Tampere University of Applied Sciences

Disintegration testing of packaging material under simulated composting conditions in laboratory scale

An experiment following standard SFS-EN 14806

Bao Nguyen

BACHELOR'S THESIS
April 2021
Degree Programme in Energy and Environmental Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Programme in Energy and Environmental Engineering

NGUYEN BAO
Disintegration testing of packaging material under simulated composting conditions in laboratory scale - An experiment following standard SFS-EN 14806

Bachelor's thesis 68 pages, of which appendices 17 pages
April 2021

Plastic pollution has been recognized as an environmental issue for decades, and one of the sources of that pollution is packaging. In 2015, packaging accounted for 60% of the plastic waste in the EU. Therefore, it is indispensable that packaging should be developed to protect not only the product and the consumers' health, but also the environment. Before new packaging material is launched onto the market, testing of degradability following certain standards is required. This thesis aimed to evaluate the disintegrability of packaging materials through laboratory-scale composting test, following standard SFS-EN 14806. Testing materials included three samples: base sheets coated differently (provided by Kemira Oyj – the commissioner), and two reference materials: non-coated base sheet (from Kemira Oyj), and base sheet coated with starch (from Tampere University of Applied Sciences – TAMK). Additionally, a cellulose-hemicellulose sheet was also added as reference material for evaluation of composting performance. The test lasted for 91 days and was implemented in Environmental Laboratory of TAMK. At termination of the test, degree of disintegration was calculated based on the mass of residues of testing materials after sieving the compost.

Results showed that after 91 days, the composting test was entirely valid. The final compost seemed to be immature although composting process has occurred enough for cellulose-hemicellulose (compost reference) to disintegrate completely. The reason leading to the outcome of immature compost, was speculated to be because of temperature profile applied during the test. Regarding disintegrability, base sheet (sample reference 1) disintegrated less than base sheet coated with starch (sample reference 2), but disintegrated more than the three coated samples. Based on the results of this thesis work, further study can be carried out to determine the biodegradability and compostability of the tested samples. However, conducting a repeat test or another test with different temperature profile is suggested, to investigate the factors causing final compost to be immature, as well as to ensure the reliability of disintegrability of the samples.

Key words: composting, disintegration, food packaging material, SFS-EN 14806

CONTENTS

TERMS

Biodegradation	Degradation caused by biological activity especially by enzymatic action leading to a significant change of the chemical structure of a material.
Composting	Biological decomposition of organic matter under aerobic conditions.
Compost	Organic soil conditioner obtained by biodegradation of mixture principally consisting various vegetable residues, occasionally with other organic matter and having a limited mineral content.
Degradation	An irreversible process leading to a significant change of the structure of a material, typically characterized by a loss of properties (e.g. integrity, mechanical strength, change of molecular weight or structure) and/or fragmentation.
Disintegration	The physical falling apart of a material into very small fragments.
Total dry solids	Amount of solids obtained by taking a known amount of test material or compost and drying at about 105 °C to constant weight.
SFS	Finnish Standards Association.
SFS-ISO 10390	This standard consists of the English text of the International Standard ISO 10390:2005. Soil quality. Determination of pH.
SFS-EN 13193	This standard consists of the English text of the European Standard EN 13193:2000. Packaging. Packaging and the environment. Terminology.
SFS-EN 13432	This standard consists of the English text of the European Standard EN 13432:2000. Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging.

SFS-EN 14806	This standard consists of the English text of the European Standard EN 14806:2005. Packaging. Preliminary evaluation of the disintegration of packaging materials under simulated composting conditions in a laboratory scale test.
SFS-EN ISO 16929	This standard consists of the English text of the European Standard EN ISO 16929:2019. Plastics. Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test.
SFS-EN ISO 20200	This standard consists of the English text of the European Standard EN ISO 20200:2015. Plastics. Determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory-scale test.
Synthetic waste	A self-composed mixture of different components, simulating the input material from composting plants.
Volatile solids	Amount of solids obtained by subtracting the residues of a known amount of test material or compost after incineration at about (550 ± 10) °C from the total dry solids content of the same sample. The volatile solids content is an indication of the amount of organic matter.

1 INTRODUCTION

It is beyond doubt that packaging makes our everyday lives easier through easy product access. However, due to the rapid growth of human population, the product consumption will increase dramatically, following by a huge amount of waste that we will also generate. Currently, significant amounts of packaging waste are escaping from the recycling system, and end up in the environment, causing environmental pollution and also economic damages. Therefore, it is crucial to rethink and redesign packaging, to phase out the use of conventional plastic, and to keep resources in a cycle. As a result, innovative packaging materials are being researched and tested to meet the sustainable development target.

This thesis work is to investigate the disintegration of packaging materials, through compost testing at laboratory scale, following standard SFS-EN 14806: “Packaging – Preliminary evaluation of the disintegration of packaging materials under simulated composting conditions in a laboratory scale test”. It is also aimed to test the standard for further experiments. The commissioner of thesis was Kemira Oyj, and the test was carried out in Environmental Laboratory of Tampere University of Applied Sciences (TAMK). The test lasted from October 12th, 2020 to February 8th, 2021.

Kemira also has its own strategies and scenarios towards the future of packaging (Kemira 2020a). For example, Kemira has introduced FennoGuard GO in 2019, which is a dispersion barrier coating used as an alternative to polyethylene (PE) plastics. This product is made partly with renewable bio-based materials and is proven to be recyclable and compostable. Therefore, it helps to reduce the traditional plastics usage in packaging as well as to cut down consumption of fossil-based raw materials (Kemira 2020b). With the progressing evolvement, new packaging materials are being developed, hence testing upon them are of the essence.

As specified in the standard, although the composting was in laboratory scale, the conditions were simulated to the conditions found in industrial composting plants. The test was only for preliminary assessment of disintegrability of the test materials, not to determine degradability nor compostability.

2 LITERATURE REVIEW

2.1 Packaging material

Throughout the history, packaging has been becoming an important connection between production and consumption (Pongrácz, 2007). One of the products that is vital to the humankind is food, and thus, packaging for food has been receiving certain attention over the years. In order to preserve food safety and quality, food packaging must provide protection from environment, chemical, and physical elements (Risch, 2009). In *A Brief History of Packaging* by Berger and Welt, packaging material was revealed to has evolved from natural objects such as shells, leaves, grass, and wood, to man-made materials like paper, glass, metal, and plastic.

The first widely used plastic was Polyethylene (PE plastic). PE plastic has many types, including low-density (LDPE), high-density (HDPE), linear low-density (LLDPE), and very low density (VLDPE). Later on, polymer film was invented. It was made of polypropylene (PP), or polyethylene terephthalate (PET). The films have better moisture vapor barrier, clarity and are more durable than PE (Risch, 2009). As the innovation progresses, active packaging has been developed. It is a technology in which packaging is the combination of active compounds (e.g. antimicrobial, antioxidant, insect repellent, etc.) and polymer films. Comprehensive summary on active packaging can be found in the review *Active Packaging Applications for Food* by Yildirim et al. (2017). A more advanced technology than active packaging is the intelligent packaging, which not only improves the food quality and safety, and extends shelf-life, but also can monitor and exchange the detailed information of the product through the supply chain (Han et al., 2018).

Over the recent years, sustainability has been taken seriously in many aspects, and packaging is not an exception. To be considered as sustainable packaging material, it should meet the expectations on all three pillars: social, economic, and environmental (Barbier, 1987). Packaging has been linked to one of the causes of environmental pollution (Kedzierski et al. 2020). In 2018, the European

Commission has published a Plastics Strategy for Circular Economy, where packaging was indicated responsible for almost 60% of plastic waste in Europe in 2015. Therefore, all novel packaging technologies should be tested for the safety of both human health and the environment. One of the current solutions to alleviate environmental pollution is that, petroleum-based polymer materials have been under researching to transit towards bio-based polymers (biopolymer). The transition to bio-based polymers not only poses a positive impact on the environment, but it also helps improve the economics in long-term. The bio-based products are easier in degrading, and thus reduce the tress and cost of waste treatment. In addition, in the circular economy point of view, bio-based product at the end-of-life phase could be convert into a new product (e.g. compost). However, due to several factors such as cost, legislation, human safety, environmental safety, and technology limits, conventional plastic is still mainly being used (Nilsen-Nygaard et al., 2020).

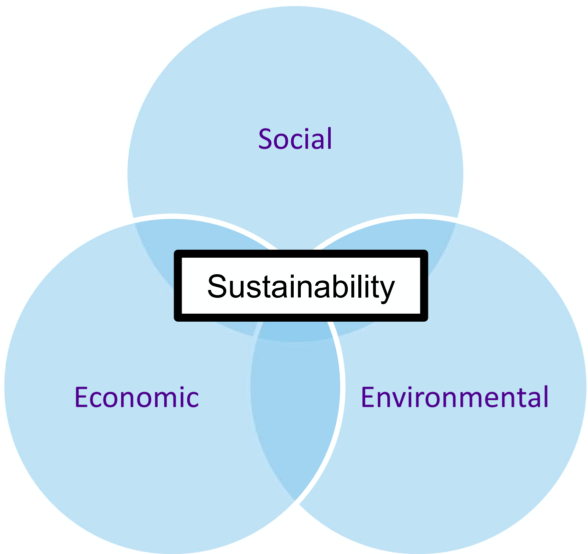


FIGURE 1. The concept of sustainability (Barbier 1987, modified)

2.2 Standards of disintegrability testing through composting

In terms of standards, currently there are many recognized standardization bodies. For example, the International Organization for Standardization (ISO), the American Society for Testing and Materials (ASTM), and the European Committee for Standardization (CEN). Furthermore, there are also national standardization bodies such as the German Deutsches Institut für Normung (DIN), the French Association Française de Normalisation (AFNOR), and the Finnish Standards Association (SFS), etc. Due to the various international and regional standard versions, comparison between studies is currently quite challenging. In this section, mainly SFS standards related to disintegrability testing through composting are discussed.

Compostability, biodegradability, and disintegrability are the terms in composting that often cause confusion, and that may lead to the misuses. In fact, the compostability of a material is determined based on four factors: the disintegrability, the biodegradability, the ecotoxicity, and the absence of heavy metals (Degli-Innocenti, 2002). On the SFS-online database at the moment, only two types of material are being evaluated through composting process: packaging materials, and plastic materials.

For packaging materials to be accepted placing on the market, it needs to meet the requirements defined in standard SFS-EN 13432: “Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging”. The packaging materials principally need to be tested for disintegrability, biodegradability, toxicity, and heavy metals content (Figure 2). Concerning the disintegrability, a packaging material shall be first tested under laboratory conditions for preliminary evaluation before a pilot-scale or full-scale test is carried out.

Besides standard SFS-EN 14806, there is another standard related to disintegration testing of packaging materials SFS-EN 14045: “Packaging – Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions”. While SFS-EN 14806 was made specifically for laboratory-scale with a fixed amount of solid matrix (i.e. 1 kg per reactor), SFS-EN 14045 works as a pilot-scale with the amount of solid matrix more than 60 kg and composited with biowaste. As the target amount of test materials corresponding to the amount of matrix, higher amount of test materials can be employed in case using standard SFS-EN 14045. In SFS-EN 14806, the temperature is controlled with the incubator at a constant desired value, while in standard SFS-EN 14045, the temperature changes naturally through composting process.

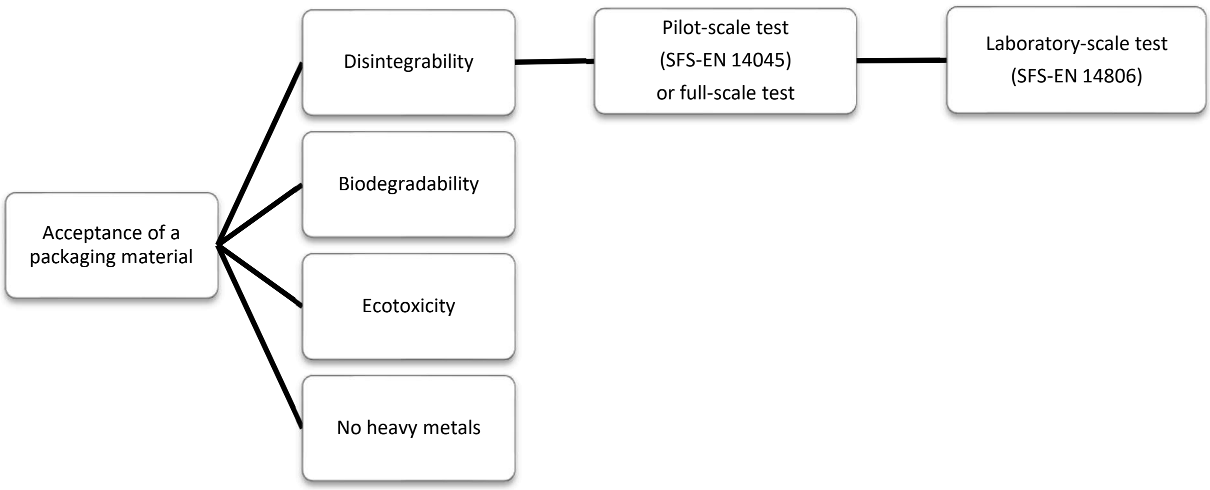


Figure 2. Main requirements for accepting a packaging material according to standard SFS-EN 13432

In relation to disintegration testing, there are also standards SFS-EN ISO 20200: "Plastics. Determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory-scale test", and standard SFS-EN ISO 16929: "Plastics. Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test". These two standards target specifically the pure plastic materials. The duration of composting process is same in all four standards above, 90 days. The comparison between those standards is shown in Table 1 and Table 2. Therefore, depending on the nature of test material and also the desired amount of test specimens, the suitable standard can be selected.

TABLE 1. Standards related to disintegration testing

Aspect		**Standard**			
		SFS-EN 14806	**SFS-EN ISO 20200**	**SFS-EN 14045**	**SFS-EN ISO 16929**
Scale		Laboratory		Pilot	
Solid matrix	**Composition**	Artificial (self-composed)		Biowaste (potentially containing pathogens) plus bulking agent; or artificial	
	Amount	1 kg		≥ 60 kg	≥ 30 kg
Test material	**Material type**	Packaging	Plastics	Packaging	Plastics
	Amount	Small 5 g – 20 g (0,5 % – 2 % of matrix mass)		High (1 % of matrix mass)	
Duration		90 days			

TABLE 2. Concerned metrics in each standard

Recorded parameters	**Standard**			
	SFS-EN 14806	SFS-EN ISO 20200	SFS-EN 14045	SFS-EN ISO 16929
pH	Yes			
Moisture content				
Dry mass				
Volatile solids				
C:N ratio				
Temperature				
Oxygen content	No		Yes	
Visual observation	Yes		Optional	
Odour observation	Yes		No	
Degree of disintegration *D*	Yes			
Validity of the test	Calculation of reduction percentage of volatile substances		Evaluate based on temperature regime, pH, and volatile fatty acids	

2.3 Composting factors

Although there are many factors that could affect a composting process, the most significant factors are oxygen content, C:N ratio, moisture, pH, and temperature. Different values of those factors may result in different states of the compost (Diaz et al. 2007, 49). Suitable adjustments shall be applied during the composting process to have the compost behave as desired.

2.3.1 Aeration – oxygen content

Since composting is usually linked to an aerobic process, it needs sufficient amount of oxygen through aeration to prevent the metabolic activities shifting to fermentation and anaerobic respiration. In addition, the provided oxygen can be blocked by the matter of particle size, moisture content, and porosity – which may also lead to anaerobic conditions. Therefore, the compost should be turned periodically to create pores for oxygen distribution, and to avoid the compaction or the overheating caused by over consumption of microbes (Epstein 2011, 20-21; Diaz et al. 2007, 55).

There are various types of systems of composting, depending on factors such as economics, type and quantity of waste, location (e.g. near residential area, or in rural area), political and regulatory aspects, environmental requirements, and desired product quality (Epstein 2011, 79). The systems are then subdivided to windrow systems and in-vessel systems (bioreactors). Windrow systems can be turned windrow, or static pile. In-vessel systems can be classified by shape (e.g. cylindrical container, channels, cells, tunnels), or by function of movement of the material (e.g. static or dynamic) (Diaz et al. 2007, 79).

2.3.2 Carbon-to-nitrogen ratio

Availability of carbon and nitrogen is most crucial. They are the nutrition needed for the microbes during composting process. Carbon is consumed by microorganisms for cellular growth and is converted into carbon dioxide CO_2. On the other hand, nitrogen is needed for cell and protein synthesis. In aerobic composting, the loss of nitrogen is mainly due to ammonia volatilization, while in anaerobic process the fixation and denitrification process occurs, leading to the reduction of nitrate to N_2 gas. A high C:N ratio will make the cellular grow rapidly at first and use up nitrogen resource – which then restraints synthesis progress and reduces cellular growth, further on resulting in slowing down the composting process. In contrast, a low C:N ratio cannot provide adequate feedstock for the microorganisms to grow. The excessive nitrogen will lead to volatilization, causing unpleasant odour. It is recommended that for optimum performance, at the beginning of the process, there should be 27-30 parts of carbon for each part of nitrogen. Although the composting process is effective with C:N ratio in the range of 22 to 40:1. A well composting process will reduce the biodegradable organic matter by 30% to 60% (Epstein 2011, 17-19; Diaz et al. 2007, 41), and reduce the C:N ratio to about 10 to 15 :1 at the end of composting (Cornell Waste Management Institute, 1996). Figure 3 illustrates an example of C:N ratio.

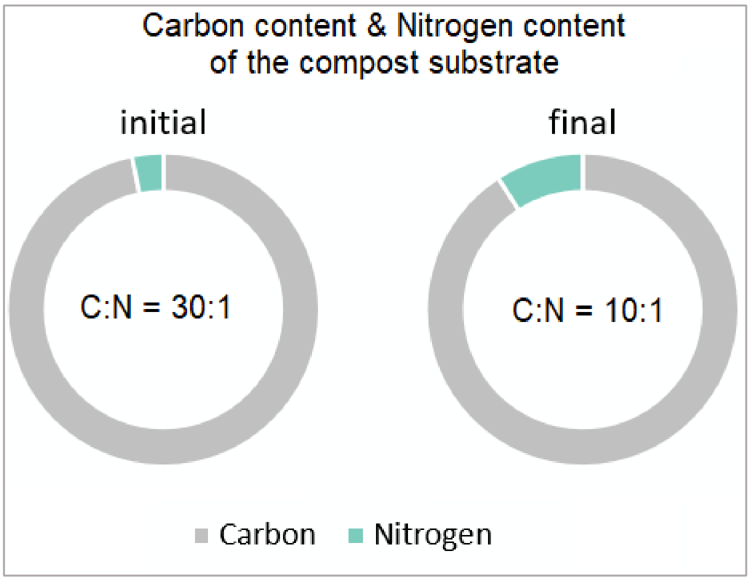


FIGURE 3. An example of initial and final C:N ratio of a compost substrate

2.3.3 Moisture

Moisture content is also one of the most important factors that has an impact on the performance of composting process. An inadequate amount of water will cease the microbial activity, while excessive amount will fill up the pores and block the air exchanging of the substance. Either cases will lower the efficiency of composting performance. According to Epstein (2011, 19), in industrial scale, a moisture content of 50-55% will give a maximum composting outcome; while Diaz et al. (2007, 56) indicated that 60% is an appropriate value at starting point.

2.3.4 pH

The optimum pH range for composting is between 5.5 and 8.0. At the starting phase, pH usually decreases due to the formation of organic acids, which produced by acid-forming bacteria. In combination with the initial high temperature, ammonia volatilization also occurs, leading to the acidic and ammonia smell in the first several days. During the composting process, the pH later increases gradually, forming an alkaline condition (pH 8 to 9), and then decreases back to neutral value (Diaz et al. 2007, 54; SFS-EN 14806, 9).

2.3.5 Temperature

The microbial activity is very much affected by temperature. In composting, four (4) phases are commonly recognized depending on the range of temperature: mesophilic phase (25-40^{o}C), thermophilic phase (35-65^{o}C), cooling phase (or second mesophilic phase), and maturation phase (Diaz et al. 2007, 33-34). When the mesophilic phase takes place, primary decomposers such as fungi, actinobacteria, and bacteria actively degrade sugars and proteins within the compost media. At the thermophilic phase, only thermophilic and temperature-tolerated organisms remain, the decomposition is then accelerated. In industrial composting, temperature is initially often adjusted above 55^{o}C for several days to eliminate the pathogens, then it is lower to achieve peak performance of decomposition (Epstein 2011, 17). This is the reason for starting the test at (58 ± 2) ^{o}C as stated in standard SFS-EN 14806.

3 MATERIALS AND METHODS

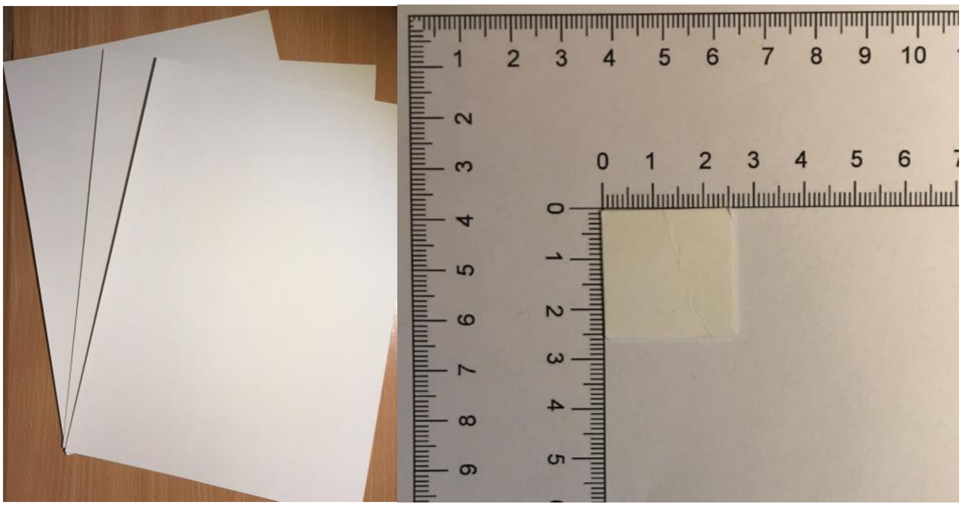
This study was conducted in laboratory scale and test specimens were packaging materials, and thus, standard SFS-EN 14806 was chosen to be followed. The system was a static in-vessel system in which composting process took place in rectangular containers (Picture 2). Temperature and aeration were regulated by using an incubator. The length of the whole experiment, including a preliminary test, was 15 weeks. There were multiple meetings between Kemira Oyj and TAMK to update the progress of the test and to discuss related issues.

3.1 Test material

Kemira Oyj provided three sample materials, which were the fibre base sheets coated with different coating materials, and the base sheets itself without coating. The non-coated base was then used as reference material for the sample materials. In addition, a second sample reference was prepared in TAMK Bioproduct laboratory, where the base sheets given by Kemira Oyj were coated with a starch layer. For evaluation of the composting performance, a material consisting of sheet-pressed cellulose-hemicellulose was also employed (Metsä Fibre Oyj, Appendix 1). Cellulose-hemicellulose material was chosen to be reference for compost performance because it is known to easily degrade in composting (Diaz et al. 2007, 27–30).

Three sample materials were coded as S1, S2, and S3. For sample reference materials, the base coated with starch and the non-coated base were named as SR1 and SR2, respectively. The compost reference – cellulose-hemicellulose material – was named as CR. Two blank reactors which contain only the matrix were also included in the study, named as B0 and all test points were having two replicates (Table 3).

Since the thickness of the test materials was only 1 mm, the test materials were cut into specimens of 25 x 25 mm in dimension (Picture 1) as defined in standard SFS 14806. All test specimens were dried in the oven at 105^{o}C for 2 hours before being weighed for about 10 g each reactor. Details of test materials employed in each reactor is shown in Table 3, including the material mass and amount of coating of test material.



PICTURE 1. Test material and the specimens after cutting

TABLE 3. Test materials preparation

Test material		Dry mass (g)	Note
Sample 1	S1A	10.0795	Coating amount: 14.5g/m^2
	S1B	10.0141	Coating amount: 15.5g/m^2
Sample 2	S2A	9.9698	Coating amount: 14.5g/m^2
	S2B	9.8995	Coating amount: 15.3g/m^2
Sample 3	S3A	9.9854	Coating amount: 14.5g/m^2
	S3B	10.0027	Coating amount: 14.7g/m^2
Sample reference 1	SR1A	10.086	Base coated with starch Coating amount: 12g/m^2
	SR1B	9.9837	
Sample reference 2	SR2A	9.9843	Non-coated base
	SR2B	9.9613	
Compost reference	CRA	10.2465	Non-coated cellulose-hemicellulose
	CRB	10.1230	
Blank	B0A		
	B0B		

3.2 Synthetic waste composition

The solid matrix used in this study was wet synthetic waste – a self-composed mixture of water and dry ingredients including sawdust, rabbit-feed, compost, starch, saccharose (sugar), cornseed oil, and urea. Although standard SFS-EN 14806 suggests using Cornseed Oil, the Rapeseed Oil was used instead. The origin of each ingredient is presented in Table 4. Image of the ingredients can be found in Appendix 2.

As specified in SFS-EN 14806, moisture content of the wet synthetic waste should be approximately 55%. Dry synthetic waste mixture was made first, then water was added to form wet synthetic waste. The composition of dry synthetic waste mixture followed the instruction defined in SFS-EN 14806. Because the compost was considered as dry ingredient, the amount of water within it was taken into consideration when mixing the synthetic waste. The needed amount of compost and the amount of water addition (into dry mixture) were calculated using Formula 1 and Formula 2, respectively. In this study, 14 reactors were employed, each needed 1 kg of solid matrix. Therefore, the quantity of wet synthetic waste mixture should be at least 14 kg. The total amount of each ingredient in use was presented in Table 4.

$$m_{compost} = m_{urea} \times 5 \times \frac{100}{100 - \%moisture\ of\ compost} \quad (1)$$

$$m_{water\ added} = m_{urea} \times 50 \times \frac{55}{45} - (\%moisture\ of\ compost \times m_{compost}) \quad (2)$$

TABLE 4. Composition of synthetic waste for 14 reactors

Material	Amount (g)	Source	Note
Sawdust	2800	Wanha Puusepänverstas (untreated wood)	Sieved with a 5 mm sieve
Rabbit feed	2100	Brand: Burgess Excel Adult Rabbit Nuggets with Mint	13% Protein 19% Cellulose content
Compost	1965	Brand: Biolan Puutarhan Musta Multa	Sieved with a 5 mm sieve Dry mass is 35.64% at the time of mixing
Starch	700	Brand: Maizena Maissitärkkelys	-
Saccharose	280	Brand: S-Rainbow Kidesokeri	-
Rapeseed oil	280	Brand: K-Menu Rapsiöljy	an alternative to Cornseed oil
Urea	140	Commercial product	-
Water added	7290		
Total	15555		

3.3 Composting reactor

According to standard SFS-EN 14806, vessel with volume between 5 L and 20 L was suggested to be used as reactor. However, due to the limited space in the incubator and there was a certain number of reactors being employed, vessels with smaller volume were chosen. The vessel used as reactor was SmartStore™ Classic 5 box (Picture 2), which was made of Polypropylene (PP) with external dimensions of 30x19x11 cm and have the volume of 3.6 L. The boxes can tolerate temperature in range of -40°C to 100°C (Orthex Group, 2016), therefore it can withstand the heat during composting process. In the middle of wide sides of the boxes, two holes of 5 mm in diameter were drilled at 6.5 cm height from the bottom (Figure 4) to allow the gas exchanging occurred and avoid anaerobic conditions.

PICTURE 2. The box used as reactor

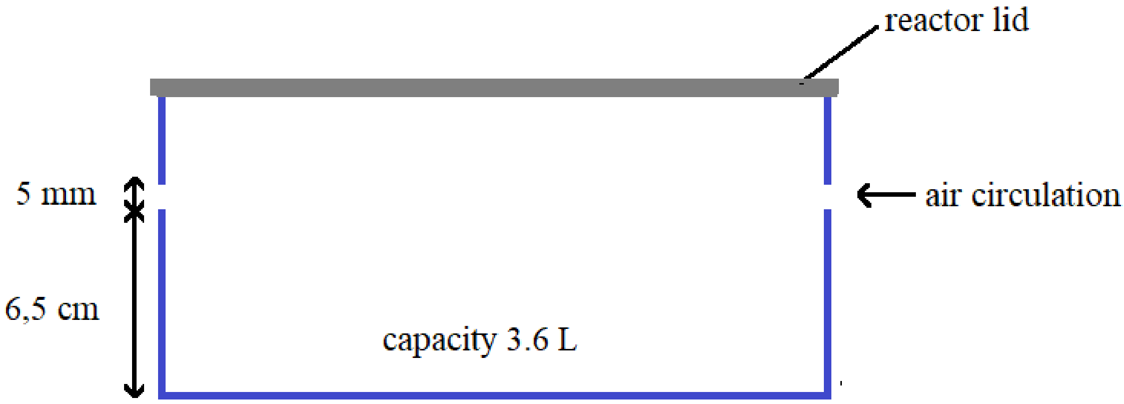


FIGURE 4. Illustration of the reactor

3.4 Monitoring of the composting factors

The monitoring was done according to standard SFS-EN 14806. At the beginning and at the end of the composting process, key parameters such as C:N ratio, moisture content, and pH were analyzed. The initial analysis of compost substrate was done based on a representative sample, which was collected from the wet synthetic waste mixture batch. Therefore, the initial result of each analysis was same in all reactors. On the other hand, the final analysis was done individually for each reactor. In addition, on day 30 the compost used in mixing the synthetic waste (Biolan Puutarhan Musta Multa) was added to each reactor for re-inoculation purpose, the amount was 25 g.

3.4.1 Aeration & temperature

All the reactors were placed in an incubator with air circulation and controllable temperature system. The incubator model was Pol-eko Aparatura – CLW 400 Smart (Pol-eko, 2019). In this test, the temperature was set at 58°C (± 2°C) at the beginning and was lowered overtime, to 45°C (± 2°C) on day 30, to 35°C (±2°C) on day 49, to 25°C (± 2°C) on day 60, and finally to 21°C (± 2°C) on day 75 until termination of the test (Figure 5). This temperature profile was based on one of the temperature schemes in standard SFS-EN 14806.

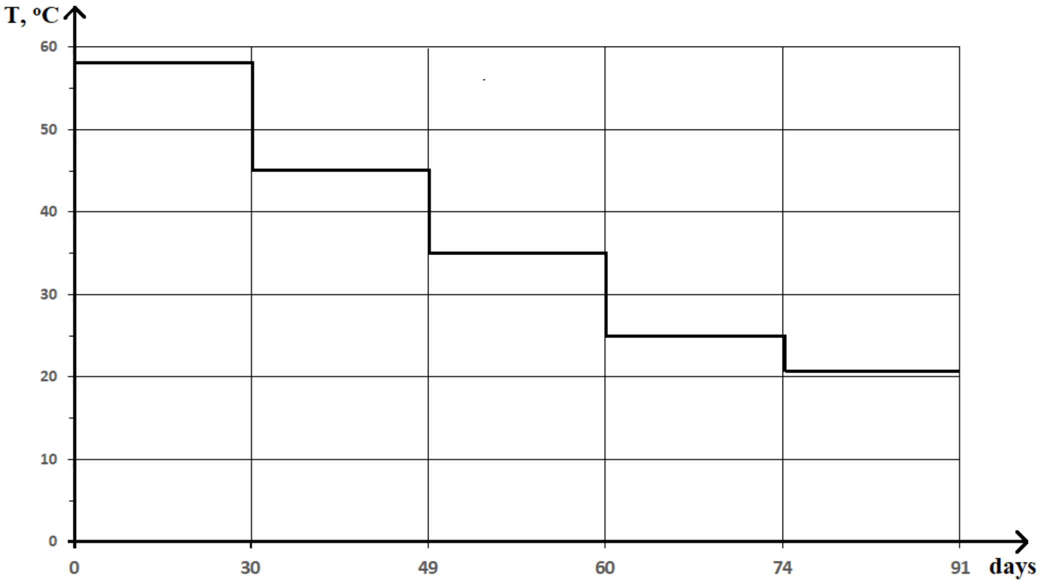


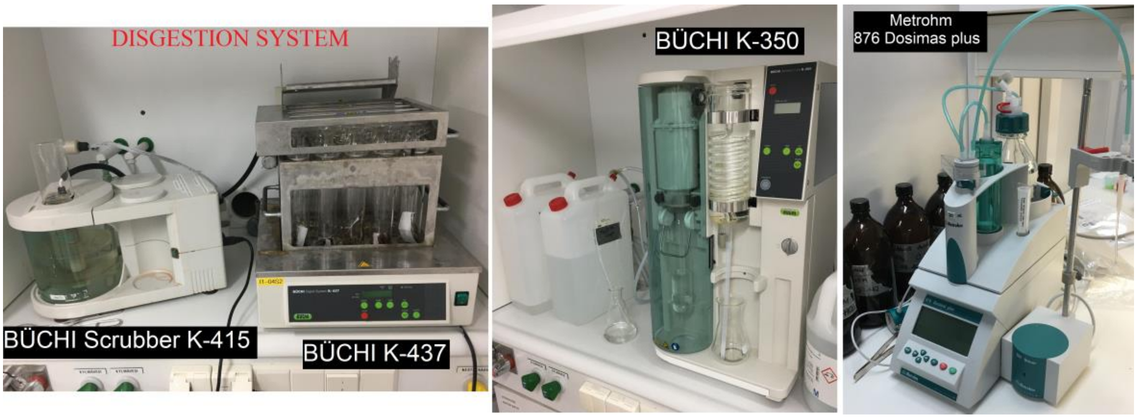
FIGURE 5. Temperature profile of composting process in this test

3.4.2 C:N ratio

The C:N ratio was determined by analyzing the carbon content and the nitrogen content. While the nitrogen content was calculated using Kjeldahl method (Egli, 2008), the carbon content was estimated by dividing the percentage of volatile substance by half (Formula 3). The volatile solids value is the mass loss after calcinating the dry sample in the oven at 550°C for 6 hours (SFS-EN 14806).

$$\%C = \frac{\%VS}{2} \quad (3)$$

The Kjeldahl method was based on BÜCHI Training papers. The process consisted of three (3) steps: digestion, distillation, and titration. Digestion process was done with device BÜCHI K-437 and BÜCHI Scrubber K-415; BÜCHI K-350 was used for the distillation (BÜCHI, 2020); and Metrohm 876 Dosimas Plus was used for titration (Metrohm, 2010). The devices are shown in Picture 3.



PICTURE 3. Devices used for measuring nitrogen content with Kjeldahl method

3.4.3 Moisture

The moisture was controlled by monitoring compost mass, following the schedule proposed in SFS-EN 14806. Compost mass was restored to 100 % of the initial mass from day 1 until day 29, to 80 % of the initial mass from day 30 until day 59, and to 70 % of the initial mass from day 60 until termination (i.e. day 91 in this test). Water was added as the means of restoring compost mass. Moisture content of the substrate, on day 0 and day 91, was measured using IR detector Precisa – XM 60 (Precisa, 2021).

PICTURE 4. IR detector – Precisa XM 60

3.4.4 pH

At the beginning and at the end of the test, pH was measured following standard SFS-ISO 10390: Soil quality — Determination of pH. During the composting process, pH of the substrate in each reactor was tracked using pH indicator papers. The pH paper was buried in the substrate for 1 minute, then the color of the paper was compared to the pH scale on the roll (Picture 5).

PICTURE 5. pH indicator paper roll

3.5 Termination of the test

According to standard SFS-EN 14806, there are certain measurements to be made at the end of the test, including dry mass, pH, volatile substances, C:N ratio, and mass of residues of test materials. Then degree of disintegration and validity of the test were calculated based on results of those measurements.

The test was terminated on day 91. All the compost from each reactor was let dry for 2 days before being sieved with a 4 mm and a 2 mm mesh size consecutively, and the residues remained on the sieves were collected for further evaluation. The residue particles considered as compost were eliminated, leaving only possible test material residues to be kept. The sorted residues of test materials were then cleaned, with water if possible, and dried in the oven at 105^{o}C for 2 hours. The dried residues were weighed, and the results were recorded for further calculations (SFS-EN 14806). The mass difference of test material at the beginning and in the end of the test is the basis for calculating the degree of disintegration. The calculation followed Formula 4 as defined in standard SFS-EN 14806.

$$D(\%) = \frac{M_i - M_r}{M_i} \times 100 \quad (4)$$

(SFS-EN 14806)

where

M_i is the initial dry mass of the test material, g

M_r is the mass of the dry residues recovered by sieving, g

The validity of the test was determined to evaluate the reliability of the results based on composting process performance. To assess that, the percentage of reduction *R* of the total volatile substances at the start and at the end of the test was calculated, following Formula 5 as defined in standard SFS-EN 14806. The compost is considered working properly if the value *R* is no less than 30%.

$$R(\%) = \frac{(M_{sw} \times DM_{sw} \times VS_{sw}) - (M_c \times DM_c \times VS_c)}{(M_{sw} \times DM_{sw} \times VS_{sw})} \times 100 \geq 30\ \% \quad (5)$$

(SFS-EN 14806)

where

M_{sw} is the initial mass of the wet synthetic waste, g

DM_{sw} is the initial percentage of dry mass of the wet synthetic waste, %

VS_{sw} is the initial percentage of volatile substances of the wet synthetic waste, %

M_c is the final mass of the compost, g

DM_c is the final percentage of dry mass of the compost, %

VS_c is the final percentage of volatile substances of the compost, %

3.6 Pre-testing of composting process

A pre-test was conducted in advance to examine the synthetic waste characteristics (pH, C:N ratio, moisture content) as well as performance of composting process. This pre-test lasted for three weeks before the actual test started. Through this pre-test, essential adjustments could be recognized and applied into actual test.

4 RESULTS

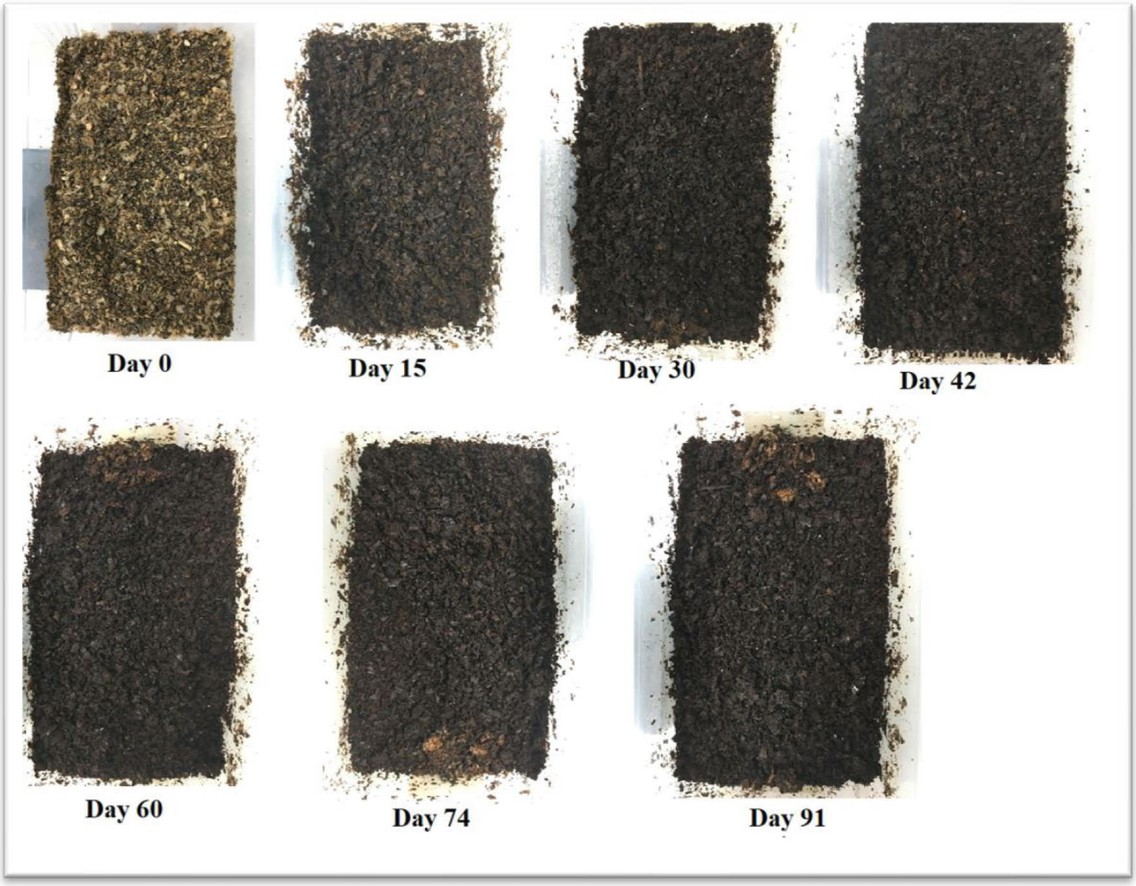
4.1 Compost substrate

Periodic inspection was planned to be carried out every 15 days: day 15, day 30, day 45, day 60, day 75, and day 90. However, due to the intervention of holidays and weekends that caused TAMK laboratory to be closed, inspection on day 45, day 75, and day 90 was re-scheduled to day 42, day 74, and day 91 respectively.

Except pH and odour, other conditions of the compost substrate (i.e. moisture, volatile substances, C:N ratio) were only analysed at the beginning and at the end of the test (SFS-EN 14806). Since the substrate of all reactors on day 0 was from the same source (i.e. wet synthetic waste mixture), the initial value of the parameters was same for all reactors. The analysis was done with at least two replicates, and the results were calculated as mean values.

4.1.1 Visual observation

Through observation, substrates from all reactors seemed to behave consistently, therefore blank reactor was chosen to represent all reactors in this sector, although photos were captured for each reactor during inspection. Picture 6 shows the state of the substrate of blank reactor throughout the composting process.



PICTURE 6. The substrate of blank reactor on follow-up days

4.1.2 Moisture content & dry mass

Table 5 shows the moisture content and dry mass of the substrate at the time the test started and ended. Moisture content in all reactors initially was 56.8%, and in the end moisture content varied from 69.7% to 74.6% depending on each reactor. Percentage of dry mass was calculated by subtracting 100% from percentage of moisture content.

TABLE 5. Moisture content and dry mass of substrate in each reactor

Reactor	Moisture (%)		Dry mass (%)	
	Initial	Final	Initial	Final
S1A	56.8	72.4	43.2	27.6
S1B		72.2		27.9
S2A		69.7		30.3
S2B		70.7		29.3
S3A		71.5		28.5
S3B		71.8		28.2
SR1A		72.3		27.7
SR1B		71.0		29.0
SR2A		72.5		27.5
SR2B		72.8		27.2
CRA		73.3		26.7
CRB		73.0		27.0
B0A		74.6		25.4
B0B		72.6		27.4

4.1.3 pH

When the test started, pH of the substrate in all reactors was acidic (6.7). On day 15, pH paper indicated that pH values in all reactors were from 8 to 9. On day 30, day 42, day 60 and day 74, pH paper indicated that pH value was from 7 to 8. On day 91, pH was measured to be from 7.6 to 7.9 depending on each reactor. The results are shown in Table 6.

TABLE 6. pH of substrate in each reactor over time.

<table>
<tr><th rowspan="3">Reactor</th><th colspan="7">pH</th></tr>
<tr><th>day 0</th><th>day 15</th><th>day 30</th><th>day 42</th><th>day 60</th><th>day 74</th><th>day 91</th></tr>
<tr><th>pH meter</th><th colspan="5">pH indicator paper</th><th>pH meter</th></tr>
<tr><td>S1A</td><td rowspan="14">6.7</td><td rowspan="14">8-9</td><td rowspan="14">7-8</td><td rowspan="14">7-8</td><td rowspan="14">7-8</td><td rowspan="14">7-8</td><td>7.6</td></tr>
<tr><td>S1B</td><td>7.6</td></tr>
<tr><td>S2A</td><td>7.7</td></tr>
<tr><td>S2B</td><td>7.6</td></tr>
<tr><td>S3A</td><td>7.8</td></tr>
<tr><td>S3B</td><td>7.8</td></tr>
<tr><td>SR1A</td><td>7.7</td></tr>
<tr><td>SR1B</td><td>7.7</td></tr>
<tr><td>SR2A</td><td>7.8</td></tr>
<tr><td>SR2B</td><td>7.9</td></tr>
<tr><td>CRA</td><td>7.8</td></tr>
<tr><td>CRB</td><td>7.8</td></tr>
<tr><td>B0A</td><td>7.7</td></tr>
<tr><td>B0B</td><td>7.7</td></tr>
</table>

4.1.4 Volatile substances & Carbon content

At the beginning, volatile substances percentage and carbon content of the substrate in all reactors were 95.3% and 47.7% respectively. At the end of the test, volatile substances varied from 88.7% to 90.7% and carbon content varied from 44.3% to 45.4%, depending on each reactor. Results are shown in Table 7.

TABLE 7. Volatile substances and carbon content of substrate in each reactor

Reactor	Volatile substances (%)		Carbon content (%)	
	Initial	Final	Initial	Final
S1A	95.3	89.8	47.7	44.9
S1B		89.9		45.0
S2A		90.1		45.0
S2B		90.6		45.3
S3A		89.8		44.9
S3B		89.7		44.9
SR1A		90.4		45.2
SR1B		89.5		44.8
SR2A		89.5		44.8
SR2B		89.5		44.8
CRA		90.7		45.4
CRB		89.6		44.8
B0A		90.4		45.2
B0B		88.7		44.3

4.1.5 C:N ratio

Initially, nitrogen content and C:N ratio in all reactors were 1.8% and about 26:1. At the time the test was terminated, nitrogen content ranged from 2.1% to 2.3%, and C:N ratio ranged from 19 to 22:1, depending on each reactor. Results in details are shown in Table 8.

TABLE 8. Nitrogen content and C:N ratio of substrate in each reactor

Reactor	Nitrogen content (%)		C:N ratio	
	initial	final	initial	final
S1A	1.8	2.3	26	20
S1B		2.1		21
S2A		2.3		20
S2B		2.3		20
S3A		2.3		19
S3B		2.3		20
SR1A		2.3		19
SR1B		2.3		20
SR2A		2.3		20
SR2B		2.1		22
CRA		2.3		20
CRB		2.3		20
B0A		2.2		21
B0B		2.1		21

4.1.6 Odour

Odour was detected and noted down weekly until the substrate had no smell. From day 0 to day 4, the composting substrate had acidic, pungent smell, and had light yellow colour. From day 7 to day 18, the substrate smelled less acidic but still pungent, also, ammonia smell was detected. The substrate turned into light brown colour. From day 21 to day 25, acidic smell has disappeared, only light ammonia smell and earth-like smell were detected. The substrate turned brown. From day 28 to day 35, very light ammonia smell and light earth-like smell were detected. The substrate turned dark brown. From day 36 onwards, no smell was detected, and the substrate stayed in dark brown colour. Documentation of odour observation is shown in Table 9.

TABLE 9. Odour recording during composting process

DAY	ODOUR	Compost colour
0-4	Acidic and pungent smell	Light yellow
7-18	Less acidic smell Pungent plus ammonia	Light brown
21-25	No acidic smell Light ammonia Earth-like smell	Brown
28	Almost no ammonia Light earth-like smell	Dark brown
36-91	No smell	

4.1.7 Validity of the test

Validity of the test is based on the reduction percentage of volatile substances (*R*) from the beginning to the end of the test. The test of each reactor is considered valid if R is no less than 30%. Wet mass of wet compost which is needed to calculate *R* value was collected from Appendix 3. Reduction percentage of volatile substances varied from 47.0% to 53.8% depending on each reactor. Results in details are shown in Table 10.

TABLE 10. Reduction percentage of volatile substances from all reactors

Reactor	Wet synthetic waste			Wet compost			Validity
	Wet mass (g)	Dry mass (%)	VS (%)	Wet mass (g)	Dry mass (%)	VS (%)	Percentage of reduction *R* (%)
S1A	1000	43.2	95.3	845.8	27.6	89.8	49.1
S1B				791.8	27.9	89.9	51.9
S2A				757.4	30.3	90.1	49.9
S2B				747.4	29.3	90.6	51.9
S3A				854.8	28.5	89.8	47.0
S3B				825.8	28.2	89.7	49.2
SR1A				791.0	27.7	90.4	51.9
SR1B				770.6	29.0	89.5	51.4
SR2A				814.0	27.5	89.5	51.4
SR2B				826.8	27.2	89.5	51.1
CRA				839.6	26.7	90.7	50.6
CRB				786.4	27.0	89.6	53.8
B0A				832.6	25.4	90.4	53.5
B0B				879.4	27.4	88.7	48.2

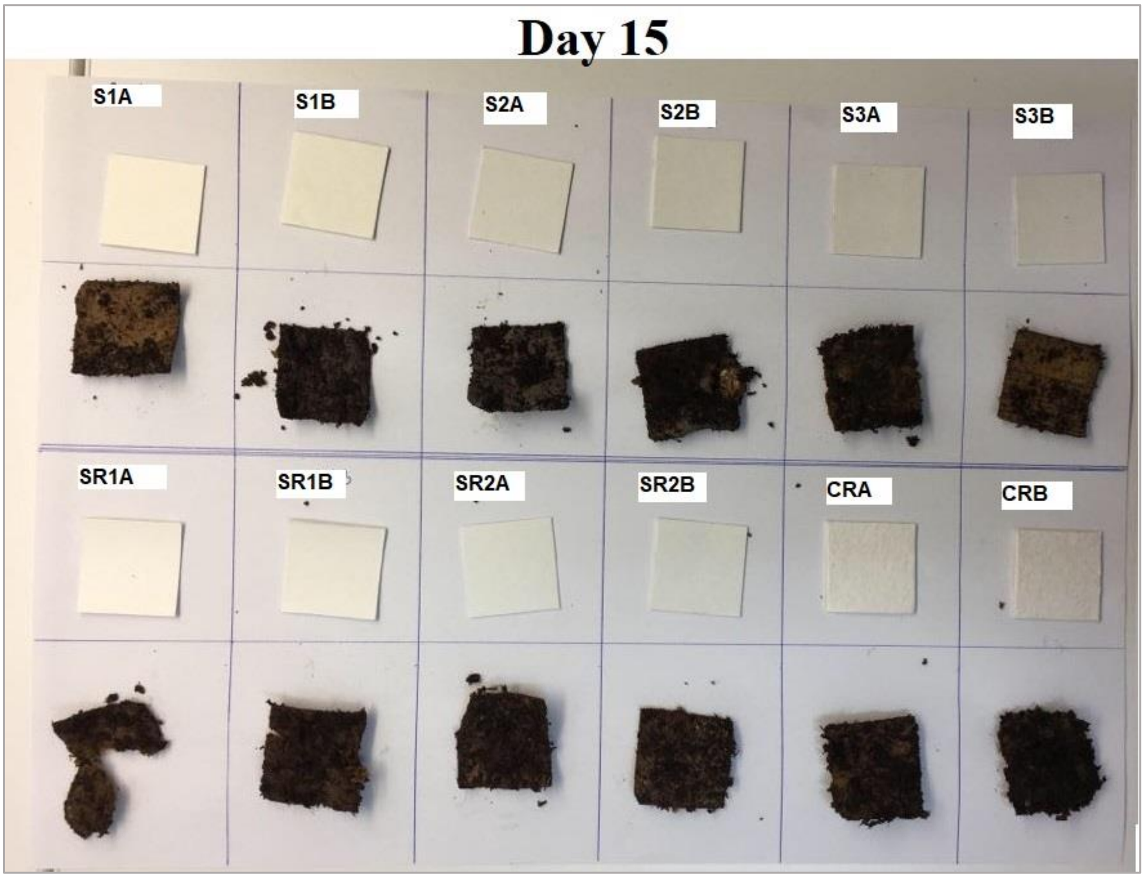
4.2 Test materials

There were two types of data that were collected concerning the test materials, including visual observation from the periodic inspections, and mass of the derived residues at the end of the test. The final mass was then used to calculate degree of disintegration. Assessment withdrawn from visual observation is relative since the selected specimens during the inspection might not be able to represent all specimens in the reactor. Hence, evaluation of disintegrability shall be from both visual observations and calculations.

4.2.1 Visual observation

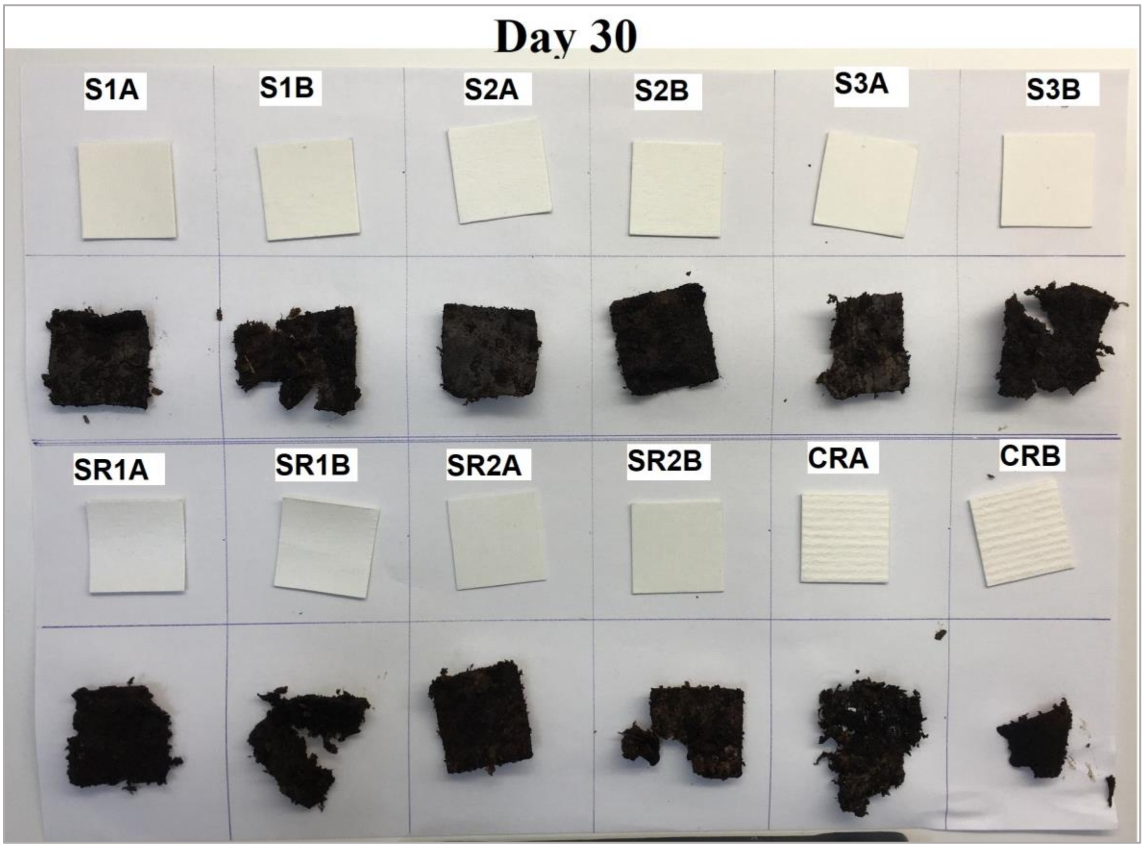
Specimens from each reactor was sampled randomly so that the first pieces found during inspection were chosen, and were placed together, along with the original test materials. Visual documentation by photographing was done at same height, angle, lighting, and location each time. Results are shown in Picture 7 to Picture 12.

On day 15, all the materials have already turned brown and become soft. In addition, reference SR1 and reference CR was detected to have edges worn out and to fragment partly (Picture 7).



PICTURE 7. Test materials on day 15

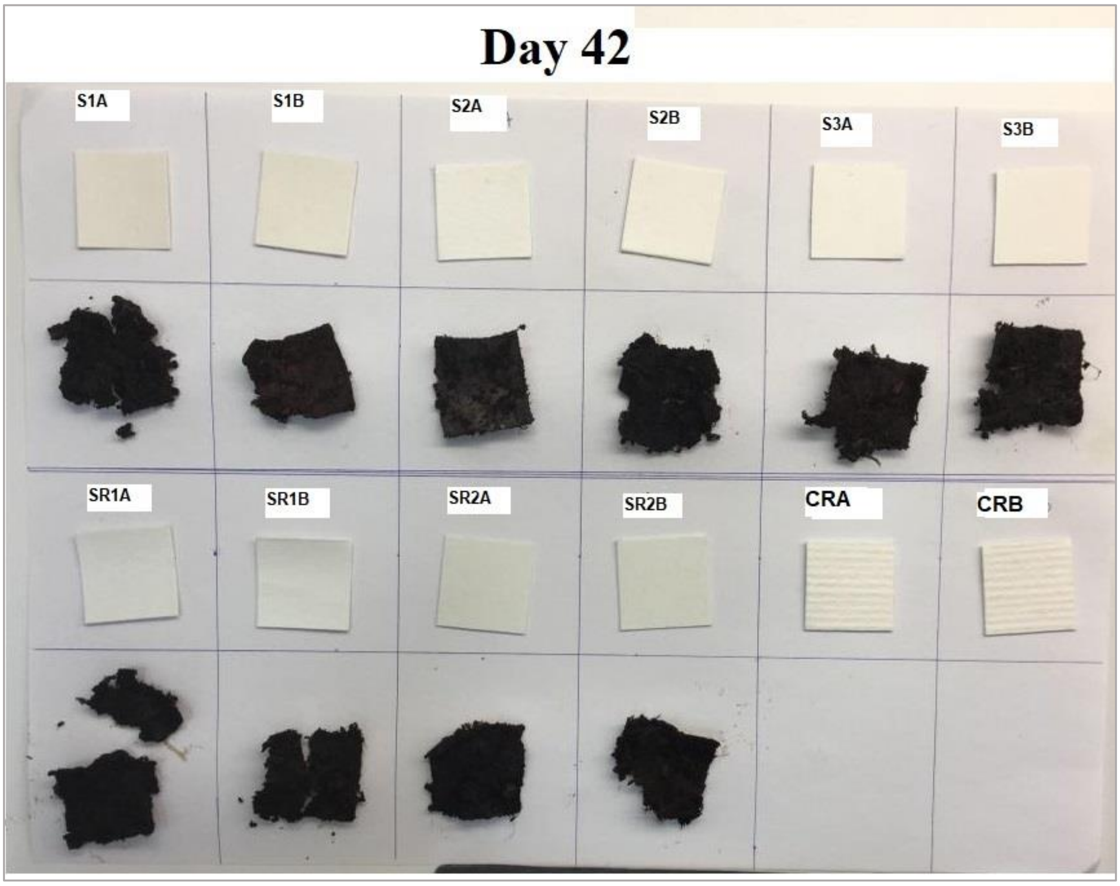
On day 30, sample S2 stayed intact, while sample S1, S3 and reference SR1, SR2 became extremely soft and fragile and their edges also began to be worn out. No visible remaining of reference CR was found. A difference of colour on two sides of the specimen was detected for sample S1, S2, and S3 (Picture 8).



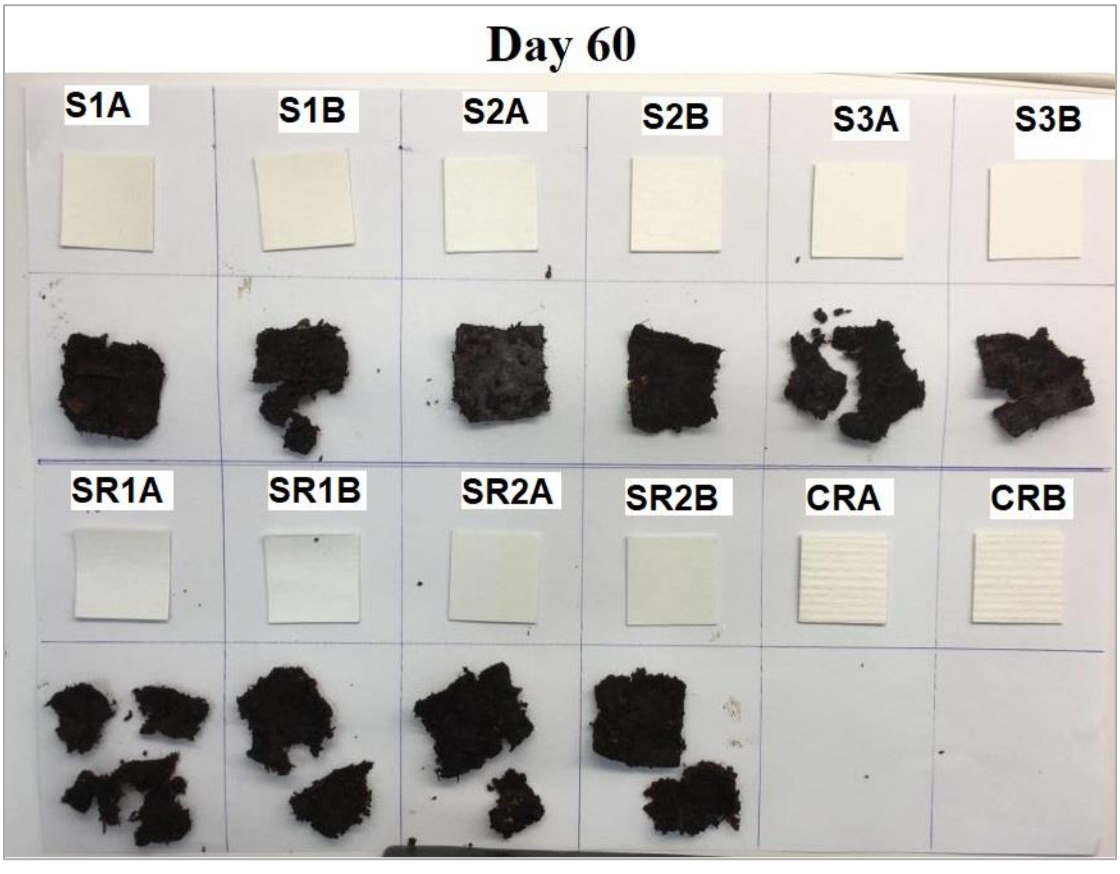
PICTURE 8. Test materials on day 30

On day 42, sample S1, S3 and reference SR1, SR2 were in similar conditions – which were extremely soft and have partly fragmented. Sample S2 still remained intact. Reference CR was not found, and it was considered to be relatively disintegrated (Picture 9).

On day 60, edges of specimens of sample S2 started to slightly be worn out. Sample S1, S3 and reference R1, R2 still had their specimens visible, although compare to day 42, some smaller fragments were detected (Picture 10).

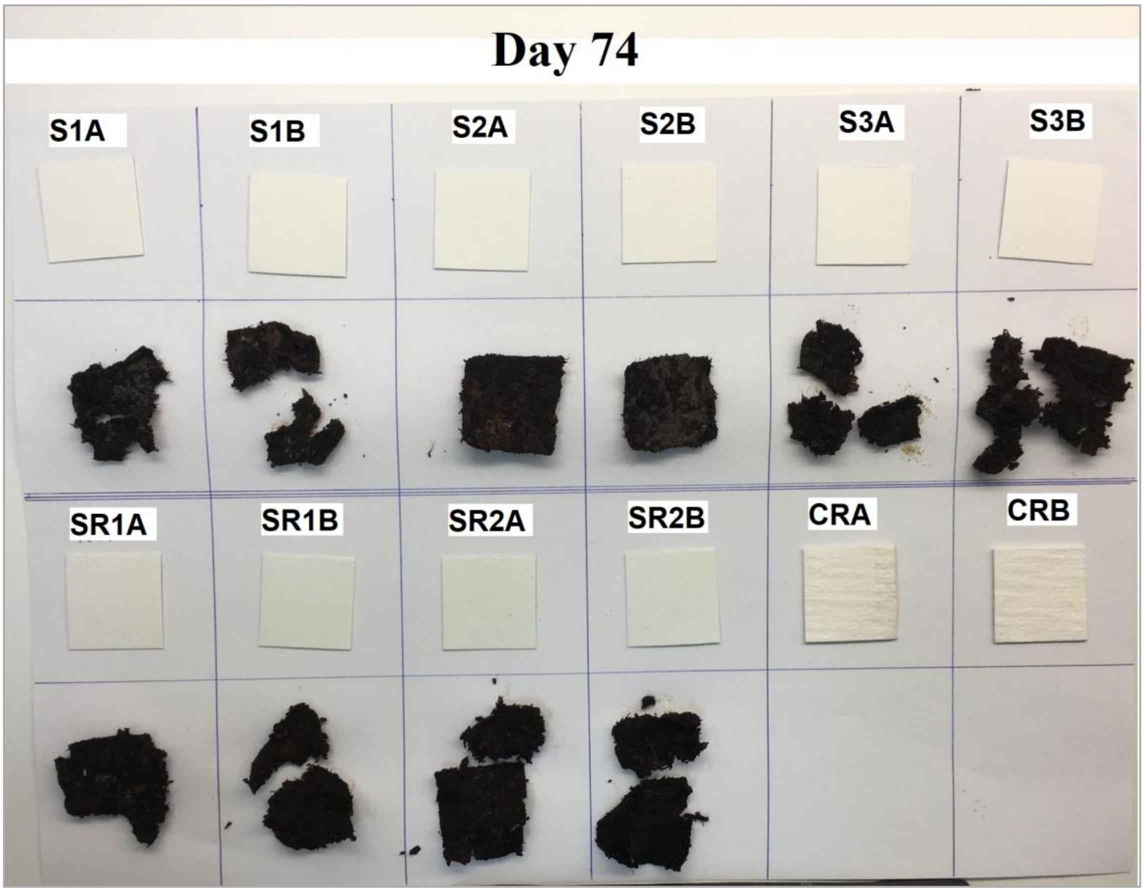


PICTURE 9. Test materials on day 42



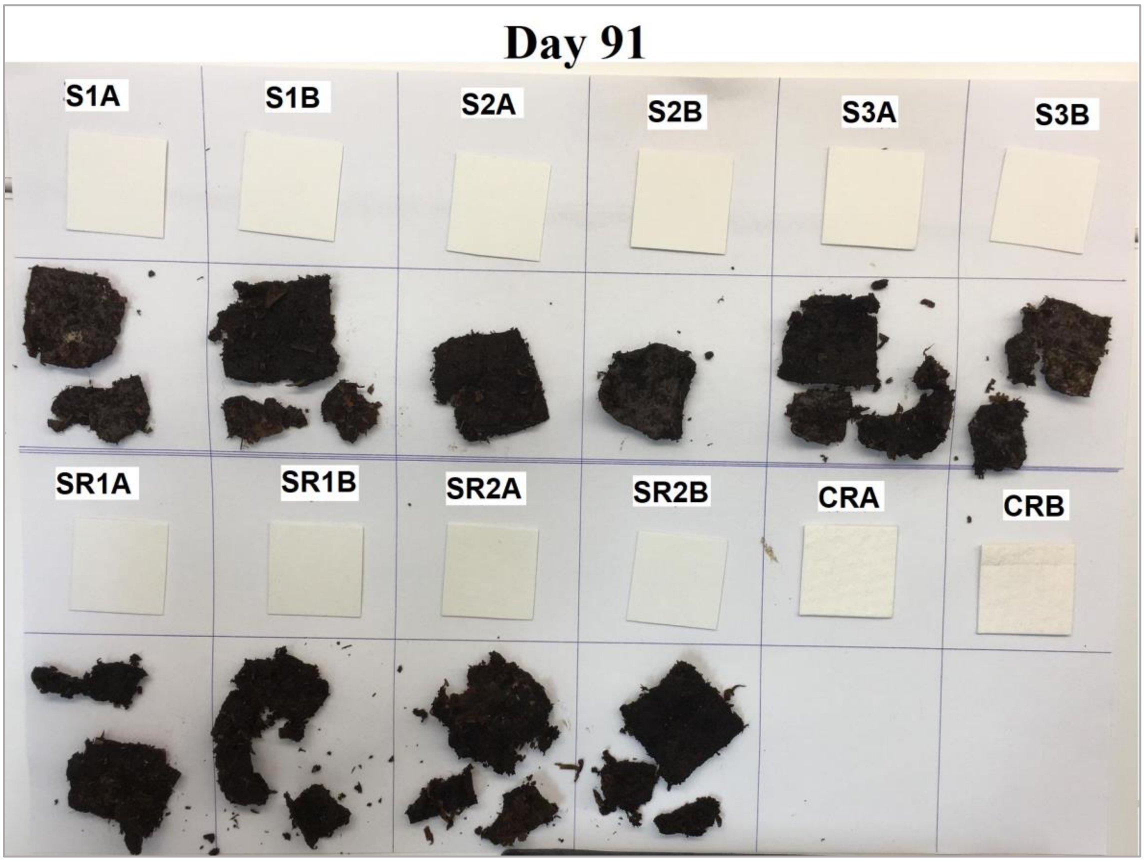
PICTURE 10. Test materials on day 60

No significant changes were recognized on day 74 compare to day 60 from all test materials (Picture 11).



PICTURE 11. Test materials on day 74

On day 91, sample S1, S3, and reference SR1, SR2 were still in same conditions as day 60. Up to that day, no fragments of sample S2 was found during visual inspection, however, some were detected via sieving process. By sieving, it was confirmed that reference CR has disintegrated completely (Picture 12).



PICTURE 12. Test materials on day 91

The changes in conditions of test materials during composting process in 91 days, as mentioned above, were collected and visualized in Figure 6.

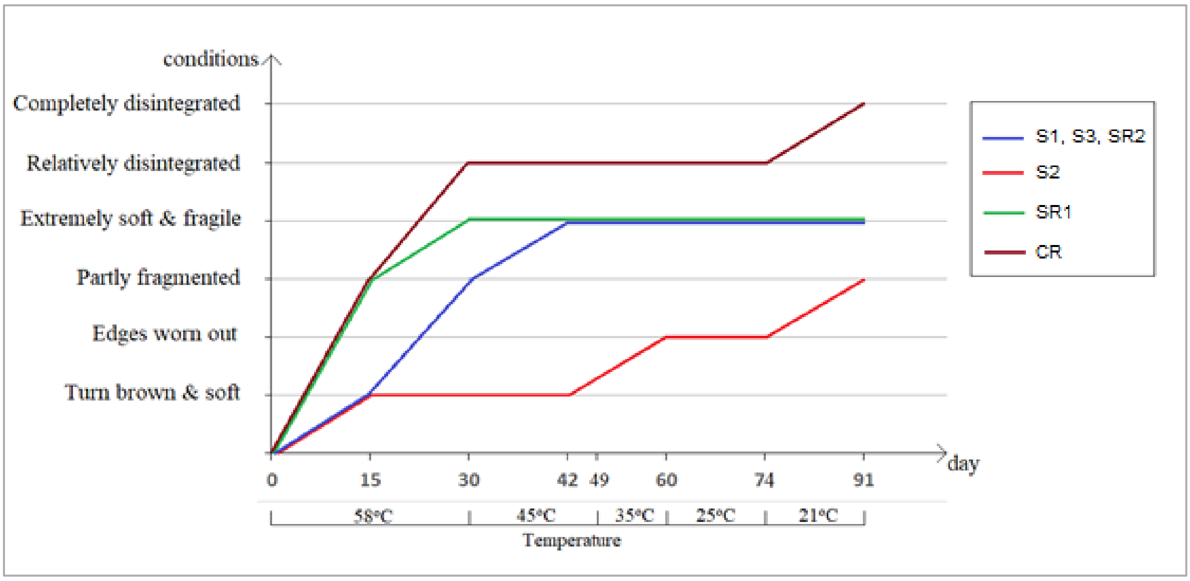
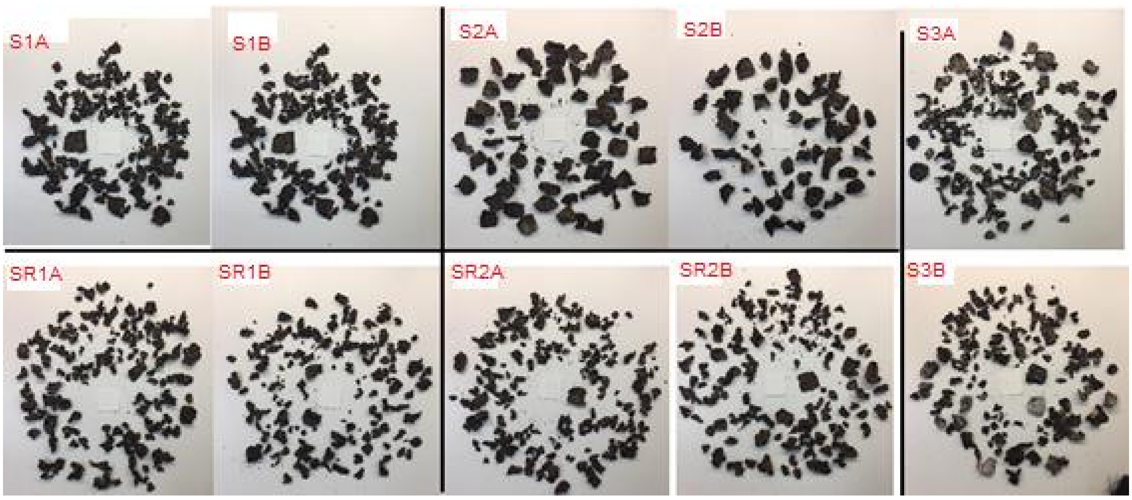


FIGURE 6. Conditions of test materials by observation

4.2.2 Degree of disintegration

Residues mass was measured after they were cleaned without water (dry-clean) and were dried in the oven at 105°C for 2 hours. Dry-cleaning was done by using tweezer to remove as much as possible the compost substrate from the residues of test materials. The residues were not cleaned with water because, except residues from reactor S2A and S2B, most of the residues from other reactors were very small (Picture 13), and when they were in contact with water, they tended to break into smaller fragments and become impossible to retrieve for measuring.

Table 11 shows the degree of disintegration of all test materials. The results were as follows: S1A (40.1%), S1B (31.7%), S2A (27.3%), S2B (30.8%), S3A (30.5%), S3B (34.6%), SR1A (36.6%), SR1B (42.0%), SR2A (39.7%), SR2B (33.8%), CRA (100%), and CRB (100%). Due to the small difference in coating amount between replicate treatments A and B of sample S1, S2, and S3 (Table 3), the average value of *D* was also calculated.



PICTURE 13. Collected residues after dry-clean

An attempt to clean with water (wet-clean) was also carried out for residues from reactor S2A and S2B (Table 12). After wet-clean, residues mass from reactor S2A reduced 20.4% and residues mass from reactor S2B reduced 32.1%. However, due to the significant difference in size between residues from reactor S2A, S3B and residues from other reactors, it was decided that those values

(20.4% and 32.1%) cannot represent for other reactors' residues. Therefore, degree of disintegration was decided to be calculated with dry-clean values only.

TABLE 11. Degree of disintegration of test materials

Reactor	Test material		Degree of disintegration *D* (%)	Average
	initial mass (g)	residues mass (g) (after dry-clean)		
S1A	10.0795	6.0387	40.1	35.9
S1B	10.0141	6.8402	31.7	
S2A	9.9698	7.2498	27.3	29.0
S2B	9.8995	6.8552	30.8	
S3A	9.9854	6.9452	30.5	32.5
S3B	10.0027	6.5448	34.6	
SR1A	10.086	6.3929	36.6	39.3
SR1B	9.9837	5.7950	42.0	
SR2A	9.9843	6.0201	39.7	36.8
SR2B	9.9613	6.5911	33.8	
CRA	10.2465	0	100.0	100.0
CRB	10.1230	0	100.0	

TABLE 12. Reduction of mass of residues from S2A and S2B after wet-clean

Reactor	Mass (g)		Reduction (%)
	Clean without water and dry at 105°C	Clean with water and dry at 105°C	
S2A	7.2498	5.7683	20.4
S2B	6.8552	4.6568	32.1

Based on data from Table 11, Figure 7 shows the degree of disintegration of test materials S1, S2, S3, SR1, and SR2.

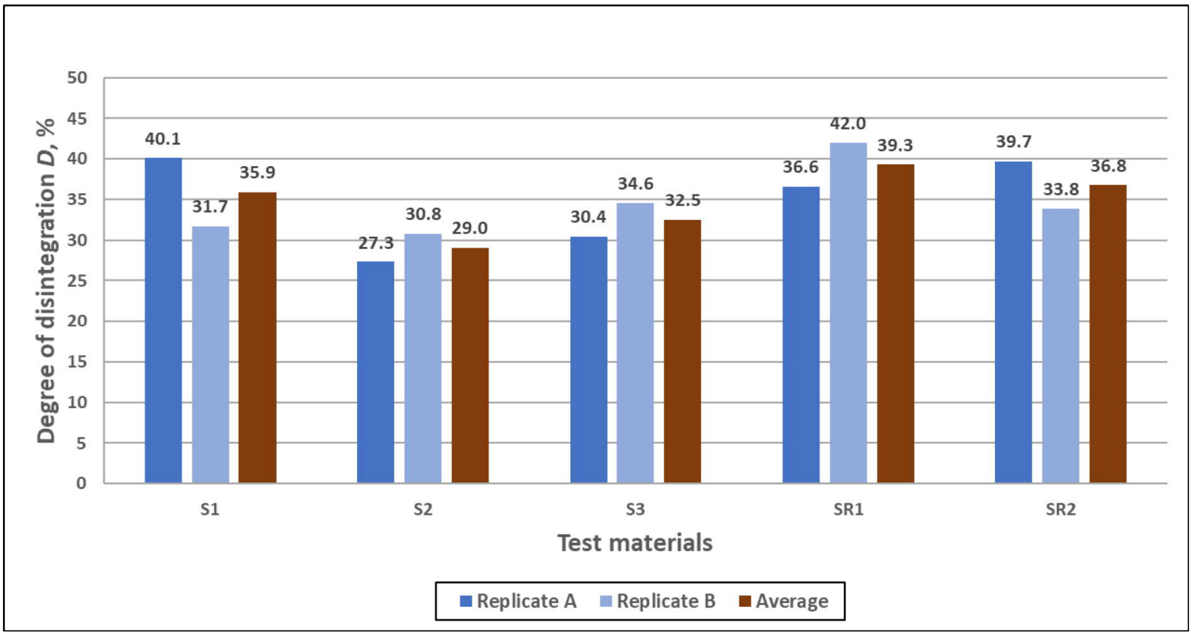


FIGURE 7. Degree of disintegration of sample materials and sample references

5 DISCUSSION

5.1 Pre-testing of composting process

The pre-test has provided valuable evaluation towards the testing procedures. In general, from the author's observation, when making the synthetic waste, ingredients with small amount (i.e. starch, oil, urea, and saccharose) should be mixed together with water first to form homogeneous mixture. Then rabbit, compost, and partly sawdust is added, consecutively. When turning the compost substance, it should be done gently to avoid mass loss in case the compost spills out. Another observation is, when adding water to restore the substrate mass, one also need to be careful with the amount to avoid excessive moisture content. Considering the visual recording, taking photos of the compost periodically is important. Photos should be captured at the same angle, height, and lighting conditions all the time to minimise the risk of visualization being affected. All in all, the preliminary test showed that despite the reactor had smaller volume than recommended, no negative outcome was recognized, and the compost worked normally. In addition, no adjustment in the synthetic waste composition was needed since the composting factors meet the requirements at the beginning of the test.

5.2 Compost substrate

From the observation, colour shifting and changes in odour indicate that the substrate worked. The pH results were also in accordance with the odour and met the expected scheme defined in SFS-EN 14806 – that is start from acidic condition (pH 6.7) and switch to neutral at the end (pH from 7.6 to 7.9).

As the substrate from all reactors was taken from the same source, measured values of the substrate were quite consistent when compare from one reactor to another. Since day 30 onwards, no water was added (Appendix 3). However, moisture content in all reactors was around 72%, while it should have been between 50%-60% (Epstein 2011, 19; Diaz et al. 2007, 56). The outcome of high moisture content could be due to the decreasing of temperature. However, the temperature adjustments and the addition of water were in line with standard SFS-EN 14806. On the other side, there are three different temperature profiles but only one method of water addition was mentioned in the standard. Thus, to understand better the reason why moisture content was high in this test, further tests with either same or different temperature profile should be carried out.

Although the moisture content was higher than 60%, no signs of anaerobic conditions were detected. This excessive moisture content could be the reason that led to slow composting process – which was indicated by high C:N ratio at termination. According to Cornell Waste Management Institute (1996), C:N ratio should have reduced to about 10-15:1, but the results in this test are 19 to 22 :1 (Table 8). Relatively high carbon content at the end of the test is also in accordance with observation during sieving process, where the substrate at termination still contained a lot of visible sawdust after 91 days of composting (Picture 13). Despite the unexpected C:N ratio, reduction percentage of volatile substances in each reactor was higher than 30%. It indicates the test is valid for all reactors.

PICTURE 13. Remaining residues on 2 mm sieve.

5.3 Test materials

Compost reference CR (cellulose-hemicellulose) has been assumed to be relatively disintegrated since day 42, because no remaining was found on two consecutive inspecting days (day 30 and day 42). However, because the observation was subjective, it could not be assured that CR has completely disintegrated until the sieving was done and no residue was found. By the fact that cellulose-hemicellulose is an easy-to-degrade material (Diaz et al. 2007, 27–30), since compost reference has completely disintegrated, it again indicated the composting process worked.

Sample S2 apparently was the most durable material as it stayed intact for a long time (Figure 6). Sample reference SR1 (base coated with starch) on the other hand was already partly disintegrated on day 15 and had become fragile on day 30. By just observation, it is difficult to distinguish the level of disintegration of sample S1, S3 and sample reference SR2 (non-coated base) to each other, since they behaved quite similar throughout the test. Based on Figure 6, it seems that sample reference SR1 would disintegrate faster than S1, S2, S3, and SR2. Those observations are recognized through the calculation of degree of disintegration. As can be seen from Figure 5, SR1 has the highest average value of degree of disintegration (39.3%), and S2 has the lowest value (29.0%). Figure 5 also shows that reference SR1 performed better than reference SR2 (39.3% compare to 36.8%). This indicates a coating starch layer may boost the disintegrability of the material. Reason behind this observation is that starch acts as food and attracts the microorganisms. Based on the results, ranking of degree of disintegration has been done among three sample materials and two sample reference materials (Figure 7).

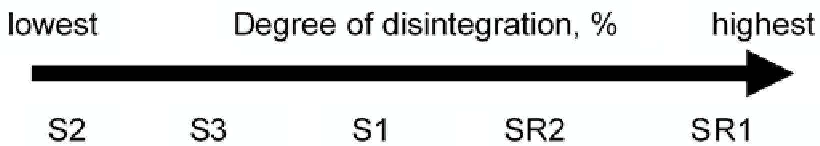


FIGURE 7. Ranking of degree of disintegration

Overall, the non-coated base (SR2) disintegrated more than coated samples (S1, S2, and S3). Sample S1 has the least difference in degree of disintegration compare to SR2 (less than 1%). Therefore, coating material embedded on S1 might be a potential material that does not affect much to the disintegrability of base material. As SR1 disintegrated more than SR2., a starch coating layer might help to boost the disintegrability of the material. In addition, because cellulose has better degradability than starch, and hemicellulose shares the characteristics with starch (Diaz et al., 2007, 27 – 30), it can be expected that a coating layer of cellulose-hemicellulose might also boost the disintegrability.

5.4 Factors affecting results

On day 42, due to real estate maintenance, which was informed in advance, there was a 4-hours power cut in TAMK's premise, leading to a temporary shut-down of the incubator. It was a short duration and the incubator's doors were not opened during that time. Nonetheless, this power cut event may have caused some error to the results.

It is still in question what was the factor causing high moisture content and eventually affecting the composting performance. The reason of high moisture content was speculated to be the decline of temperature. However, if this situation likely happens when applying this temperature profile, then high moisture content will become an apparent outcome. Unfortunately, no other study following standard SFS-EN 14806 with same temperature profile as in this test was found to make comparison. Therefore, as mentioned above, a repeat of this test or a test with another temperature profile is needed to evaluate this unexpected result.

During the sieving phase at the end of the test, there were difficulties in identifying test materials' residues. The compost needed to get dry before sieving, and thus there was a gap time between the moment the test was terminated and the moment sieving process was started. During that time, test materials may continue to disintegrate, therefore the results may not correspond to day 91. Because most of the compost did not go through the 2 mm sieve (Picture 13), identifying which residues belong to test materials was very challenging and time-consuming. As it objectively depends on the examiner's ability, there was potential human errors that might cause some residues unrecovered, which could lead to inaccurate calculation of degree of disintegration.

Another factor that affects the calculation of degree of disintegration is the cleaning process of the residues. As mentioned in the visual observation of test materials, the residues were in fragile condition, thus it was extremely challenging to clean them with water. The cleaning was then decided to be dry-cleaned only, there was still some compost substrate attaching to the residues, making the residues mass greater than it should be.

Assuming the errors from sieving phase is less significant than the errors from cleaning phase, then the degree of disintegration could be higher than calculated as in Table 11.

5.5 Practical usability of Standard SFS-EN 14806

In general, standard SFS-EN 14806 has been easy to follow, although there are some aspects that might need further guidance. The most struggling phases in this test were considered to be identifying residues of material during sieving phase, and cleaning the residues at the end. In this test, the test materials have fragmented into a large number of small fragments, therefore it took at least five hours to both retrieve and clean the residues from each reactor. The standard could have instructed clearer how to pre-treat the compost before sieving, for example, let the compost dry at room temperature for a certain time. Because wet compost tends to be stuck on the sieves and thus making sieving process ineffective and time-consuming. A more detailed instruction of cleaning residues would also be helpful. For instance, in case the residues could not be washed with water, what should be done, or how to assess the influence on uncertainty in measurement results.

6 CONCLUSION

Based on the results obtained from this study, following conclusions can be drawn: (1) the composting process worked (colour and odour results, and validity of the test met the expectations; cellulose-hemicellulose material disintegrated completely), but seemed to slow down and remained immature as the temperature declined. As a consequence of this situation, the results are concerned just relatively reliable. (2) the coating substances embedded on sample 1, sample 2, and sample 3 have reduced the ability to disintegrate of the base material. Coating substance embedded on sample 1 affected least, while coating substance embedded on sample 2 affected most (difference of degree of disintegration compare to non-coated base was about 1% and 8%, respectively). (3) the coating layer of starch might have slightly boosted the disintegration (SR1 disintegrated 2.5% more than SR2). (4) Standard SFS-EN 14806 was easy to follow, although some clearer guidance towards handling of test material residues would be helpful.

From the author observations, it is suggested that further test with same or different temperature profile should be conducted to determine the temperature profile which generates the best composting performance. In addition, cellulose-hemicellulose or other easy-to-degrade plant-based compound might be used as coating substance to test the boosting effect on disintegration. Temperature loggers can also be employed to track the temperature in case there is any unexpected disturbance. The loggers could also work as a means to evaluate the reliability of the incubator’s system.

REFERENCES

Barbier, E. B. 1987. The concept of Sustainable Economic Development. Journal of Environmental Conservation 14 (02), 101 – 110.

Berger, K. R. & Welt, B. 2005. A Brief History of Packaging. Read on 25.02.2021. https://ufdc.ufl.edu/IR00001524/00001

BÜCHI. 2020. Homepage website. Read on 27.02.2021. https://www.buchi.com/en

Cornell Waste Management Institute. 1996. Compost chemistry. Read on 21.02.2021. http://compost.css.cornell.edu/chemistry.html

Degli-Innocenti, F. 2002. Biodegradability and Compostability. In Chiellini, E. & Solaro, R. 2003. Biodegradable Polymer and Plastic. Italy: The International Norms, 33–45.

Diaz, L. F., Bertoldi, M., Bidlingmaier, W. & Stentiford, E. 2007. 1st ed. Compost Science and Technology. Amsterdam, The Netherlands: Elsevier.

Egli, H. 2008. Kjeldahl guide. 1st ed. Flawil, Switzerland: Büchi Labortechnik AG.

Epstein, E. 2011. Industrial composting: Environmental Engineering and Facilities Management. United States of America: CRC Press – Taylor & Francis Group.

European Commission. 2018. A European Strategy for Plastics in a Circular Economy. Read on 06.01.2020. https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf

Finnish Standard SFS-ISO 10390. 2007. Soil quality – Determination of pH. Read on 21.09.2020. Requires access right. https://online.sfs.fi/fi/index.html.stx

Finnish Standard SFS-EN 13193. 2000. Packaging – Packaging and the environment – Terminology. Read on 21.09.2020. Requires access right. https://online.sfs.fi/fi/index.html.stx

Finnish Standard SFS-EN 14045. 2003. Packaging – Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions. Read on 21.09.2020. Requires access right. https://online.sfs.fi/fi/index.html.stx

Finnish Standard SFS-EN 14806. 2006. Packaging – Preliminary evaluation of the disintegration of packaging materials under simulated composting conditions in a laboratory scale test. Read on 21.09.2020. Requires access right. https://online.sfs.fi/fi/index.html.stx

Han, J-W., Ruiz-Garcia, L., Qian, J-P. & Yang, X-T. 05.2018. Food Packaging: A Comprehensive Review and Future Trends. Comprehensive Reviews in Food Science and Food Safety. Read on 30.03.2021. https://onlinelibrary.wiley.com/doi/full/10.1111/1541-4337.12343

Kedzierski, M., Frère, D., Le Maguer, G. & Bruzaud, S. 2020. Why is there plastic packaging in the natural environment? Understanding the roots of our individual plastic waste management behaviours. Elsevier: Science of the Total Environment, 740 (2020).

Kemira. 2020a. Future of food packaging: Four scenarios for 2030. Read on 06.01.2020. https://www.kemira.com/insights/future-food-packaging-four-scenarios-2030/

Kemira. 2020b. FennoGuard GO barrier coating for food packaging – 10 questions answered. Read on 06.01.2020. https://www.kemira.com/insights/fennoguard-go-barrier-coating-for-food-packaging-10-questions-answered/

Metsä. 2020. Metsä Pine Bleached Softwood Kraft Pulp – RMA. Read on 17.03.2021. https://www.metsafibre.com/en/Documents/Data-sheets/Metsa-softwood-pulp/Metsa-Pine-RMA.pdf

Metrohm. 2010. Titration device – 876 Dosimat plus. Read on 10.03.2021. https://www.metrohm.com/en/products/liquid-handling/dosimat-plus/28760010#

Nilsen-Nygaard, J., Fernández, E. N., Radusin, T., Rotabakk, B. T., Sarfraz, J., Sharmin, N., Sivertsvik, M., Sone, I. & Pettersen, M. K. 06.02.2021. Current status of biobased and biodegradable food packaging materials: Impact on food quality and effect of innovative processing technologies. Comprehensive Reviews in Food Science and Food Safety. Read on 25.02.2021. https://onlinelibrary.wiley.com/doi/10.1111/1541-4337.12715

Orthex Group. 2016. SmartStore™ Classic 5. Read on 27.02.2021. https://www.orthexgroup.fi/tuotteet/sailytys/sailytyslaatikot/smartstore-classic/smartstore-classic-5

Pol-Eko. 2019. Homepage. Read on 27.02.2021. https://www.pol-eko.com.pl/model/laboratory-incubator-clw/laboratory-incubator-clw-400/

Pongrácz, E. March 2007. The environmental impacts of packaging. In Kutz, M. Environmentally Conscious Materials and Chemicals Processing. Canada: John Wiley & Sons, Inc. Chapter 9, 237-273.

Precisa. 2021. Homepage. Read on 27.02.2021. https://www.precisa.com/products?f=Moisture%20Analyzers

Risch, S. J. 2009. Food Packaging History and Innovations. Journal of Agricultural and Food Chemistry 57, 8089-8092.

Yildirim, S., Röcker, B., Pettersen, M. K., Nilsen-Nygaard, J., Ayhan, Z., Rutkaite, R., Radusin, T., Suminska, P., Marcos, B. & Coma, V. 28.11.2017. Active Packaging Applications for Food. Comprehensive Reviews in Food Science and

Food Safety. Read on 25.2.2021. https://onlinelibrary.wiley.com/doi/abs/10.1111/1541-4337.12322

APPENDICES

Appendix 1. Details of cellulose-hemicellulose material

(Metsä, 2020) 1(2)

Date: 20/05/2020

Metsä Pine RMA

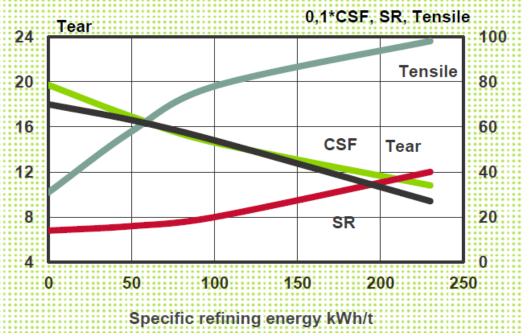
Bleached Softwood Kraft Pulp

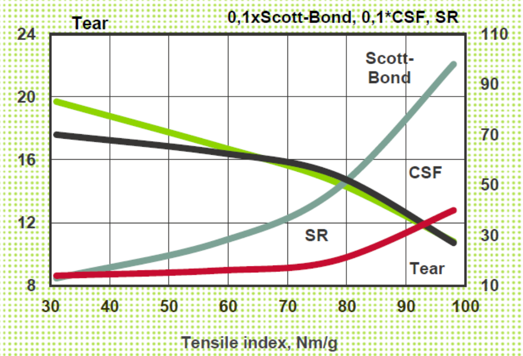
Raw material

Pine (pinus sylvestris)	**Spruce** (picea abies)
70–100%	0–30%

Pulp characteristics

Brightness, ISO (PulpExpertDCD) Target 88.5%	**Fibre length, mm** (PulpExpert) Typical value 2,15 mm
Coarseness (Kajaani FS-5 mod) 0.145–0.175 mg/m	**Ash content** (ISO 1762:2001) 0–0.4%
Viscosity (ISO 5351) Min. 750 ml/g	**pH** (ISO 6588) 5.0–7.0





Specific refining energy	CSF	Schopper-Riegler - number	Tensile index	Tensile stiffness index	Tear index	Scott-Bond	Density	Opacity	Air resistance
kWh/t	ml		Nm/g	kNm/g	mNm²/g	J/m²	kg/m³	%	(Gurley) s
0	703	14	31	4,2	19,7	126	576	70,6	1,4
50	628	16	58	6,1	16,9	268	642	66,6	3,5
100	543	20	78	7,5	14,6	480	703	63,0	10
230	271	40	98	8,8	10,8	987	782	58,4	401
67	**600**	17	66	6,6	16,1	333	664	65,3	5,0
123	**500**	23	85	8,0	13,7	592	727	61,5	18
98	546	**20**	78	7,5	14,7	470	701	63,1	10
141	465	**25**	90	8,3	13,5	681	743	60,5	29
77	583	18	**70**	6,9	15,6	374	676	64,6	6,2
142	463	25	**90**	8,3	13,0	686	744	60,5	30

Mean (indicative) values from pulp testing with Lab-Finer using standard water.
Specific Edge Load 2,5 Ws/m, ISO testing methods, testing climate 50 % RH, 23°C. Handsheets 65 g/m².

Metsä Fibre Oy, Rauma Mill
Address: P.P. Box 165, FI-26101 Rauma, Finland

Metsä

Date: 20/´05/2020

Metsä Pine RMA

Bleached Softwood Kraft Pulp

Applications

— Speciality papers

— Wood free papers

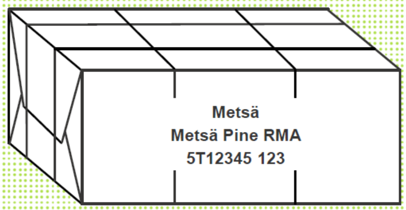
— Tissue papers

Sheets

— Size: 84 x 78 cm

— Grammage: 850 – 980 g/m^2

Bales



Size: 84 x 78 x 42 cm

Gross weight : 250 kg

Wrappers: Pulp sheet

Wires: 4 galvanized wires, diameters 2.3 mm

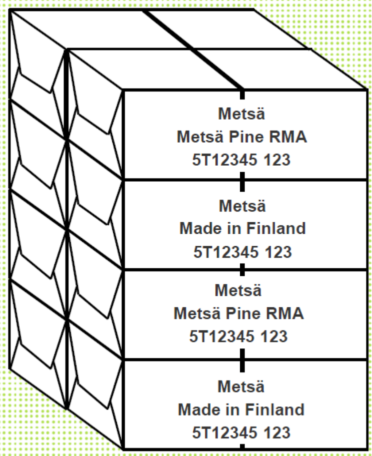
Markings:

Black ink-jet printing, water soluble ink

Brand name and bale number

on both side of the bale

Units



Size: 85 x 160 x 175 cm

Gross weight : 2,000 kg (8 x 250 kg)

Wires: 8 galvanized wires, diameter 3.0 mm

Identification: RFID tag 1/ton

Metsä Fibre Oy, Rauma Mill
Address: P.P. Box 165, FI-26101 Rauma, Finland

Metsä

Appendix 2. Components of synthetic waste

Material	Photo
Sawdust http://wanhapuusepanverstas.com/	
Rabbit feed https://www.burgesspetcare.com/shop/rabbit-food/adult/excel-adult-rabbit-nuggets-with-mint/	
Compost https://www.biolan.fi/tuotteet/biolan-puutarhan-musta-multa.html	
Starch https://www.foodie.fi/entry/maizena-400g-maissitarkkelys/8718114782591	
Saccharose (sugar)	
Rapeseed oil https://www.k-ruoka.fi/kauppa/tuote/k-menu-rapsioljy-1l-6410405147158	

Appendix 3. Water addition during the test

<table>
<tr><th colspan="5">Reactor: S1A</th></tr>
<tr><th>Day</th><th>Reactor mass (g)</th><th>Water added (g)</th><th>Turning (X = yes)</th><th>Notes</th></tr>
<tr><td>0</td><td>1183.5</td><td></td><td rowspan="6">X</td><td>reactor vessel = 173.4 g</td></tr>
<tr><td>1</td><td>1165.4</td><td>18.1</td><td></td></tr>
<tr><td>2</td><td>1168.2</td><td>15.3</td><td></td></tr>
<tr><td>3</td><td>1161.0</td><td>22.5</td><td></td></tr>
<tr><td>4</td><td>1162.0</td><td>21.5</td><td></td></tr>
<tr><td>7</td><td>1144.6</td><td>38.9</td><td></td></tr>
<tr><td>8</td><td>1168.4</td><td>15.1</td><td></td><td></td></tr>
<tr><td>9</td><td>1167.4</td><td>16.1</td><td>X</td><td></td></tr>
<tr><td>10</td><td>1173.2</td><td>10.3</td><td></td><td></td></tr>
<tr><td>11</td><td>1172.8</td><td>10.7</td><td rowspan="2">X</td><td></td></tr>
<tr><td>14</td><td>1144.0</td><td>39.5</td><td></td></tr>
<tr><td>16</td><td>1165.4</td><td>18.1</td><td rowspan="6"></td><td></td></tr>
<tr><td>18</td><td>1152.2</td><td>31.3</td><td></td></tr>
<tr><td>21</td><td>1147.6</td><td>35.9</td><td></td></tr>
<tr><td>23</td><td>1163.4</td><td>20.1</td><td></td></tr>
<tr><td>25</td><td>1156.2</td><td>27.3</td><td></td></tr>
<tr><td>28</td><td>1152.8</td><td>30.7</td><td></td></tr>
<tr><td>30</td><td>1165.2</td><td>0</td><td>X</td><td>Add 25 g compost as re-inoculation.</td></tr>
<tr><td>32</td><td>1178.8</td><td>0</td><td rowspan="4"></td><td rowspan="7">Add water to restore mass to 966.8 g (80% of initial mass)</td></tr>
<tr><td>36</td><td>1163.4</td><td>0</td></tr>
<tr><td>39</td><td>1151.2</td><td>0</td></tr>
<tr><td>42</td><td>1141.2</td><td>0</td></tr>
<tr><td>49</td><td>1100.4</td><td>0</td><td>X</td></tr>
<tr><td>52</td><td>1090.4</td><td>0</td><td rowspan="13"></td></tr>
<tr><td>56</td><td>1076.6</td><td>0</td></tr>
<tr><td>60</td><td>1060.6</td><td>0</td><td rowspan="11">Add water to restore mass to 846 g (70% of initial mass)</td></tr>
<tr><td>63</td><td>1053.8</td><td>0</td></tr>
<tr><td>66</td><td>1048.0</td><td>0</td></tr>
<tr><td>68</td><td>1042.8</td><td>0</td></tr>
<tr><td>71</td><td>1038.6</td><td>0</td></tr>
<tr><td>74</td><td>1034.8</td><td>0</td></tr>
<tr><td>78</td><td>1032.2</td><td>0</td></tr>
<tr><td>81</td><td>1027.6</td><td>0</td></tr>
<tr><td>85</td><td>1024.8</td><td>0</td></tr>
<tr><td>88</td><td>1021.4</td><td>0</td></tr>
<tr><td>91</td><td>1019.2</td><td>0</td></tr>
<tr><td colspan="5">Final compost wet mass = 1019.2 - 173.4 = 845.8 g</td></tr>
</table>

Reactor: S1B				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.4		X	reactor vessel = 173.4 g
1	1161.4	22.0		
2	1161.2	22.2		
3	1153.6	29.8		
4	1161.0	22.4		
7	1112.8	70.6		
8	1167.2	16.2		
9	1160.4	23.0	X	
10	1170.2	13.2		
11	1165.4	18.0	X	
14	1145.6	37.8		
16	1157.2	26.2		
18	1147.4	36.0		
21	1144.2	39.2		
23	1165.6	17.8		
25	1152.8	30.6		
28	1148.8	34.6		
30	1162.0	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)
32	1172.0	0		Add water to restore mass to 966.7 g (80% of initial mass)
36	1140.8	0		
39	1121.8	0		
42	1098.2	0		
49	1059.0	0	X	
52	1050.6	0		
56	1042.0	0		
60	1032.0	0		Add water to restore mass to 845.9 g (70% of initial mass)
63	1022.2	0		
66	1014.4	0		
68	1002.8	0		
71	997.6	0		
74	994.2	0		
78	992.0	0		
81	986.4	0		
85	979.4	0		
88	970.0	0		
91	965.2	0		
Final compost wet mass = 965.2 - 173.4 = 791.8 g				

Reactor: S2A				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.4		X	reactor vessel = 173.4 g
1	1164.4	19.0		
2	1171.0	12.4		
3	1167.8	15.6		
4	1158.2	25.2		
7	1137.6	45.8		
8	1165.4	18.0		
9	1161.4	22.0	X	
10	1169.2	14.2		
11	1166.0	17.4	X	
14	1144.4	39.0		
16	1153.2	30.2		
18	1157.6	25.8		
21	1146.4	37.0		
23	1159.2	24.2		
25	1154.2	29.2		
28	1147.0	36.4		
30	1157.2	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)
32	1159.2	0		Add water to restore mass to 966.7 g (80% of initial mass)
36	1127.0	0		
39	1113.2	0		
42	1084.4	0		
49	1036.2	0	X	
52	1023.2	0		
56	1007.6	0		
60	1053.6	0		Add water to restore mass to 846 g (70% of initial mass)
63	980.4	0		
66	972.2	0		
68	965.0	0		
71	958.2	0		
74	954.8	0		
78	951.6	0		
81	947.4	0		
85	942.8	0		
88	936.2	0		
91	930.8	0		
Final compost wet mass = 930.8 - 173.4 = 757.4 g				

<table>
<tr><th colspan="5">Reactor: S2B</th></tr>
<tr><th>Day</th><th>Reactor mass (g)</th><th>Water added (g)</th><th>Turning
(X = yes)</th><th>Notes</th></tr>
<tr><td>0</td><td>1183.3</td><td></td><td rowspan="6">X</td><td>reactor vessel = 173.4 g</td></tr>
<tr><td>1</td><td>1165.1</td><td>18.2</td><td></td></tr>
<tr><td>2</td><td>1165.2</td><td>18.1</td><td></td></tr>
<tr><td>3</td><td>1155.8</td><td>27.5</td><td></td></tr>
<tr><td>4</td><td>1164.2</td><td>19.1</td><td></td></tr>
<tr><td>7</td><td>1130.8</td><td>52.5</td><td></td></tr>
<tr><td>8</td><td>1167.6</td><td>15.7</td><td></td><td></td></tr>
<tr><td>9</td><td>1160.0</td><td>23.3</td><td>X</td><td></td></tr>
<tr><td>10</td><td>1169.4</td><td>13.9</td><td></td><td></td></tr>
<tr><td>11</td><td>1167.2</td><td>16.1</td><td rowspan="2">X</td><td></td></tr>
<tr><td>14</td><td>1160.4</td><td>22.9</td><td></td></tr>
<tr><td>16</td><td>1166.0</td><td>17.3</td><td rowspan="7"></td><td></td></tr>
<tr><td>18</td><td>1155.4</td><td>27.9</td><td></td></tr>
<tr><td>21</td><td>1132.8</td><td>50.5</td><td></td></tr>
<tr><td>23</td><td>1164.6</td><td>18.7</td><td></td></tr>
<tr><td>25</td><td>1156.8</td><td>26.5</td><td></td></tr>
<tr><td>28</td><td>1150.6</td><td>32.7</td><td></td></tr>
<tr><td>30</td><td>1155.6</td><td>0</td><td>X</td><td>Add 25 g compost as re-inoculation.
(“new” initial mass = 1208.5 g)</td></tr>
<tr><td>32</td><td>1165.4</td><td>0</td><td rowspan="4"></td><td rowspan="7">Add water to restore mass to 966.6 g
(80% of initial mass)</td></tr>
<tr><td>36</td><td>1130.8</td><td>0</td></tr>
<tr><td>39</td><td>1109.8</td><td>0</td></tr>
<tr><td>42</td><td>1074.2</td><td>0</td></tr>
<tr><td>49</td><td>1036.2</td><td>0</td><td>X</td></tr>
<tr><td>52</td><td>1020.0</td><td>0</td><td rowspan="13"></td></tr>
<tr><td>56</td><td>1003.6</td><td>0</td></tr>
<tr><td>60</td><td>985.2</td><td>0</td><td rowspan="11">Add water to restore mass to 845.8 g
(70% of initial mass)</td></tr>
<tr><td>63</td><td>974.0</td><td>0</td></tr>
<tr><td>66</td><td>966.4</td><td>0</td></tr>
<tr><td>68</td><td>958.0</td><td>0</td></tr>
<tr><td>71</td><td>949.8</td><td>0</td></tr>
<tr><td>74</td><td>945.6</td><td>0</td></tr>
<tr><td>78</td><td>943.8</td><td>0</td></tr>
<tr><td>81</td><td>938.4</td><td>0</td></tr>
<tr><td>85</td><td>930.6</td><td>0</td></tr>
<tr><td>88</td><td>924.8</td><td>0</td></tr>
<tr><td>91</td><td>920.8</td><td>0</td></tr>
<tr><td colspan="5">Final compost wet mass = 920.8 - 173.4 = 747.4 g</td></tr>
</table>

Reactor: S3A				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.4		X	reactor vessel = 173.4 g
1	1163.8	19.6		
2	1162.4	21.0		
3	1163.4	20.0		
4	1166.8	16.6		
7	1133.8	49.6		
8	1171.6	11.8		
9	1168.6	14.8	X	
10	1176.4	7.0		
11	1172.4	11.0	X	
14	1151.6	31.8		
16	1159.8	23.6		
18	1163.0	20.4		
21	1157.8	25.6		
23	1162.4	21.0		
25	1162.2	21.2		
28	1154.2	29.2		
30	1161.4	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)
32	1177.2	0		Add water to restore mass to 966.7 g (80% of initial mass)
36	1156.6	0		
39	1139.8	0		
42	1130.4	0		
49	1097.8	0	X	
52	1089.6	0		
56	1080.8	0		
60	1067.4	0		Add water to restore mass to 846 g (70% of initial mass)
63	1060.4	0		
66	1055.8	0		
68	1050.6	0		
71	1046.6	0		
74	1044.6	0		
78	1042.8	0		
81	1039.2	0		
85	1033.4	0		
88	1029.8	0		
91	1028.2	0		
Final compost wet mass = 1028.2 - 173.4 = 854.8 g				

<table>
<tr><th colspan="5">Reactor: S3B</th></tr>
<tr><th>Day</th><th>Reactor mass (g)</th><th>Water added (g)</th><th>Turning (X = yes)</th><th>Notes</th></tr>
<tr><td>0</td><td>1183.4</td><td></td><td rowspan="6">X</td><td>reactor vessel = 173.4 g</td></tr>
<tr><td>1</td><td>1173.5</td><td>9.9</td><td></td></tr>
<tr><td>2</td><td>1169.0</td><td>14.4</td><td></td></tr>
<tr><td>3</td><td>1164.2</td><td>19.2</td><td></td></tr>
<tr><td>4</td><td>1170.4</td><td>13.0</td><td></td></tr>
<tr><td>7</td><td>1124.4</td><td>59.0</td><td></td></tr>
<tr><td>8</td><td>1173.0</td><td>10.4</td><td></td><td></td></tr>
<tr><td>9</td><td>1167.2</td><td>16.2</td><td>X</td><td></td></tr>
<tr><td>10</td><td>1178.0</td><td>5.4</td><td></td><td></td></tr>
<tr><td>11</td><td>1172.2</td><td>11.2</td><td rowspan="2">X</td><td></td></tr>
<tr><td>14</td><td>1146.2</td><td>37.2</td><td></td></tr>
<tr><td>16</td><td>1155.4</td><td>28.0</td><td rowspan="6"></td><td></td></tr>
<tr><td>18</td><td>1159.4</td><td>24.0</td><td></td></tr>
<tr><td>21</td><td>1154.2</td><td>29.2</td><td></td></tr>
<tr><td>23</td><td>1160.0</td><td>23.4</td><td></td></tr>
<tr><td>25</td><td>1158.8</td><td>24.6</td><td></td></tr>
<tr><td>28</td><td>1154.8</td><td>28.6</td><td></td></tr>
<tr><td>30</td><td>1155.4</td><td>0</td><td>X</td><td>Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)</td></tr>
<tr><td>32</td><td>1164.6</td><td>0</td><td rowspan="4"></td><td rowspan="7">Add water to restore mass to 966.7 g (80% of initial mass)</td></tr>
<tr><td>36</td><td>1147.4</td><td>0</td></tr>
<tr><td>39</td><td>1133.0</td><td>0</td></tr>
<tr><td>42</td><td>1125.2</td><td>0</td></tr>
<tr><td>49</td><td>1086.6</td><td>0</td><td>X</td></tr>
<tr><td>52</td><td>1075.2</td><td>0</td><td rowspan="13"></td></tr>
<tr><td>56</td><td>1059.2</td><td>0</td></tr>
<tr><td>60</td><td>1045.0</td><td>0</td><td rowspan="11">Add water to restore mass to 846 g (70% of initial mass)</td></tr>
<tr><td>63</td><td>1035.8</td><td>0</td></tr>
<tr><td>66</td><td>1030.8</td><td>0</td></tr>
<tr><td>68</td><td>1022.8</td><td>0</td></tr>
<tr><td>71</td><td>1016.0</td><td>0</td></tr>
<tr><td>74</td><td>1013.8</td><td>0</td></tr>
<tr><td>78</td><td>1011.6</td><td>0</td></tr>
<tr><td>81</td><td>1009.2</td><td>0</td></tr>
<tr><td>85</td><td>1006.0</td><td>0</td></tr>
<tr><td>88</td><td>1002.2</td><td>0</td></tr>
<tr><td>91</td><td>999.2</td><td>0</td></tr>
<tr><td colspan="5">Final compost wet mass = 999.2 - 173.4 = 825.8 g</td></tr>
</table>

Reactor: SR1A				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.5		X	reactor vessel = 173.4 g
1	1168.2	15.3		
2	1167.2	16.3		
3	1160.4	23.1		
4	1153.2	30.3		
7	1125.0	58.5		
8	1162.8	20.7		
9	1164.4	19.1	X	
10	1169.4	14.1		
11	1160.6	22.9	X	
14	1149.8	33.7		
16	1156.4	27.1		
18	1165.2	18.3		
21	1157.6	25.9		
23	1109.4	74.1		
25	1160.4	23.1		
28	1146.2	37.3		
30	1157.2	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.5 g)
32	1167.4	0		Add water to restore mass to 966.8 g (80% of initial mass)
36	1147.0	0		
39	1127.2	0		
42	1120.8	0		
49	1065.6	0	X	
52	1051.2	0		
56	1041.4	0		
60	1024.6	0		Add water to restore mass to 846 g (70% of initial mass)
63	1013.6	0		
66	1006.0	0		
68	997.8	0		
71	991.4	0		
74	988.6	0		
78	986.8	0		
81	981.2	0		
85	974.0	0		
88	977.4	0		
91	964.4	0		
Final compost wet mass = 964.4 - 173.4 = 791 g				

Reactor: SR1B				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.4		X	reactor vessel = 173.4 g
1	1161.2	22.2		
2	1157.8	25.6		
3	1163.8	19.6		
4	1161.4	22.0		
7	1140.0	43.4		
8	1177.0	6.4		
9	1158.0	25.4	X	
10	1159.8	23.6		
11	1164.2	19.2	X	
14	1131.0	52.4		
16	1157.2	26.2		
18	1155.4	28.0		
21	1137.8	45.6		
23	1154.8	28.6		
25	1159.6	23.8		
28	1148.6	34.8		
30	1161.8	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)
32	1172.0	0		Add water to restore mass to 966.7 g (80% of initial mass)
36	1146.6	0		
39	1123.6	0		
42	1110.8	0		
49	1058.6	0	X	
52	1047.6	0		
56	1026.0	0		
60	1006.2	0		Add water to restore mass to 846 g (70% of initial mass)
63	994.0	0		
66	988.0	0		
68	978.8	0		
71	973.2	0		
74	969.8	0		
78	966.6	0		
81	961.6	0		
85	955.6	0		
88	949.2	0		
91	944.0	0		
Final compost wet mass = 944 - 173.4 = 770.6 g				

Reactor: SR2A				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.4		X	reactor vessel = 173.4 g
1	1173.2	10.2		
2	1153.8	29.6		
3	1165.8	17.6		
4	1164.0	19.4		
7	1135.6	47.8		
8	1164.2	19.2		
9	1163.6	19.8	X	
10	1172.6	10.8		
11	1160.0	23.4	X	
14	1145.2	38.2		
16	1163.0	20.4		
18	1167.4	16.0		
21	1153.0	30.4		
23	1159.4	24.0		
25	1162.2	21.2		
28	1149.2	34.2		
30	1159.8	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)
32	1171.8	0		Add water to restore mass to 966.7 g (80% of initial mass)
36	1149.6	0		
39	1128.6	0		
42	1114.8	0		
49	1071.2	0	X	
52	1062.8	0		
56	1049.8	0		
60	1033.2	0		Add water to restore mass to 846 g (70% of initial mass)
63	1023.6	0		
66	1016.0	0		
68	1010.6	0		
71	1008.2	0		
74	1004.0	0		
78	1002.8	0		
81	1000.2	0		
85	996.2	0		
88	991.2	0		
91	987.4	0		
Final compost wet mass = 987.4 - 173.4 = 814 g				

Reactor: SR2B				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.4		X	reactor vessel = 173.4 g
1	1162.4	21.0		
2	1169.8	13.6		
3	1160.2	23.2		
4	1163.2	20.2		
7	1147.8	35.6		
8	1163.0	20.4		
9	1166.2	17.2	X	
10	1168.0	15.4		
11	1140.2	43.2	X	
14	1158.2	25.2		
16	1160.0	23.4		
18	1161.8	21.6		
21	1155.8	27.6		
23	1154.6	28.8		
25	1164.6	18.8		
28	1147.8	35.6		
30	1171.0	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.4 g)
32	1182.4	0		Add water to restore mass to 966.7 g (80% of initial mass)
36	1176.8	0		
39	1164.0	0		
42	1156.8	0		
49	1096.0	0	X	
52	1084.2	0		
56	1071.0	0		
60	1059.2	0		Add water to restore mass to 846 g (70% of initial mass)
63	1049.4	0		
66	1043.0	0		
68	1033.8	0		
71	1025.2	0		
74	1020.2	0		
78	1017.8	0		
81	1013.8	0		
85	1008.8	0		
88	1003.6	0		
91	1000.2	0		
Final compost wet mass = 1000.2 - 173.4 = 826.8 g				

Reactor: CRA				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.6		X	reactor vessel = 173.4 g
1	1170.6	13.0		
2	1154.6	29.0		
3	1162.0	21.6		
4	1165.8	17.8		
7	1124.2	59.4		
8	1174.2	9.4		
9	1158.2	25.4	X	
10	1168.4	15.2		
11	1174.0	9.6	X	
14	1173.0	10.6		
16	1152.0	31.6		
18	1158.6	25.0		
21	1159.0	24.6		
23	1150.0	33.6		
25	1158.4	25.2		
28	1153.4	30.2		
30	1165.4	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.6 g)
32	1181.8	0		Add water to restore mass to 966.9 g (80% of initial mass)
36	1157.2	0		
39	1139.8	0		
42	1129.8	0		
49	1092.0	0	X	
52	1079.6	0		
56	1067.4	0		
60	1051.4	0		Add water to restore mass to 846 g (70% of initial mass)
63	1045.4	0		
66	1041.2	0		
68	1037.6	0		
71	1034.0	0		
74	1031.2	0		
78	1029.6	0		
81	1028.4	0		
85	1024.0	0		
88	1016.2	0		
91	1013.0	0		
Final compost wet mass = 1013 - 173.4 = 839.6 g				

Reactor: CRB				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1183.5		X	reactor vessel = 173.4 g
1	1170.6	12.9		
2	1161.0	22.5		
3	1157.0	26.5		
4	1163.8	19.7		
7	1128.2	55.3		
8	1165.6	17.9		
9	1160.8	22.7	X	
10	1168.2	15.3		
11	1165.6	17.9	X	
14	1140.8	42.7		
16	1145.4	38.1		
18	1160.0	23.5		
21	1154.6	28.9		
23	1152.6	30.9		
25	1156.2	27.3		
28	1150.8	32.7		
30	1165.8	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1208.5 g)
32	1168.6	0		Add water to restore mass to 966.8 g (80% of initial mass)
36	1153.0	0		
39	1131.2	0		
42	1120.6	0		
49	1069.4	0	X	
52	1059.6	0		
56	1038.2	0		
60	1023.0	0		Add water to restore mass to 846 g (70% of initial mass)
63	1011.2	0		
66	1001.4	0		
68	995.0	0		
71	990.4	0		
74	986.2	0		
78	983.2	0		
81	976.8	0		
85	967.4	0		
88	963.0	0		
91	959.8	0		
Final compost wet mass = 959.8 - 173.4 = 786.4 g				

<table>
<tr><th colspan="5">Reactor: B0A</th></tr>
<tr><th>Day</th><th>Reactor mass (g)</th><th>Water added (g)</th><th>Turning (X = yes)</th><th>Notes</th></tr>
<tr><td>0</td><td>1173.4</td><td></td><td rowspan="6">X</td><td>reactor vessel = 173.4 g</td></tr>
<tr><td>1</td><td>1163.4</td><td>10.0</td><td></td></tr>
<tr><td>2</td><td>1146.0</td><td>27.4</td><td></td></tr>
<tr><td>3</td><td>1151.6</td><td>21.8</td><td></td></tr>
<tr><td>4</td><td>1156.4</td><td>17.0</td><td></td></tr>
<tr><td>7</td><td>1127.2</td><td>46.2</td><td></td></tr>
<tr><td>8</td><td>1165.8</td><td>7.6</td><td></td><td></td></tr>
<tr><td>9</td><td>1165.4</td><td>8.0</td><td>X</td><td></td></tr>
<tr><td>10</td><td>1164.2</td><td>9.2</td><td></td><td></td></tr>
<tr><td>11</td><td>1158.4</td><td>15.0</td><td rowspan="2">X</td><td></td></tr>
<tr><td>14</td><td>1124.6</td><td>48.8</td><td></td></tr>
<tr><td>16</td><td>1148.0</td><td>25.4</td><td rowspan="7"></td><td></td></tr>
<tr><td>18</td><td>1158.4</td><td>15.0</td><td></td></tr>
<tr><td>21</td><td>1144.2</td><td>29.2</td><td></td></tr>
<tr><td>23</td><td>1141.2</td><td>32.2</td><td></td></tr>
<tr><td>25</td><td>1150.8</td><td>22.6</td><td></td></tr>
<tr><td>28</td><td>1134.0</td><td>39.4</td><td></td></tr>
<tr><td>30</td><td>1152.0</td><td>0</td><td>X</td><td>Add 25 g compost as re-inoculation. (“new” initial mass = 1198.4 g)</td></tr>
<tr><td>32</td><td>1168.0</td><td>0</td><td rowspan="4"></td><td rowspan="7">Add water to restore mass to 958.7 g (80% of initial mass)</td></tr>
<tr><td>36</td><td>1148.4</td><td>0</td></tr>
<tr><td>39</td><td>1123.2</td><td>0</td></tr>
<tr><td>42</td><td>1110.4</td><td>0</td></tr>
<tr><td>49</td><td>1077.0</td><td>0</td><td>X</td></tr>
<tr><td>52</td><td>1066.0</td><td>0</td><td rowspan="13"></td></tr>
<tr><td>56</td><td>1051.8</td><td>0</td></tr>
<tr><td>60</td><td>1043.6</td><td>0</td><td rowspan="11">Add water to restore mass to 838.9 g (70% of initial mass)</td></tr>
<tr><td>63</td><td>1004.0</td><td>0</td></tr>
<tr><td>66</td><td>104.4</td><td>0</td></tr>
<tr><td>68</td><td>1031.2</td><td>0</td></tr>
<tr><td>71</td><td>1024.8</td><td>0</td></tr>
<tr><td>74</td><td>1022.6</td><td>0</td></tr>
<tr><td>78</td><td>1020.2</td><td>0</td></tr>
<tr><td>81</td><td>1016.8</td><td>0</td></tr>
<tr><td>85</td><td>1011.8</td><td>0</td></tr>
<tr><td>88</td><td>1008.8</td><td>0</td></tr>
<tr><td>91</td><td>1006.0</td><td>0</td></tr>
<tr><td colspan="5">Final compost wet mass = 1006 - 173.4 = 832.6 g</td></tr>
</table>

Reactor: B0B				
Day	Reactor mass (g)	Water added (g)	Turning (X = yes)	Notes
0	1173.4		X	reactor vessel = 173.4 g
1	1160.2	13.2		
2	1158.0	15.4		
3	1145.6	27.8		
4	1142.0	31.4		
7	1133.4	40.0		
8	1166.2	7.2		
9	1161.8	11.6	X	
10	1160.8	12.6		
11	1156.6	16.8	X	
14	1138.6	34.8		
16	1148.4	25.0		
18	1154.8	18.6		
21	1127.2	46.2		
23	1155.6	17.8		
25	1154.6	18.8		
28	1131.8	41.6		
30	1148.2	0	X	Add 25 g compost as re-inoculation. (“new” initial mass = 1198.4 g)
32	1159.2	0		Add water to restore mass to 958.7 g (80% of initial mass)
36	1145.0	0		
39	1132.2	0		
42	1125.6	0		
49	1103.0	0	X	
52	1097.0	0		
56	1089.8	0		
60	1078.8	0		Add water to restore mass to 838.9 g (70% of initial mass)
63	1074.6	0		
66	1071.8	0		
68	1067.4	0		
71	1063.0	0		
74	1061.6	0		
78	1060.6	0		
81	1059.2	0		
85	1056.8	0		
88	1054.6	0		
91	1052.8	0		
Final compost wet mass = 1052.8 - 173.4 = 879.4 g				