temperature drops down to around 38°C and mesophilic microbes recolonize. The oxygen uptake rate also decreases that frequent turning and aeration is no longer needed (Cooperband 2000.). The microorganisms including bacteria and fungi start to digest starch and cellulose (Insam & Bertodi 2007, 34). In addition, odor potential is also lower in this curing phase than the previous (Haug 1993).

The final phase, the maturation phase happens when substrate downgrades in quality and the whole microbial community is replaced (Insam & Bertodi 2007, 34). Normally, it takes roughly 1 to 4 months to reach this stage. The maturation of compost is very important as immature compost might contain unfavorable features that harm plants such as high C:N ratio, high pH or salt content (Cooperband 2000.).

### **2.3 Factor that affect the composting process**



Different authors proposed different factors that could affect the success of composting process. However, there are a few factors which they all had in common. Accordingly, the major affecting factors are moisture, oxygen, temperature, pH and nutrient.

### **2.3.1 Moisture**

Moisture is the first essential factor for composting process since it is needed for microbial activity and can influence decomposition rate. Too low moisture content below 40% causes early dehydration and therefore results in unstable compost. Additionally, low moisture retards the process and the organic material would decompose very slowly. On the other hand, in the condition of too high moisture content above 60%, the water tends to block pores making the pores filled with water instead of oxygen. As the consequence, anaerobic condition could occur and results in slow process and unsatisfied final product. Moisture content between 50% and 55% is preferred. Appropriate moisture content should be achieved from the beginning and maintained during the whole process since frequent adjustment of water content could affect other factors (Diaz & Savage 2007, 56; Cooperband 2000; Stanly & Turner 2010, 35; Epstein 1997, 32.).

### **2.3.2 Oxygen content**

In aerobic composting, it is very crucial to supply enough oxygen for aerobic microorganism activity. The average air content is 20% consisting of 15-20% oxygen and 0.5-5% carbon dioxide. The oxygen content lower than the range allow anaerobic microbial community to replenish and overpower. As the consequences, unpleasant odor and toxic chemical in the compost are produced unwantedly. Therefore, frequent turning and aeration should be implemented in order to ensure adequate amount of oxygen in the compost heap (Diaz & Savage 2007, 54; Cooperband 2000; Stanly & Turner 2010, 35.).

### **2.3.3 Temperature**

Temperature is another dominating factor which influence whether the composting could be successful or not. Temperature involves in the activity of microbial community which has a direct impact on the decomposing rate of organic matter. Composting is an exothermic process that release a considerable amount of energy. Most of which is lost in the mass under the form of heat and therefore results in temperature increase possibly up to 70-90°C. Thermophilic phase is very crucial for eliminating pathogens. However, other than which, the high heat would constrain microbial growth. De Bartodi et al (1983), Finstein (1983) and Steintford (1993) recommended that between 30°C and 45°C is the most suitable temperature to achieve high rate biodegradation and maximum microbial diversity. Whereas, Diaz & Savage (2007, 53) studied that at nearly 60°C, the highest oxygen uptake indicates the optimum decomposing temperature. Figure 7 shows time-temperature curve which expresses the temperature change throughout composting process of biosolid and wood chip. Generally, the temperature rises in the beginning of the process and then gradually diminish (Diaz & Savage 2007, 53&54; Cooperband 2000; Epstein 1997, 36-38.).

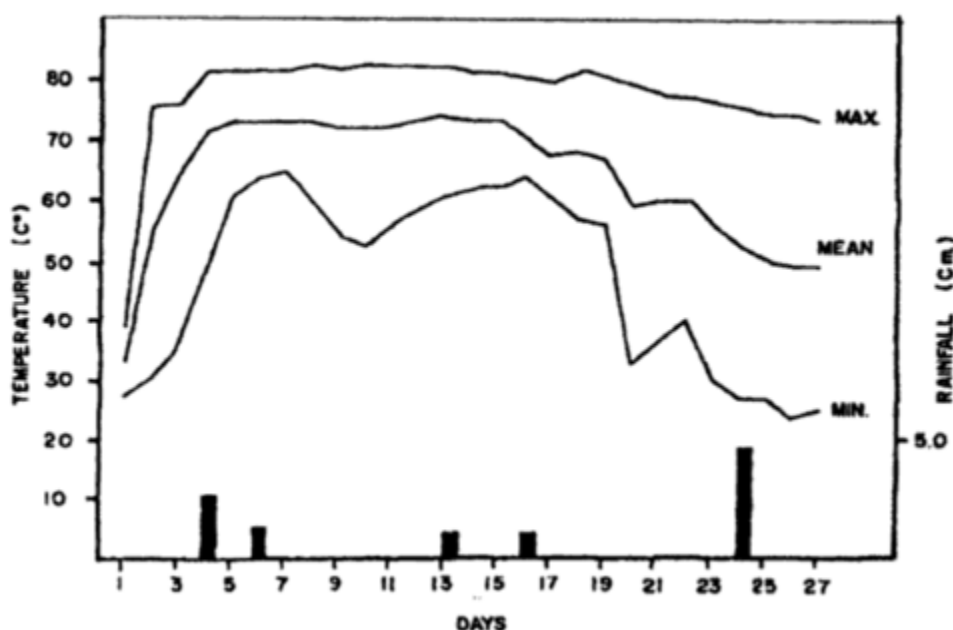


Figure 7. Time-temperature curve of biosolid and wood chip (Epstein 1997, 37)

### 2.3.4 pH

Within pH range between 3 to 11, organic matter can be normally composted. Nonetheless, the optimal composting rate would happen within pH 5 to 8. The bacteria favor nearly neutral pH whereas fungi flourish in rather acidic pH. Additionally, higher than 7.5 pH could lead to nitrogen loss as the consequence of ammonia evaporation (Diaz & Savage 2007,54; Cooperband 2000.).

In the beginning of composting process, the pH usually drops under 5 due to the activity of acid-forming bacteria. After which, as the intermediate metabolites are entirely mineralized, pH would rise again and reach roughly pH 8-8.5 in the end of the process (Diaz & Savage 2007,54.).

### **2.3.5 Nutrient and C/N ratio**

Carbon and nitrogen are the most essential nutrient. Furthermore, the balance between carbon and nitrogen influence the success of the process and even product quality (Epstein 1997, 39.). Carbon is important for cellular growth while nitrogen is needed for protein synthesis (Epstein 1997, 39&43). Studies have shown that, 25 to 30 parts of C for every unit of N, which means C/N ratio equal 25:1 to 30:1, is the optimal balance for most type of waste (Diaz & Savage 2007,51; Stanly & Turner 2010, 34; Epstein 1997, 39). The balance is very crucial and thus there would be penalties as consequences from imbalances. In general, too high C/N ratio exceeding the adequate range leads to slow decomposition and composting due to nitrogen deficiency causing diminished cellular growth (Epstein 1997, 43). On the other hand, if the C/N ratio is too low, nitrogen loss through evaporation may occur. The loss could even be worse when there is a combination of high temperature and high pH from 8-9 (Diaz & Savage 2007,51.). according to Diaz & Savage (2007,51), C/N ratio would abate continuously throughout the well-controlled process due to biological mineralization of carbon and loss as carbon dioxide.

## **2.4 Differences between biodegradability and compostability**

The term “biodegradability” and “compostability” have been used interchangeably. As the consequence, commercial consumers are confused from the misunderstanding between the two terms (Ebnesajjad 2013, 189). Despite the fact that they are both natural processes where microorganism such as bacteria, fungi are in charge of breaking down organic matter in the material into simple substances, “biodegradability” and “compostability” are not analogous (Ashter 2016, 61). The different can be vividly observed in figure 8.

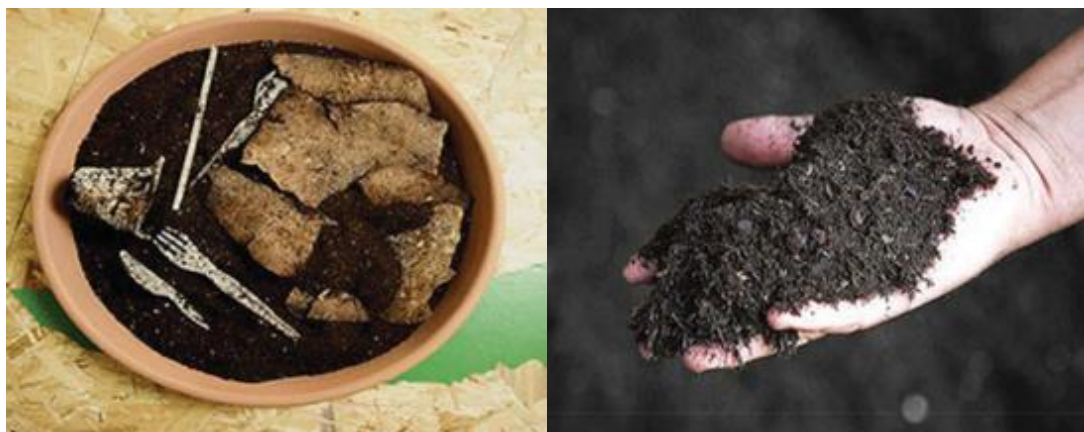


Figure 8. Biodegradability (a) and Compostability (b) (Ashter 2016,61&62)

Briefly, biodegradability is the ability of material to be broken down into simpler compounds such as carbon dioxide, water and mineral salts. The process is also termed mineralization. In fact, completely mineralization does not always occur. Figure 8 (a) shows biodegradable material biodegrading in the soil media. On the other hand, a material claimed to be compostable beside possessing biodegradability, it as well decomposes and loose visibility in the soil media to create a final product called compost which is shown in figure (b). That physical ability to fragment and amalgam with the compost media is called disintegration (Ashter 2016, 60; Degli-Innocenti 2002, 5.).

Despite being used widely, the term “biodegradable” from scientific point of view is not very descriptive and unable to provide sufficient information regarding the extent of biodegradation whether it is partial or complete conversion (Ebnesajjad 2013, 190). According to Ebnesajjad (2013, 191), “A plastic can be degradable without being biodegradable, i.e., it might disintegrate into pieces or even an in-

visible powder, but not be assimilated by microorganism. A plastic can be degradable and even biodegradable without being compostable, i.e., it might biodegrade at a rate that is too slow to be called compostable.”

Studies have shown that any organic compound can be biodegradable (Degli-Innocenti 2002, 1). Therefore, material claimed to be compostable have to fulfill stricter requirements characterized by SFS standard EN 13432:2000. Other than being able to biodegrade into carbon dioxide, water, inorganic compounds and biomass, they have to disintegrate into the compost and shows almost no visibility. Furthermore, the material after the completion of the process must possess no heavy metal, toxicity and leave no toxicity effect to the final compost and the quality of which must reach specific criteria listed in, for example, SFS standard EN 13432:2000 Ebnesajjad (2013, 191; Kale et al 2007.). The properties are summarized in figure 9.

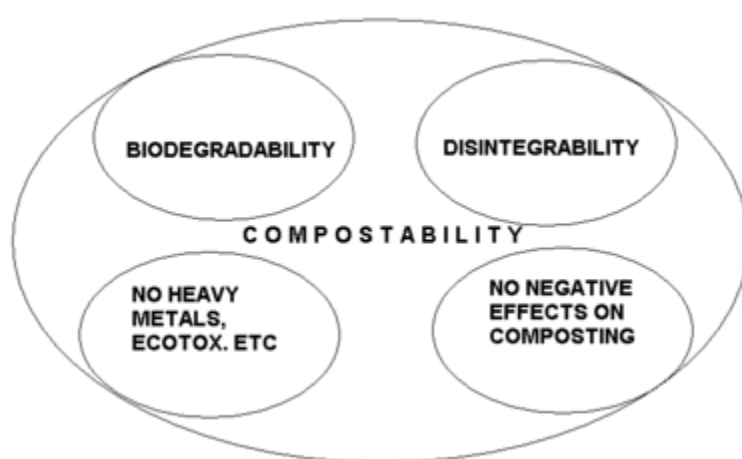


Figure9. The characteristics of compostability (Degli-Innocenti 2002)

## 2.5 Biodegradable and compostable polymer for packaging

Thanks to the effort of science and technology, plastic was invented and become a great convenience every fields of life and industry including packaging fields. Nonetheless, the conventional plastic which are most used for packaging such as Polyethylene Terephthalate (PET), Polyethylene (PE), Polystyrene (PS), Polypropylene (PP) or Polyvinyl Chloride (PVC) were originally designed to be resistant and non-biodegradable. As the consequence, their accumulation has

been a great threat. The invention of biodegradable plastic as well as compostable plastic is a considerable approach to alleviate the problem (Tokiwa et al, 3722&3723.).

The term “biodegradable” plastic and “compostable” plastic have to be distinguished. According to Ebnesajjad (2013, 191), compostable plastic was specifically designed to a given safe disposal method which is composting. In the end of use, compostable plastic will biodegrade in composting process. In general, all compostable plastics are biodegradable but not all biodegradable plastics are compostable (Kale et al 2007). Therefore, “biodegradable” term should be avoided to label plastic material and packaging (The UK Plastics Pact 2020, 4). The specific requirements for labelling a plastic material as “compostable” can be consulted from European standard EN 13432 (Oakes 2019). Since the topic of this thesis focus on disintegration during aerobic composting, the requirement for disintegration aspect in aerobic composting process is quoted: “Following submission to the composting process for a maximum of twelve weeks, not more than 10 % of the original dry weight of test material shall fail to pass through a > 2 mm fraction sieve.”

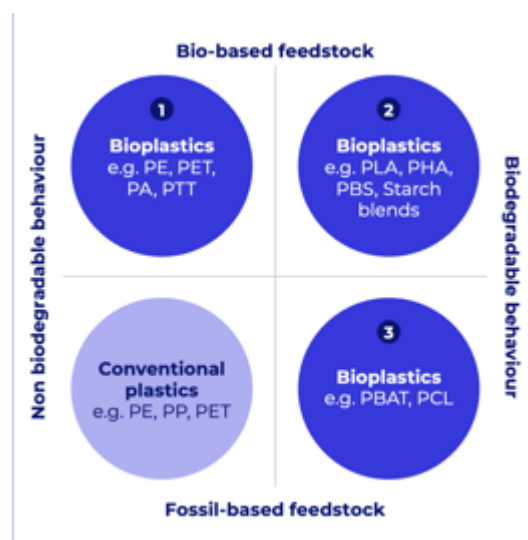


Figure 10. Bio-based plastic and fossil-based plastic (The UK Plastics Pact 2020, 5)

Plastic are usually constructed from bio-based and fossil-based feedstock as raw material. It is noteworthy that not all bio-based plastics are compostable or even

biodegradable and vice versa (The UK Plastics Pact 2020, 5). A few examples are presented in figure 10.

From Ebnesajjad (2013, 191) point of view, compostable plastic is categorized differently and based on both their origin or preparation method (Figure 11).

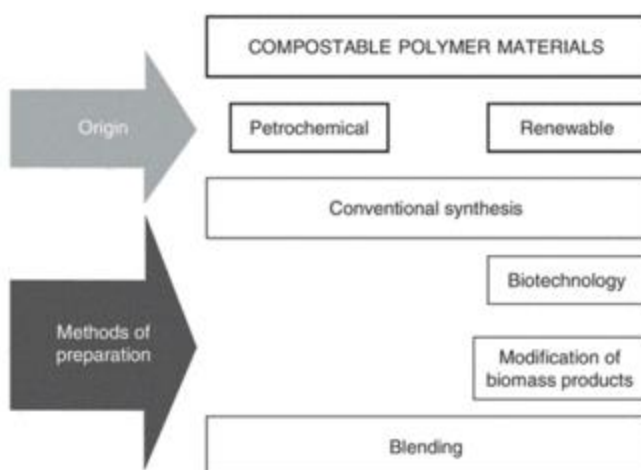


Figure 11. Compostable plastic categories (Ebnesajjad 2013, 191)

Poly lactide (PLA), Polyhydroxyalkanoates (PHB), thermoplastic starch, cellulose, chitosan, proteins are a few examples of biodegradable plastics derived from renewable resources. In which, only thermoplastic starch, cellulose, chitosan, proteins are recognized as compostable. On the other hand, PCL, PVA, PBS are biodegradable plastic from petroleum resources. None of which are considered as compostable. However, with some methods of preparation, compostable polymer material can be produced from either type of polymer. For instance, compostable polymer PHBV can be produced via biological routes, or starch-PCL blends can be prepared by blending. The blending method is usually utilized to enhance the properties of compostable polymer Ebnesajjad (2013, 191-192.).

### 3 MATERIAL AND METHODS

#### 3.1 Overview of the experiment

The disintegration of the material was evaluated by aerobic composting under a defined condition following the European Standard EN 14045:2003. The experiment was implemented in six pilot-scale compost bins in Soil Science laboratory of Tampere University of Applied Sciences (figure 12). The study lasted for 12 weeks from 6<sup>th</sup> of June to 4<sup>th</sup> of September 2019.



Figure 12. The six composters

The set-up of the experiment is presented in figure 13. Two compost bins included the test material, two other (T1, T2) contained reference material (R1, R2) and finally the last two were controls (C1, C2). To emphasize, the standard has stated that disintegration of the material is the main purpose of this standard, biodegradability is a distinctive concept and should be evaluated using other methods.



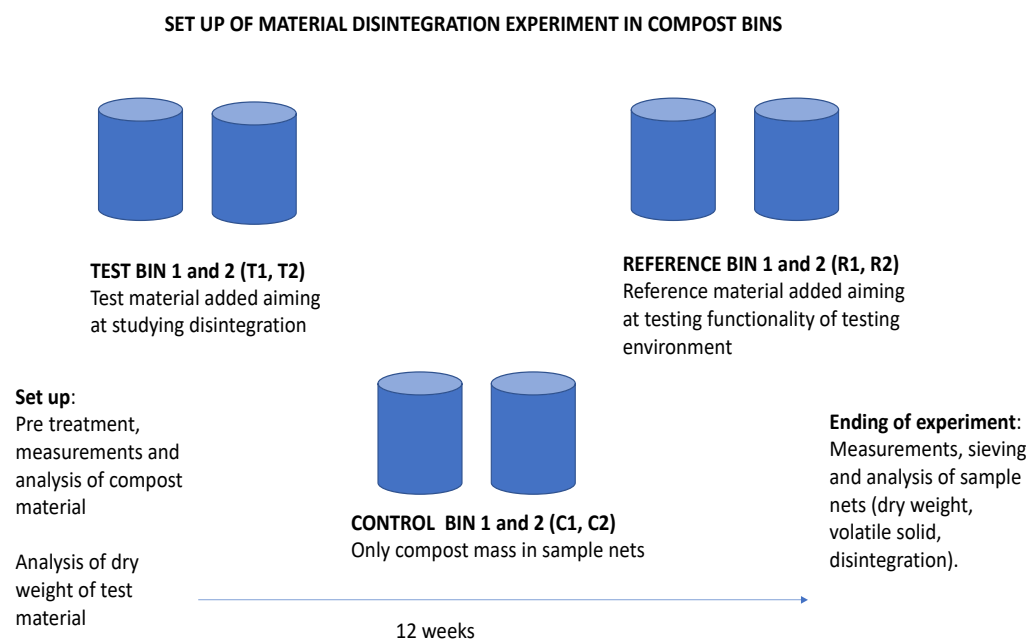


Figure 13. Overview of the experiment

### 3.2 The test and reference material

The polymer packaging material for testing (figure 14) in this experiment was received from VTT. Figure 15 presents our reference material which was composed of cellulose.



Figure 14. Polymer packaging test material



Figure 15. Reference material

### 3.3 Setting up the compost bins

#### 3.3.1 Collecting the composting media



Figure 16. Biowaste from Pirkanmaan Jätehuolto (Photo by: Inka Honkala)

According to standard, for the best composting process, the biowaste should be homogeneous, at the same age and origin. In practice, it is quite impossible to fulfil completely the criteria. In Tarastenjärvi (Pirkanmaan jätehuolto) bio-waste is collected and stored in the same place and it was unlikely that the it was at the same age. Sources of biowaste are various. In addition, the biowaste was noticed to be containing a lot of different material including plastic or metal packaging

which needed further handling prior to the experiment. The biowaste was collected twice in two weeks in a row to fulfil the quantity since it was unable to collect enough biowaste all at once (figure 16).

### 3.4 Analysis of the compost media

According to the standard, the obtained biowaste was carefully analysed and prepared to ensure some basic requirements. The requirements include C/N ratio, moisture content, pH and volatile solids. It was very important that the biowaste should fulfil the mentioned requirements. Otherwise, the incompetence could affect the whole process and fault results could be derived. Following the standard, the samples were taken separately for the analyses and taken after mixing the biowaste from two collecting rounds.

#### 3.4.1 Volatile solids

The volatile solid of the biowaste mixture was achieved by the determination of loss on ignition. The experiment was carried out following SFS standard EN 15935:2012. Basically, volatile solid represents the amount of organic solid contained in the biowaste, which are lost on ignition as the dry solid is ignited at 550°C.

For this test, random amount of biowaste mixture was dried overnight in the oven at 105°C. From which, three samples were prepared in three crucibles. Each crucible contained roughly 5 grams of the dried mixture. The filled crucibles were then placed in a cold furnace while the temperature was slowly raised to (550±25)°C for one hour, then hold the temperature for 2 hours. The weighting was implemented after the crucibles were cooled down to ambient temperature. From which, the loss on ignition presenting the volatile solid of the biowaste mixture was calculated with formula (1) from the Method Book by FCQAO and presented in APPENDIX.

$$GV = [(M_{vdG} - M_{ndG}) / (M_{vdG} - M_{tara})] \cong 100[\%] \quad (1)$$

In which,

GV: Loss on ignition (%)

$M_{\text{tara}}$ : Mass of the empty crucible (g)

$M_{\text{vdG}}$ : Sample weight +  $M_{\text{tara}}$  before burning

$M_{\text{ndG}}$ : Sample weight +  $M_{\text{tara}}$  after burning

The final loss on ignition was taken as the average of the three samples. Accordingly, the volatile solid content of the biowaste mixture was 92.8%, which fulfilled the requirement stated by SFS Standard EN 14045:2003. The standard implied that the volatile solid content should not be below 50%.

### 3.4.2 C/N ratio

To calculate the carbon and nitrogen ratio, the carbon and nitrogen in percentage contained in the biowaste mixture had to be analysed and calculated separately. While the carbon content could be achieved from the loss on ignition test, the nitrogen content was yielded with Kjeldahl digestion. As stated in SFS Standard EN 14045:2003, the optimum C/N ratio of the mixture should be between 20 and 30. Otherwise, some treatment should be implemented. In our case, we had had a good C/N ratio which fulfilled the criteria.

Since there was no prior information concerning the nitrogen contained in the biowaste, three different sample masses were tested. This was essential to implement in order to discover which mass amount would result in the optimal consumption of titrant, which was 0.25M Sulphuric acid. The titrant volume ranged between 3mL and 17mL. From the titrant consumptions yielded from the experiment, nitrogen content in the biowaste mixture was calculated and revealed appendix 3. Finally, the final nitrogen content in percentage of the biowaste mixture was calculated as the average and the result was 2.15%.

On the other hand, the carbon content of the biowaste mixture could be yielded from the loss on ignition test with the calculation below.

$$C - value = 92.8\% \cdot 0.58 = 53.2\%$$

Finally, the C/N ration of the biowaste mixture could be calculated as following.

$$C/N = 53.2/2.15 = 25.03$$

C/N ratio fulfilled the requirement of the standard.

### **3.4.3 Moisture content and pH**

According to used standard, moisture content should be at least 50% or water had to be added to achieve the requirement. Moisture of the biowaste mixture was studied from three samples taken randomly in different positions of the mixture using Precisa XM 60 device. Samples of 2 g was burnt under the heat of 105°C until there was no more moisture to evaporate. In addition, the test was carried out three times with the same method. The results are presented in appendix. Biowaste mixture fulfilled the requirements of the standard.

According to the standard, pH shall be above 5. The pH was measured from five samples taken randomly from the biowaste using Mettler Toledo device. Prior to testing, the device was carefully calibrated the sample were well mixed with de-ionized water in a ration of 1:5 then left for settling for roughly 10 minutes before measuring the liquid phase.

### **3.5 Set up of the compost bins**

According to SFS Standard EN 14045:2003, 60 kg of pure biowaste should be filled in each compost bin in total. In addition, the sample nets should contain at least 20L biowaste mixture and the material went into the net should equal to 1% of the biowaste mass. Accordingly, the content of the compost bin with the sample net (figure17) was calculated based on known information filled as close as possible to the standard.

Biowaste and bulking agent ratio equal to 1:3 volume based informed by the waste management company. In addition, the density the biowaste mixture was estimated to be 1.14kg/L. Eventually, each compost bin was filled 77.164 kg in total. In which, the nets contained 15kg of biowaste mixture and 114g of material.

Notably, the net content was carefully treated by taking out unbiodegradable pieces and breaking down big chunks.



Figure 17. The sample nets

### 3.6 Monitoring the process

The test duration was 12 weeks in total. During which, daily and weekly monitoring were carried out, including checking the composters' pH, moisture, temperature, mixing the content of both inside and outside of the net, and visual observation.

According on standard, the mixing should be done every week during the first 4 week and every 2nd week until the end of the test in order to break down clumps and remix water, microorganism and substrate. However, due to lack of oxygen

measurement equipment, the procedure had to be adjusted. The composter including the content of the net were mixed manually twice a week for the first 4 weeks then every other week until week 12. However, there was difficulty in mixing all the way down to the bottom. Therefore, the composters were mixed from the bottom to the top occasionally.

The moisture content and pH were checked once or twice every week with the same method as in section 3.4.3 to ensure the quality of the compost. However, the moisture content was only carefully inspected from week 4. Before that, it was observed visually.

On the other hand, the temperature was daily checked to ensure that the temperature would not exceed 65°C. There were as well temperature loggers installed and would be read in the end of the test.

### **3.7 Termination of the experiment**

#### **3.7.1 Sieving procedure**

The compost collected from the nets of each composter was sieved through a 10mm sieve. The packaging material and reference material was searched from the portion which were overflow from the 10mm sieve. The sieved portion was then divided into two equal portions. One of which would go through sieving to separate fraction which was 2-10mm and fraction which was smaller than 2mm while the other one was used for used for other tests. Only the material which belonged to 2-10mm fraction had to be separated and analysed along with the material from the previous fraction (bigger than 10mm fraction). The sieving procedure is described shortly in figure 18.

The sieving through the 10mm sieve was simple since the grids were large and the compost could be easily screened through. In contrast, there was trouble in sieving the smaller fraction since the compost was too wet to be screened through such small grids. Therefore, the compost portion was left to dry for more than a month. As the compost dried out, the moisture was loss and the initial compost mass decreased. After the period, it was able to use the mechanical sieve to

sieve the fraction. Instead of only sieving through 2mm sieve, 4mm sieve was also used for easier separation of the material later after. All the retrieved material after being separated from compost were carefully washed and air dried.

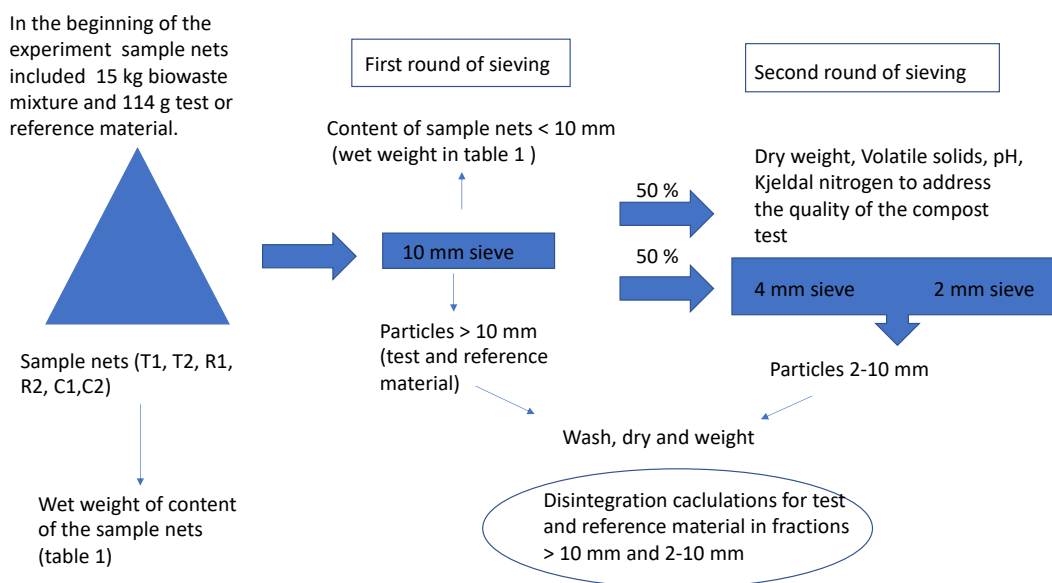


Figure 18. Sieving procedure

### 3.7.2 Dry weight of the material

The main aim of SFS Standard EN 14045:2003 and this experiment was to find out disintegration degree of the polymer packaging material. Prior to calculate the disintegration degree, dry mass testing was implemented on the retrieved material and original material (test/packaging material and reference material). The dry mass indicated the residual mass after the material was dried under a specific temperature which in this case, was 105°C.

Since there was no particular standard for such material, standard for testing cellulose acetate moisture content, International Standard ISO 585:1990, was consulted to do the test. Based on the mass of retrieved material of each compost, a suitable amount of the material was weighted to crucibles which were put into constant mass in prior. Since the melting point of both test material and reference material were unknown, it was decided to first dry under 40°C. However, since there was no major difference detached and there was some error, the sample was subsequently dried under 105°C for three hours. Eventually, the dry mass was yielded by 100% subtracting the moisture content calculated according to



ISO Standard 585:1990. It was noted that the dry mass of the retrieved material was unable to achieved by the method in section 3.2.3 due to small amount of the material available.

### 3.8 Disintegration

The disintegration of the test material (on dry weight basis) >2 mm with formula (2) according to SFS Standard EN 14045:2003. According to the standard, “The disintegration of the test material (on dry weight basis) >2 mm should be calculated pn the basis of the results of the analyses and weight determinations of the various sieving fractions”

$$\text{Disintegration of test material } D (\%) = \frac{m_{(1)} \cdot R - m_{(2)}}{m_{(1)} \cdot R} \times 100 \quad (2)$$

In which,

$m_{(1)}$ : Dry weight of test substances input

$m_{(2)}$ : Dry weight of the retrieved test substance > 2mm

and,

$$R = \frac{\text{compost screened}}{\text{total compost}} \left( \frac{w}{w} \right) \quad (3)$$

In the standard, it was noted that: “The disintegration of the test material (on dry weight basis) >2 mm should be calculated on the basis of the results of the analyses and weight determination of the various fraction.” Whereas, the residual amount of tested material should be calculated with the ratio between the amount of the retrieved material at the end of the test and add material at the test beginning. The calculation is expressed by formula (4).

$$\text{Residual amount of tested material} = \frac{\text{retrieved material (g)}}{\text{input material (g)}} \left( \frac{w}{w} \right) \quad (4)$$

## 4 RESULTS

### 4.1 The finished compost – Analysing the content of the net

Table 1 shows the mass of the whole net content, mass of the fraction bigger and smaller than 10mm after the first round and second round of sieving.

Table 1. Mass of the net content and different fraction after the first and second round of sieving (kg)

Sample net	Wet weight of the net content (kg)	Mass of the fraction > 10mm (kg)	Mass of the fraction < 10mm (kg)
T1	12.65	4.55	7.7
T2	12.35	4.35	8.0
R1	11.65	4.15	7.45
R2	12.55	3.95	8.6
C1	12.5	3.8	8.75
C2	12.8	5.05	7.45

The fraction which was smaller than 10mm was then divided in two. One of which was brought to separate through 4mm and 2mm sieve and weighted. The results are indicated in table 2.

Table 2. Mass of the final compost with fraction smaller than 10mm of the second round of sieving

Sample net	Mass of fraction < 10mm divided (kg)	Mass of different fractions (kg)		
		> 4mm	> 2mm	< 2mm
T1	3.85	0.4582	0.167	0.4106
T2	4	0.6512	0.1152	0.3550
R1	3.375	0.5152	0.1332	0.3948
R2	4.15	0.5368	0.1940	0.3176
C1	4.2	0.5782	0.1336	0.4140
C2	3.75	0.5210	0.1290	0.2872

## 4.2 The material

### 4.2.1 Visually observation during the experiment

Figure 19 below shows the test material and reference material 12 days after the test started. The reference material had started to show signs of biodegradation and disintegration as it became yellowish and the edge looked like it was ripped while the test material was still remained unchanged.



Figure 19. Test material (left) and reference material (right) on 18.6.2019 (Photo by: Mariia Kornei)

Figure 20 shows the test material and reference material 27 days after the test started. The test material still did not show any visible sign of disintegration while the reference material had become more yellowish the size was reduced.

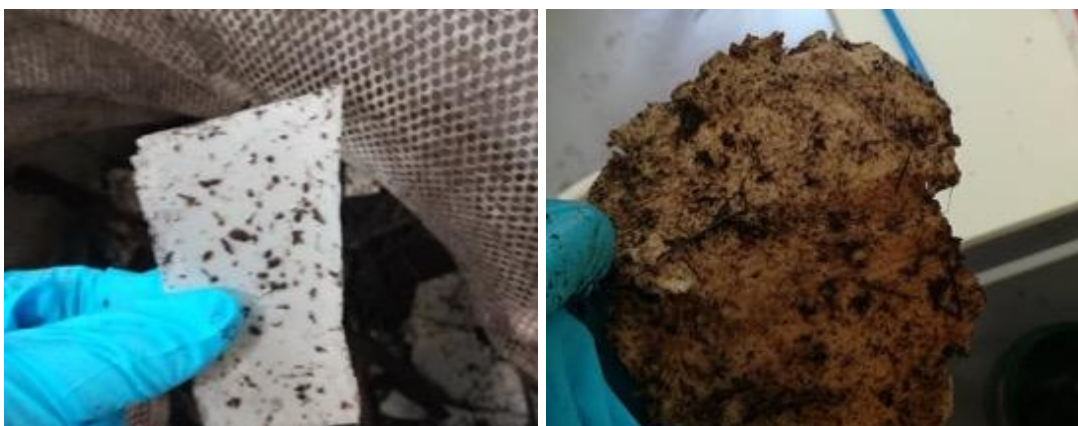


Figure 20. Test material (left) and reference material (right) on 2.7.2019 (Photo by: Mariia Kornei)

Figure 21 shows the test material and reference material 32 days after the test started. the test material started to show signs of disintegration as the edge was ripped. However, the colour was roughly the same as in the beginning. On the other hand, the reference material had been further degraded by observing the colour and the size.



Figure 21. Test material (left) and reference material (right) on 10.7.2019 (Photo by: Mariia Kornei)

Figure 22 shows the material 6 days before the test was ended. The test material was significantly reduced in size and no big pieces were found. Although the reference material although showed earlier in the experiment signs of degrading, big pieces were still found at this point.





Figure 22. Test material (upper left) and reference material (upper right and bottom) on 10.7.2019 (Photo by: Mariia Kornei)

#### 4.2.2 Sieving and weighting

From each compost fraction, the test material and reference material were separated, washed and weighted. There was no reference material found in R1. The mass after the samples were washed are indicated in table 3. It should be noticed

that the material collected from under 10mm fraction have to multiplied by two to get the final results (see figure 18 for the sieving procedure). The reason of which is because the compost in this fraction was divided in half.

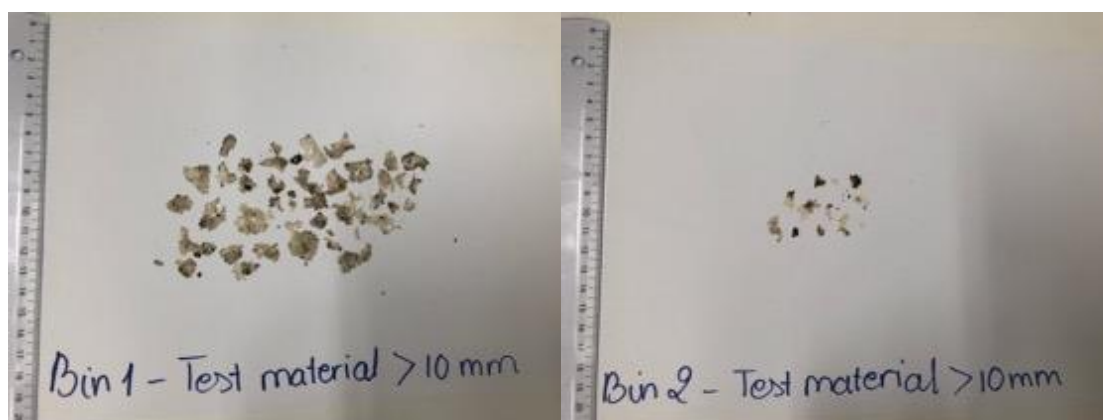


Figure 23. Test material fraction  $> 10\text{mm}$  from T1&T2



Figure 24. Reference material fraction  $> 10\text{mm}$  from R1&R2

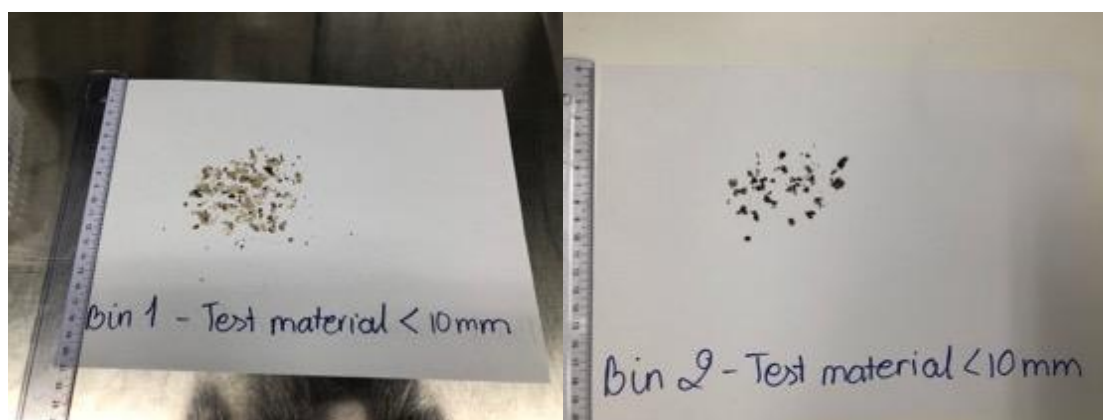


Figure 25. Test material fraction  $< 10\text{ mm}$  ( $> 2\text{mm}$ ) T1&T2

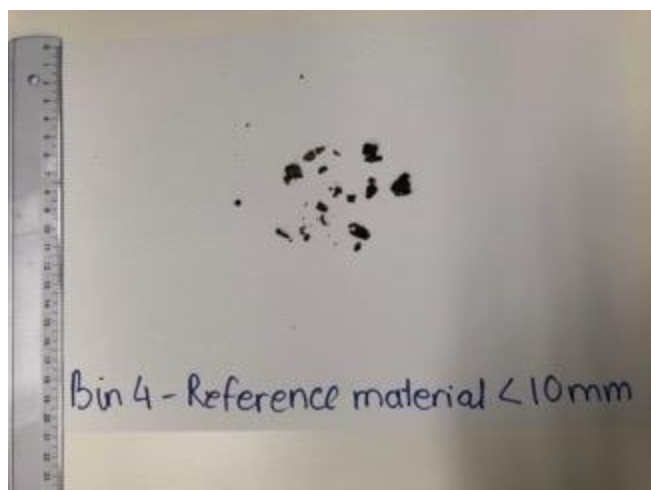


Figure 26. Reference material fraction <10mm (> 2mm) R2

Table 3. The mass of the material of each composter and fraction

Sample net	Mass of the retrieved material (g)	Mass final (multiplied by 2) (g)
T1 (<10mm)	0.2598	0.5196
T1 (>10mm)	0.5864	0.5864
T2 (<10mm)	0.0345	0.069
T2 (>10mm)	0.0805	0.0805
R1 (<10mm)	-	-
R1 (>10mm)	20.9475	20.9475
R2 (<10mm)	0.1144	0.2288
R2 (>10mm)	7.0535	7.0535

#### 4.2.3 Dry mass

Since there was no previous knowledge regarding the melting point of the material, it was decided that the material should be dried under 40°C. As the result, no visual difference was observed compared to the original sample. In addition, the mass difference was too small that the weighting procedure was fail and giving false results which can be seen in appendix 5. As indicated in the table, it does not reasonable to have the dried mass more significant than the wet mass.

The material was then dried under 105°C. Visually, it was challenging to define the differences compared to the original sample. It was noted that the colour of the dried samples was slightly more yellowish than the original one. The samples after being dried under 105°C is visually displayed in figure 28 and figure 29. On the other hand, the mass after drying under 105°C showed more considerable difference than under 40°C. However, the differences are not very significant. Furthermore, in the case of test material in composter 2, the mass difference was so small that the dry mass percentage was roughly 100%. The residual mass and dry mass under 105°C are presented in appendix 6.



Figure 27. Test material after being dried under 105°C



Figure 28. Reference material after being dried under 105°C

#### 4.2.4 Disintegration based on analyses and determinations of various fraction

From the data from table 3 indicating the mass of the final compost contented in the net with different fraction. Ratio R between the screened compost and total compost of each composter are calculated for both <10mm and >10mm fraction. The calculations are implemented applying (3). For instance, R ratio for <10mm fraction of T1 is calculated as following:



$$R = \frac{7.7}{12.65} = 0.61$$

With the same method, the rest R ratio are calculated and presented in the following table.

Table 4. R ratio

Compost bin	R	
	<10mm fraction	>10mm fraction
T1	0.61	0.36
T2	0.65	0.35
R1	0.64	0.36
R2	0.69	0.31

The dried mass of the original material and the total retrieved material are calculated. For example, following is the calculation of test material <10mm collected from T1.

$$\text{Retrieved material mass} = \frac{0.5196 \cdot 99.7}{100} = 0.5180 \text{ (g)}$$

The rest are calculated by the same method and indicated in table 5.

Table 5. Dry mass of the material

Sample net	Dry mass (%)	Retrieved material wet mass (g)	Retrieved material dry mass (g)
T1 (<10mm)	99.7	0.5196	0.518
T1 (>10mm)	99.7	0.5864	0.585
T2 (<10mm)	100	0.0690	0.069
T2 (>10mm)	100	0.0805	0.081
R1 (<10mm)	-	-	-
R1 (>10mm)	96.69	20.9475	20.254
R2 (>10mm)	98.85	7.0535	6.761
R2 (<10mm)	95.85	0.2288	0.219
Test	99.40	114 (input)	113.316
Reference	99.61	114 (input)	113.555

Finally, the disintegration of the material on the basis of various sieving fraction are calculated and presented in the table 6. The calculation was implemented applying formula (2).

For instance, the amount of input material contained in <10 mm fraction is:

$$113.316 \cdot 0.61 = 69.12276$$

Hence, the disintegration of test material of this fraction is:

$$D (\%) = \frac{69.12276 - 0.518}{69.12276} \cdot 100 = 99.25\%$$

Table 6. Disintegration of the material in various sieving fraction (%)

Material/ Composter/ fraction	Disintegration (%)
T1(<10mm)	99.25
T1 (>10mm)	98.57
T2 (<10mm)	99.91
T2 (>10mm)	99.8
R1 (<10mm)	-
R1 (>10mm)	49.93
R2(<10mm)	99.72
R2 (>10mm)	81.08

#### 4.3 Residual amount and disintegrated amount of tested material

The residual amount of tested material is yielded by applying formula (4). For instance, the residual amount of tested material of the test material in T1 is calculated as follow:

$$\text{Residual amount of tested material} = \frac{0.518 + 0.585}{113.316} \cdot 100 = 0.97\% \approx 1\%$$

Accordingly, the disintegrated amount of tested material is:

$$\text{Disintegrated amount of tested material} = 100\% - 0.97\% = 99.03\%$$

Eventually, the residual amount and disintegrated amount of tested material of the other composter are calculated and presented in table 7.

Table 7. Residual amount of tested material

Composter/ material	Residual amount of tested material (%)	Disintegrated amount of tested material (%)
T1	0.97	99.03
T2	0.13	99.87
R1	6.01	93.99
R2	17.8	82.2

#### 4.4 Volatile Solid

The volatile solid of the original material and retrieved material is calculated by the same method applied for the original biowaste in section 3.2.1 and presented in table 8. Figure 30 show the test material after being ignited under 550°C. Whereas, the reference material is shown in figure 31.

Table 8. Volatile solid of the material

Compost bin/ fraction	Dry sample+ crucible mass (g)	Ignited sample +crucible mass (g)	Volatile solid (%)
T1 (<10mm)	15.0646	14.8701	97.74
T1 (>10mm)	16.5810	16.3853	97.85
T2 (<10mm)	15.9573	15.9387	92.54
T2 (>10mm)	17.4759	17.4576	90.95
R1 (<10mm)	-	-	-
R1 (>10mm)	15.2968	15.1207	91.29
R2 (<10mm)	14.9268	14.9116	82.16
R2 (>10mm)	14.8810	14.7010	93.85
Original test material	15.8411	15.6443	98.94
Original reference material	14.9851	14.7925	100



Figure 29. Test material after ignition



Figure 30. Reference material after ignition

## 5 DISCUSSION AND CONCLUSION

### 5.1 Material analyses

Visual observation of test material in compost bins showed signs of disintegration during the last four weeks of experiment. At the end, the size of the test material was reduced significantly compared to the input material in the beginning (10 cm x 10 cm size). All the found pieces were very small and the mass of each sieved fraction was noted to be very low in which the highest mass recorded was roughly 0.6 g. In contrast, the reference material displayed quite significant changes in both colour and size after a few days the experiment started. At the end there was hardly any sign of reference material found in fraction < 10 mm, but big pieces remained on 10 mm sieve and the mass as well were quite high (21 g in R1 and 7.1 g in R2).

The calculations of disintegration of test material based on various sieving fraction showed that the material almost totally disintegrated. Test material in T1 blended into the compost 99.25% and 98.57% in >10 mm fraction and <10 mm fraction respectively; test material in T2 blended into the compost 99.91% and 98.8% in >10 mm fraction and <10 mm fraction respectively. In addition, only 0.97% of original dry weight in T1, and 0.13% of original dry weight in T2, was remained, failed to pass through 2 mm sieve, which fulfilled the requirements of SFS standard EN 13432:2000, "Following submission to the composting process for a maximum of twelve weeks, not more than 10 % of the original dry weight of test material shall fail to pass through a > 2 mm fraction sieve." Eventually, in T1, 99.03% of the test material disintegrated and in T2, the number was 99.87%.

Reference material in R1 and R2 remained in larger residuals, which means the reference material in R1 did not fulfil the validity of the test. The composting conditions such as temperature and moisture can affect the decomposing and disintegrating situation so sometimes in unpredictable manner.

The reduction in volatile solid was observed if compared between retrieved material and the input material. For instance, the original test material was 98.94%.

after the composting period, the volatile solid of the retrieved test material decreased to roughly 98% in compost bin T1. According to Varma et al. (2016, 8), volatile solid reduction occurs majorly at the end of late thermophilic stage. The loss of volatile solid throughout the composting period is resulted from the loss of CO<sub>2</sub> following microbial respiration. The loss indicates the decomposition, mineralization and maturity of the composting process (Hamideh et al., 2020.).

## 5.2 Error evaluation

Despite following SFS standard 14045:2003, the instruction of the standard was not always clear and interpreting was sometime challenging. The standard provides the guidelines for the composition of the biowaste mix. For technical reasons, the biowaste was obtained as a ready-made mixture of biowaste and bulking material and it probably wasn't fully optimal for this experiment. The volumetric ratio of the biowaste: bulking agent was suitable for an industrial composting facility but not necessarily for the smaller-scale experiment. In addition, the age of the biowaste in the mixture was not known. The mixture also contained other materials, such as plastic or metal due to its origin (source-separated biowaste) that may impinge the interpretation of the test.

During the composting period, it was noticed that the mixing/ turning should be implemented from the bottom to the top otherwise the composition rate would vary in different parts of the compost bins. In our case, the bottom was not mixed well in the beginning resulted in unpleasant smell and rotting in the bottom part and the compost there became too dense to mix.

The sieving procedure was difficult to implemented especially for 2 mm sieve since the compost was too wet that it hardly passed through the sieved. Hence, it was time consuming to let the compost dry enough to carry out the procedure. In addition, although the separation of the material was carefully implemented, it was unavoidable to miss some pieces in the compost resulting in errors in subsequent analyses. During the analyses, it was noted that the material was so light that it was difficult to handle especially in weighting so it was possible to exist some errors. The small amount of retrieved material was also problematic in analyses since there was not enough sample for some analysing method.

### **5.3 Suggestion for the development**

The biowaste and bulking agent mixture should be mixed in the lab for more accurate and optimum ratio. The biowaste picking-up process should be more effective to ensure the quality of the biowaste. In this experiment, the biowaste was picked up twice, which resulted in the difference in quality and age of the biowaste. During the monitoring period, the compost bins should be mixed from the bottom to the top from the beginning. In our case, we started mixing in the bottom only when the smell was noticed and by then, the bottom was rotten and hard to mix. Finally, the oxygen content should be monitored to ensure the oxygen resource for microbial activity and to not under or over mix the compost bins.



## 6 CONCLUSION

In conclusion, the test material was well disintegrated. The residual amount of the test material fulfilled the validity of the test stated by SFS standard EN 13432:2000 that no more than 10% of material should fail to pass through 2mm sieve. However, to be qualified as “compostable”, the packaging material still has to pass other test to evaluate its biodegradability and toxicity to the compost.

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**APPENDICES**

## Appendix 1. Moisture content (%) of the biowaste mixture

Sample	Initial mass (g)	Mass loss (g)	Moisture (%)
1	1.863	0.660	64.59
2	1.754	0.964	55.05
3	1.845	1.223	66.44

## Appendix 2. pH of the biowaste

Sample	pH
1	4.48
2	5.69
3	5.67
4	4.68
5	4.22

## Appendix 3. The nitrogen content in percentage of the biowaste samples

<b>Sample</b>	<b>Sample mass or volume (g or mL)</b>	<b>Titrant in sample (mL)</b>	<b>Titrant in blank, n=5 (mL)</b>	<b>Titrant c (M)</b>	<b>%N</b>
<b>2g-1</b>	1,9997	5,86	0,0792	0,25	2,02
<b>2g-2</b>	1,9878	6,32	0,0792	0,25	2,20
<b>2g-3</b>	2,0329	5,35	0,0792	0,25	1,82
<b>2g-4</b>	2,098	5,75	0,0792	0,25	1,89
<b>2g-5</b>	2,0495	6,32	0,0792	0,25	2,13
<b>1g-1</b>	1,0056	3,26	0,0792	0,25	2,22
<b>1g-2</b>	1,0031	3,58	0,0792	0,25	2,44
<b>1g-3</b>	1,0574	3,38	0,0792	0,25	2,19
<b>1g-4</b>	1,0154	3,31	0,0792	0,25	2,23
<b>1g-5</b>	1,0557	3,53	0,0792	0,25	2,29
<b>0.5g-1</b>	0,5055	1,54	0,0792	0,25	2,03
<b>0.5g-2</b>	0,5166	1,76	0,0792	0,25	2,28
<b>0.5g-3</b>	0,5104	1,58	0,0792	0,25	2,06
<b>0.5g-4</b>	0,5055	1,88	0,0792	0,25	2,50
<b>0.5g-5</b>	0,5145	1,48	0,0792	0,25	1,90

## Appendix 4. Loss on ignition of the biowaste mixture

Crucible	Loss on ignition (%)
1	92.5821
2	93.1678
3	92.7143
Average	92.8



## Appendix 5. Dry mass under 40 °C

Sample net	Crucible mass (g)	Sample initial mass (g)	Sample + Crucible mass (g)	Dried sample (40 °C) + crucible mass (g)	
T1 (<10mm)	14.8656	0.1995	15.0651	15.0648	
T1 (>10mm)	16.3810	0.2006	16.5816	16.5834	False result
T2 (<10mm)	15.9372	0.0201	15.9573	15.9580	False result
T2 (>10mm)	17.4557	0.0202	17.4759	17.9767	False result
R1 (>10mm)	15.1039	0.1995	15.3034	15.3025	
R2 (<10mm)	14.9083	0.0193	14.9278	14.9309	False result
R2 (>10mm)	14.6892	0.2001	14.8893	14.8848	
Original test material	15.6422	0.2002	15.8424	15.8432	False result
Original reference material	14.9933	0.2006	14.9939	14.9867	

## Appendix 6. Dry mass under 105 °C

Sample net	Sample initial mass (g)	Sample residual (dry) mass (g)	Dry mass under 105°C (%)
T1 (<10mm)	0.1995	0.1990	99.7
T1 (>10mm)	0.2006	0.2000	99.7
T2 (<10mm)	0.0201	0.0201	100
T2 (>10mm)	0.0202	0.0202	100
R1 (>10mm)	0.1995	0.1929	96.69
R2 (<10mm)	0.0193	0.0185	95.854
R2 (>10mm)	0.2001	0.1918	95.852
Original test material	0.2002	0.1989	99.4
Original reference material	0.2006	0.1918	99.61