Fefco

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Background – EU Law and CEN

Packaging legislation

- The European Parliament and Council Directive 94/62/EC of 20 December 1994 on Packaging and Packaging Waste provides measures aimed at limiting the production of packaging waste and promoting recycling, re-use and other forms of waste recovery.
- The requirements placed by the EU Packaging and Packaging Waste Directive (94/62/EC) on packaging in EU are:
  - Collection and recycling requirements
  - Construction requirements.

Packaging legislation

- The packaging construction requirements are set out in the EU directive as the Essential Requirements, and involve the following:
  - The weight and volume of the packaging must be kept to a minimum
  - The packaging should permit re-use or recycling/material recovery
  - The content of harmful and hazardous substances must be minimised
- These requirements apply to all packaging placed on the European market.

Packaging legislation

- The European Committee for Standardisation, CEN, has developed six standards which show how to evaluate whether packaging meets the above essential requirements:
  - Prevention of waste (EN 13428:2004)
  - Re-use (EN 13429:2004)
  - Material recovery (EN 13430:2004)
  - Energy recovery (EN 13431:2004)
  - Composting and biodegradation (EN 13432:2000)
  - Instructions for applying the above standards (EN 13427:2004)

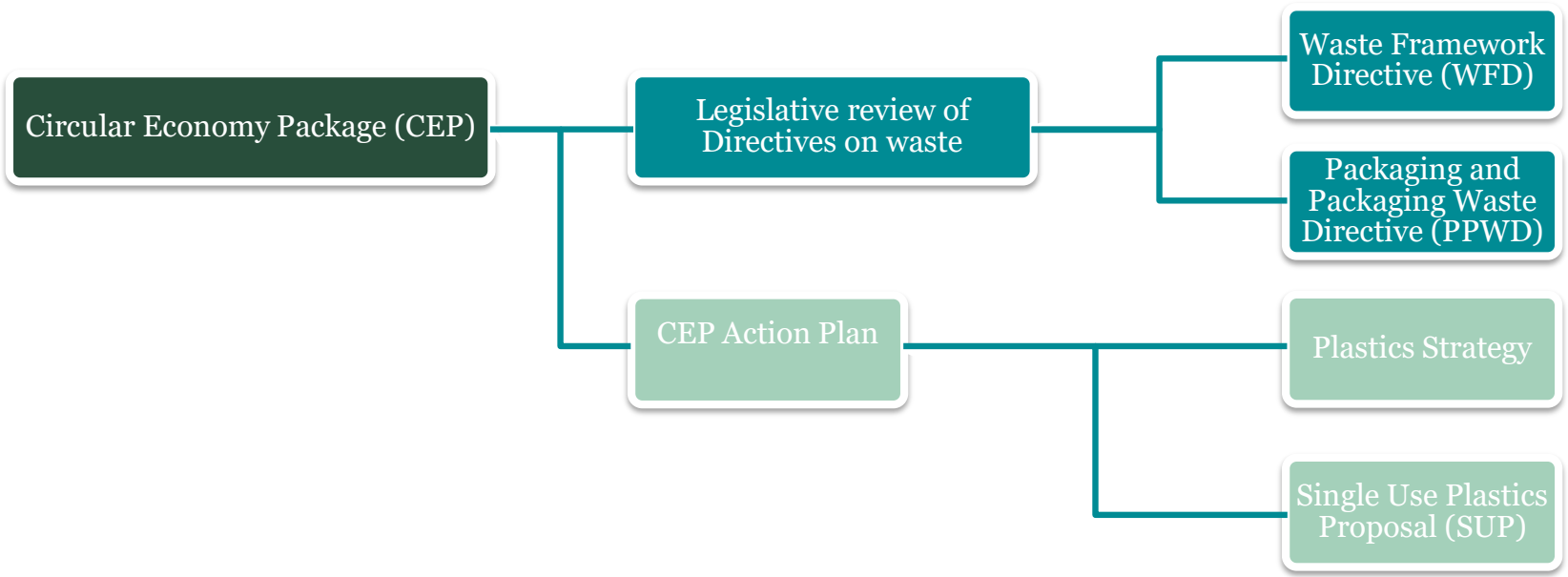
Circular Economy Package

- Already prior to the Circular Economy Package introduced in 2015, existing EU waste policies have contributed to moving towards a circular economy.
- Although waste management in the European Union (EU) has improved considerably in the past decades, almost a third of municipal waste is still landfilled and less than half is recycled or composted, with wide variations between Member States. Improving waste management could deliver positive effects for the environment, climate, human health and the economy.
- Therefore, the EU Commission has introduced the Circular Economy Package that consists of an EU Action Plan for the Circular Economy
- The proposed actions will contribute to "closing the loop" of product lifecycles through greater recycling and re-use and bring benefits for both the environment and the economy.

Review of Directives on waste

New demands on packaging producers

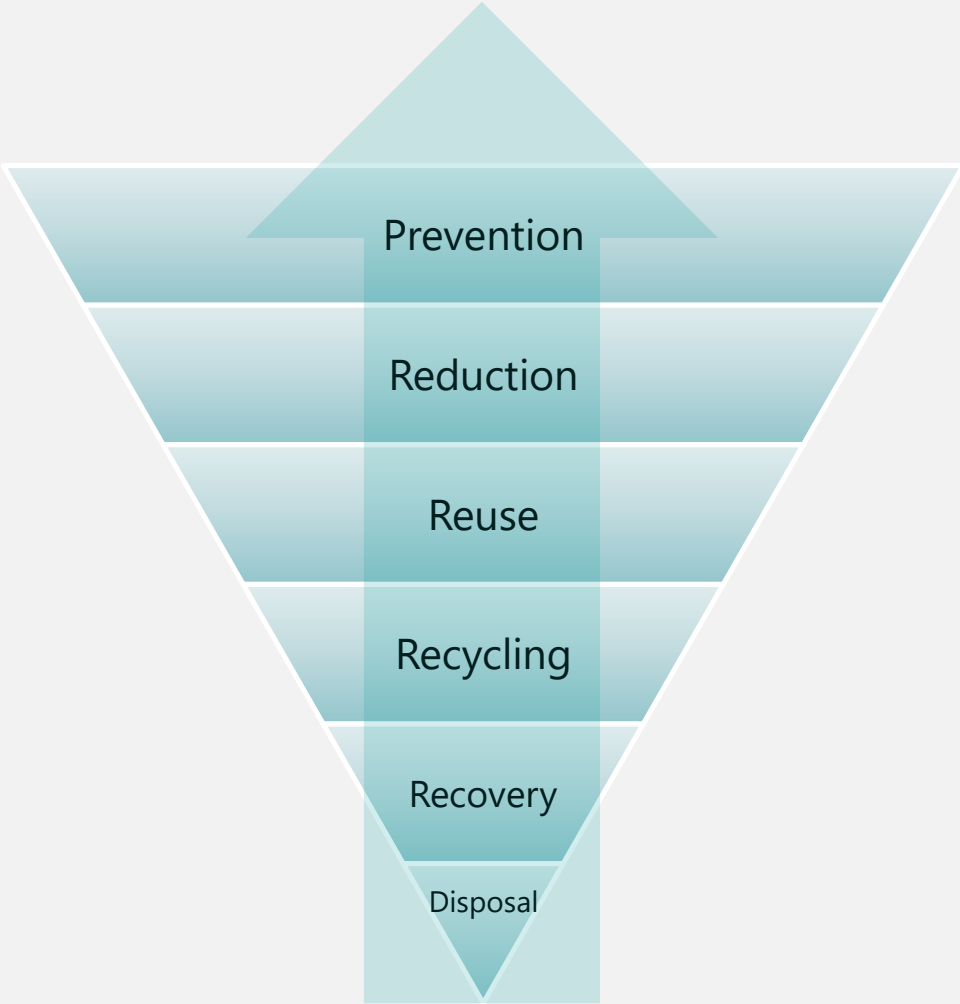
EU - Legislative review of Directives on waste



WFD and the PPWD.
22 May 2018
SUP
5 June 2019.

Reviewed and new Packaging and packaging waste legislation in EU

- Packaging and packaging waste directive 94/62/EG
  - (EU) 2015/720
  - (EU) 2018/852
- Waste directive 2008/98/EG
  - (EU) 2018/851
- Directive on the reduction of the impact of certain plastic products on the environment
  - (EU) 2019/904



The revised packaging directive

- Stronger link to the waste hierarchy
- The recycling targets are higher
- Strengthen the essential requirements further in order to improve packaging design
  - design for reuse and improved high quality recycling
  - report to Commission in December 2020 regarding proposals to further strengthen the essential requirements.

The revised packaging directive
- bio-based materials

- Benefits
  - of using bio-based materials and materials that can be recycled several times
  - Using bio-based recyclable material materials then favorable from a life cycle perspective

The Study - Biodegradability and compostability Fefco

Aim of the study

- To perform a literature study with focus on research/studies from Europe and US/Canada regarding biodegradability and compostability of corrugated boxes.
- To synthesize results from fact-based studies/research that can be used to backup communication on biodegradability or compostability of corrugated boxes.

Project activities

- The main project activities are based on overview of available reports, abstracts, and research articles (Europe and US/Canada), a literature study with data collection combined with RISE expertise within the pulp, fiberbased material and sustainable packaging area. A report with summary of the literature study (Power Point report).

- Startup and literature overview
- Literature study, including studies of biodegradability and compostability for corrugated sheet (only paper +starch) and for corrugated boxes (printed and glued).
- Summary of results

Overview – search - contacts

Literature

- Search in selected databases at RISE
- Literature search at different websites (industry organizations, research institutes etc.)

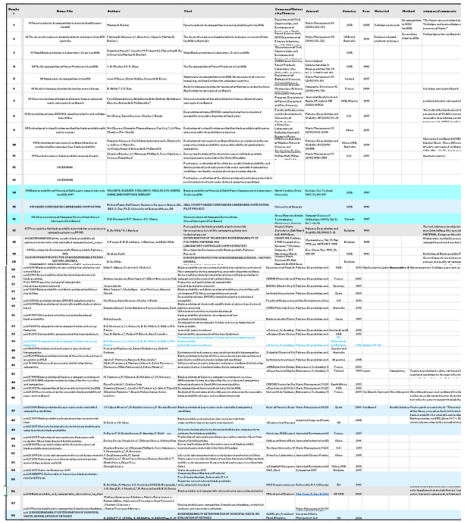
Contacts:

- RISE Sweden
  - RISE informationspecialist
  - RISE Borås and RISE Uppsala (sites that performs compostability studies)
- Swedish institute for Standards
- German institute for Standards
- Organic Waste Systems, Ghent, Belgium
- RISE UK

Extended scope

- The initial criteria set for the literature study by the project partners were: *"focus on research/studies from Europe and US/Canada regarding biodegradability and compostability of corrugated boxes"*
- However, this first resulted in a small amount of studies, so the scope was extended to also include studies from corrugated board material and other fiberbased packaging materials.

Result
Litterature search and selection 1



Litterature overview
58

Selection
19

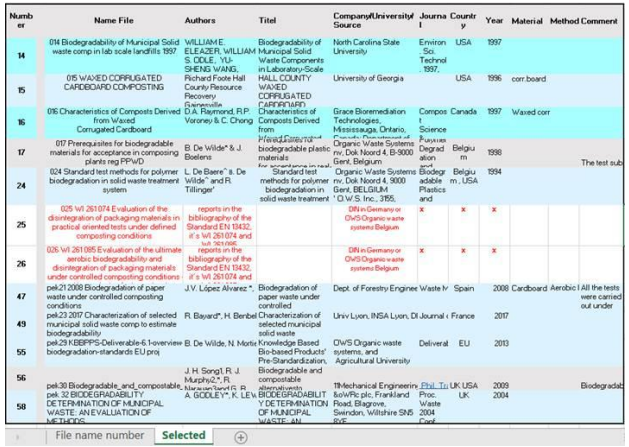
Number	Name File	Authors	Titel	Company/University/ Source	Journal	Country	Year	Material	Method	Comment
14	014 Biodegradability of Municipal Solid waste comp in lab scale landfills 1997	WILLIAM E. ELEAZER, WILLIAM S. ODLE, YU-SHENG WANG,	Biodegradability of Municipal Solid Waste Components in Laboratory-Scale	North Carolina State University	Environ Sci. Technol. 1997,	USA	1997			
15	015 WAXED CORRUGATED CARDBOARD COMPOSTING	Richard Foote Hall County Resource Recovery Gainesville	HALL COUNTY WAXED CORRUGATED CARRIBOARD	University of Georgia		USA	1996	corr.board		
16	016 Characteristics of Composts Derived from Waxed Corrugated Cardboard	D.A. Raymond, R.P. Voroney & C. Chong	Characteristics of Composts Derived from Waxed Corrugated	Grace Bioremediation Technologies, Mississauga, Ontario,	Compost Science & Utilization	Canada	1997	Waxed corr		
17	017 Prerequisites for biodegradable materials for acceptance in composting plants reg PPWD	B. De Wilde* & J. Boelens	Prerequisites for biodegradable plastic materials	Organic Waste Systems nv, Dok Noord 4, B-9000 Gent, Belgium	Degradation and	Belgium	1998			The test sub
24	024 Standard test methods for polymer biodegradation in solid waste treatment system	L. De Baere^ 8. De Wilde^ and R. Tillinger'	Standard test methods for polymer biodegradation in solid waste treatment	Organic Waste Systems nv, Dok Noord 4, 9000 Gent, BELGIUM ' O.W.S. Inc., 3155,	Biodegradable Plastics and	Belgium, USA	1994			
25	025 WI 261074 Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions	reports in the bibliography of the Standard EN 13432, it´s WI 261074 and sub 261086		DIN in Germany or OWS Organic waste systems Belgium	x	x	x			
26	026 WI 261085 Evaluation of the ultimate aerobic biodegradability and disintegration of packaging materials under controlled composting conditions	reports in the bibliography of the Standard EN 13432, it´s WI 261074 and		DIN in Germany or OWS Organic waste systems Belgium	x	x	x			
47	pek.21 2008 Biodegradation of paper waste under controlled composting conditions	J.V. López Alvarez *,	Biodegradation of paper waste under controlled	Dept. of Forestry Enginee	Waste M	Spain	2008	Cardboard	Aerobic I	All the tests were carried out under
49	pek.23 2017 Characterization of selected municipal solid waste comp to estimate biodegradability	R. Bayard*, H. Benbal	Characterization of selected municipal solid waste	Univ Lyon, INSA Lyon, DI	Journal (	France	2017			
55	pek.29 KBBPPS-Deliverable-6.1-overview biodegradaion-standards EU proj	B. De Wilde, N. Mortie	Knowledge Based Bio-based Products' Pre-Standardization,	OWS Organic waste systems, and Agricultural University	Deliveral	EU	2013			
56	pek.30 Biodegradable_and_compostable_	J. H. Song1, R. J. Murphy2,*, R. Narayan3and R. P.	Biodegradable and compostable alternativesIn	TIMechanical Engineerin	Phil. Tr	UK USA	2009			Biodegradab
58	pek. 32 BIODEGRADABILITY DETERMINATION OF MUNICIPAL WASTE: AN EVALUATION OF METHODS	A. GODLEY*, K. LEW	BIODEGRADABILITY DETERMINATION OF MUNICIPAL WASTE: AN	BioWRc plc, Frankland Road, Blagrove, Swindon, Wiltshire SN5 8YF,	Proc. Waste 2004 Conf.	UK	2004			

File name number | Selected

Selection 1

- review of the selected reports
- some of the reports were sorted out
  - did not contain enough detailed information
  - did not contain the information searched for

Litterature overview and selection 2



Number	Name File	Authors	Titel	Company/University/ Source	Journal	Country	Year	Materi	Meth	Comme
14	014 Biodegradability of Municipal Solid waste comp in lab scale landfills 1997	WILLIAM E. ELEAZER, WILLIAM S. ODLE, YU-SHENG WANG, AND MORTON A. BARLAZ	Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills	North Carolina State University	Environ. Sci. Technol. 1997, 31,	USA	1997			
15	015 WAXED CORRUGATED CARDBOARD COMPOSTING	Richard Foote Hall County Resource Recovery Gainesville,	HALL COUNTY WAXED CORRUGATED CARDBOARD COMPOSTING PILOT PROJECT	University of Georgia		USA	1996	corr.board		
16	016 Characteristics of Composts Derived from Waxed Corrugated Cardboard	D.A. Raymond, R.P. Voroney & C. Chong	Characteristics of Composts Derived from Waxed Corrugated Cardboard	Grace Bioremediation Technologies, Mississauga, Ontario,	Compost Science & Utilization	Canada	1997	Waxed corr		
32	Pek 6 1997 Properties and appl of compostable starch-based plastic material	Jurgen Lörcks	Properties and applications of compostable starch-based plastic material	BIOTEC. Blinder Weg 3(	Polymer De	Germany	1997			
47	pek21 2008 Biodegradation of paper waste under controlled composting conditions	J.V. López Alvarez *, M.	Biodegradation of paper waste under controlled composting conditions	Dept. of Forestry Engin	Waste Man	Spain	2008	Cardbo	Aerob	All the tests were

Selection
9 reports

Selection 2

Number	Titel	University/Source	Journal	Comment
14	Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills	North Carolina State University	Environ. Sci. Technol. 1997, 31, 911-917	
15	HALL COUNTY WAXED CORRUGATED CARDBOARD COMPOSTING PILOT PROJECT	University of Georgia		
16	Characteristics of Composts Derived from Waxed Corrugated Cardboard	Grace Bioremediation Technologies, Mississauga, Ontario, Canada; Department of Land Resource Science, University of Guelph, Ontario, Canada;	Compost Science & Utilization, (1997), Vol. 5, No.3, 60-70	
18	DETERMINATION OF TEE AEROBIC BIODEGRADABILITY OF POLYMERIC MATERIAL IN A LABORATORY CONTROLLED COMPOSTING TEST	I) BASF AG, Ecology, 67056 Luwigshafcn, Germany *) Organic Waste Systems, 9000 Ghent, Belgium	Chemosphere, Vol. 31, Nos 11112, pp. 4475 4487, 1995	
58	BIODEGRADABILITY DETERMINATION OF MUNICIPAL WASTE: AN EVALUATION OF METHODS	Cranfield University	Proc. Waste 2004 Conf. Integrated Waste Management and Pollution Control	
47	Biodegradation of paper waste under controlled composting conditions	Dept. of Forestry Engineering, E.T.S.I. De Montes (Superior Technical Forestry Engineering School), Technologic University of Madrid, 28040 Madrid, Spain	Waste Management 29 (2009) 1514–1519	
49	Characterization of selected municipal solid waste components to estimate their biodegradability	Univ Lyon, INSA Lyon, DEEP Laboratory, EA7429, F-69621, Villeurbanne cedex, France	Journal of Environmental Management 216 (2018)	
25	025 WI 261 074 Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions	DIN in Germany or OWS Organic waste systems Belgium	x	reports in the bibliography of the Standard EN 13432, it´s WI 261 074 and WI 261 085.
26	026 WI 261 085 Evaluation of the ultimate aerobic biodegradability and disintegration of packaging materials under controlled composting conditions - method by analysis of released carbon dioxide	DIN in Germany or OWS Organic waste systems Belgium	x	

Short summary

- The results from the selected reports demonstrates that corrugated board material is a biodegradable and compostable material.
- How efficient the compostable/biodegradable process of corrugated board is, depends on the conditions under which the process is carried out

- Waxed corrugated board is easily decomposed during composting and, in this regard, is an excellent feedstock material
- Decomposition of old corrugated cardboard is equal to the decomposition of uncoated paper
- Waxed corrugated cardboard is a very good source of carbon and may be composted with broiler litter or hen manure successfully.
- Corrugated board waste components have a higher aerobic biodegradability than newsprints and magazines

Is Corrugated board compostable?

Yes!
Facts and figures can be found in:

- ”Hall County Waxed Corrugated Cardboard composting pilot project”
  (report no 15)
- “Characteristics of Composts Derived from Waxed Corrugated Cardboard”,
  (report no 16)
- ”Determination of the aerobic biodegradability of polymeric material in a laboratory controlled composting test”
  (report no 18)

Is Corrugated board biodegradable?

Yes !
Facts and figures can be found in:

- "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills"
  (report no 14)
- "Biodegradation of paper waste under controlled composting conditions"
  (report no 47)
- "Characterization of selected municipal solid waste components to estimate their biodegradability"
  (report no 49)
- "Determination of the aerobic biodegradability of polymeric material in a laboratory controlled composting test"
  (report no 18)

Are other fiberbased materials biodegradability and compostability studied in the selected reports?

Yes,

- Newsprint
- Office paper
- Magazines
- Packaging paper of unbleached kraft softwood
- Coated paper
- Card board
- Tissue paper

Summary selected reports

No. 25, 26, 18, 16, 14, 15, 47, 49, 58

Report No. 25, 26

025 WI 261 074 Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions

026 WI 261 085 Evaluation of the ultimate aerobic biodegradability and disintegration of packaging materials under controlled composting conditions - method by analysis of released carbon dioxide

No. 25, 26, 16, 14, 15, 47, 49, 32

No. 18

Summary of report no. 25, 26

- Report 25 and 26 are work item reports by CEN.
- Those projects were performed when the EN13432 “Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging” was developed.
- When standard EN13432 “Requirements for packaging recoverable through composting and biodegradation” was developed the parts of the results from the work reports became the standard EN 14046.
- In the annex D of the standard EN 14046, information about the tests can be found and the test results are published in report – ”Determination of the aerobic biodegradability of polumeric material in a laboratory controlled composting test” (in this project this is Report no. 18)

No. 18

Contact DIN Deutsches Institut für Normung

Regarding Standardization project: Composting and biodegradation (EN 13432:2000)

CEN gives every standardization project a work Item number.

- **WI 00261074** is the work item number for EN 14045:2003, *Packaging - Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions*

00261074 - EN 14045:2003

Packaging - Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions

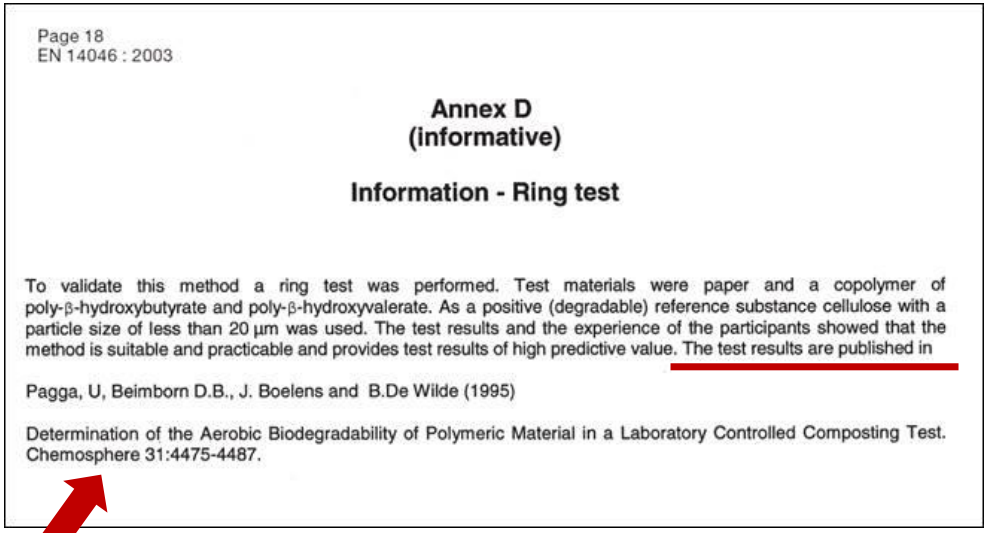
Responsible:	CEN/TC 261	Drafting:	CEN/TC 261/SC 4/WG 2	Project Leader:	-
WI/Standard status:	Active/Published	Track:	EN/ENQ+FV		
Category:	Main	Parallel:	No		

- **WI 00261085** is the work item number for EN 14046:2003, *Packaging - Evaluation of the ultimate aerobic biodegradability of packaging materials under controlled composting conditions - Method by analysis of released carbon dioxide.*

00261085 - EN 14046:2003

Packaging - Evaluation of the ultimate aerobic biodegradability of packaging materials under controlled composting conditions - Method by analysis of released carbon dioxide

Responsible:	CEN/TC 261	Drafting:	CEN/TC 261/SC 4/WG 2	Project Leader:	-
WI/Standard status:	Active/Published	Track:	EN/ENQ+FV		
Category:	Main	Parallel:	No		



Page 18
EN 14046 : 2003

Annex D
(informative)

Information - Ring test

To validate this method a ring test was performed. Test materials were paper and a copolymer of poly-β-hydroxybutyrate and poly-β-hydroxyvalerate. As a positive (degradable) reference substance cellulose with a particle size of less than 20 µm was used. The test results and the experience of the participants showed that the method is suitable and practicable and provides test results of high predictive value. The test results are published in

Pagga, U, Beimborn D.B., J. Boelens and B.De Wilde (1995)

Determination of the Aerobic Biodegradability of Polymeric Material in a Laboratory Controlled Composting Test. Chemosphere 31:4475-4487.

Report no. 18

Contact person Mr Ruediger Beck

Report No. 18

DETERMINATION OF THE AEROBIC BIODEGRADABILITY OF POLYMERIC MATERIAL IN A LABORATORY CONTROLLED COMPOSTING TEST

No. 25, 26, 18, 16, 14, 15, 47, 49, 58

No. 18

Summary of report no. 18

- The tests that was performed to develop a method for a material to be approved as compostable according to standard EN 13432 are based on tests carried out on 3 different materials, kraft packaging paper, biocel and avicel.
- The results was based on CO2 evolution and expressed as percentage of the theoretical. Paper showed a biodegradation of about 80%, the mean degree of Biopol biodegradation was 88% and Avicel was degraded to about 84% on average.
- No tests were carried out on corrugated cardboard, but it was considered that the test results confirm that the test method is suitable for investigating the ultimate aerobic biodegradation of an organic material in a composting environment.
- Se report 18

No. 18

Title:

DETERMINATION OF TEE AEROBIC BIODEGRADABILITY OF POLYMERIC MATERIAL IN A LABORATORY CONTROLLED COMPOSTING TEST

- U.Pagga, * '), D .B .B eimborn'), J. Boelens" and B.De Wilde2'
- I) BASF AG, Ecology, 67056 Luwigshafcn, Germany *) Organic Waste Systems, 9000 Ghent, Belgium
- *Chemosphere,* Vol. 31, Nos 11112, pp. 4475-4487, 1995.
- Copyright 1995 Elsevier Science Ltd Printed in Great Britain. All rights reserved.
- OBS, *All rights reserved*.

No. 18

Objecitives

The test is designed to become a European Standard in connection with determining the compostability of packagings and packaging materials.

No. 18

Materials and methods

- A laboratory method is presented for investigating the biodegradation of an organic test material in an aerobic composting system based on the evolution of carbon dioxide
- The test results and the experience gained by the participants showed that the method is suitable and practicable.
- The test conditions are designed to simulate typical aerobic composting facilities for the treatment of the organic fraction of mixed municipal solid waste.
- A mixture of mature compost and the test material is introduced into closed vessels and incubated under optimal oxygen, temperature and moisture conditions for a test period of normally 45 days. In parallel, blank vessels with compost only and controls with compost and a reference substance are investigated.

No. 18

Materials and methods

- The process of biodegradation is shown in a curve where carbon dioxide production or biodegradation percentage is plotted as a function of time.
- As additional information the weight loss of the test material and the disintegration of a compact material can be determined at the end of the test.

Test materials

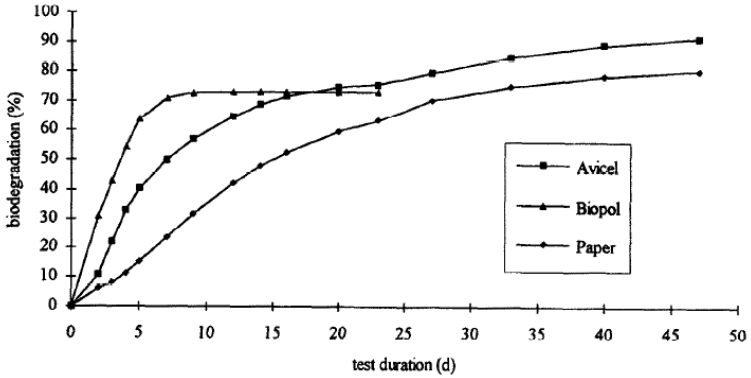
1. Common packaging paper made from only virgin kraft unbleached softwood pulp cut into pieces of about 2x2 cm
2. Poly-P-hydroxybutyrate, poly+hydroxyvalerate copolymers (Biopol)
3. Microcrystalline cellulose powder (Avicel)

Test results

The test results based on CO2 evolution and expressed as percentage of the theoretical.

1. Paper* showed a biodegradation of about 80%.
2. The mean degree of Biopol biodegradation was 88%.
3. Avicel was degraded to about 84% on average.

- Composting test at a constant temperature of 58 C



*=Common packaging paper made from virgin kraft unbleached softwood pulp cut into pieces of about 2x2 cm

No. 18

Discussion/conclusions

- The test results confirm that the test method is suitable for investigating the ultimate aerobic biodegradation of an organic test material in a composting environment.
- The big advantage of the test is the simulation of real composting conditions including the action of fungi and thermophilic micro-organisms.

Report No. 16

Characteristics of Composts Derived from Waxed Corrugated Cardboard

No. 25, 26, 18, 16, 14, 15, 47, 49, 58

No. 16

Summary of report no. 16

- In the report “Characteristics of Composts Derived from Waxed Corrugated Cardboard”, the objectives was to evaluate the effects of including waxed corrugated cardboard (WCC) on the quality of composts produced in combination with spent mushroom substrate (SMS) and pulverized wood wastes
- The results from the study demonstrated that Waxed corrugated board (WCC) was easily decomposed during composting and, in this regard, is an excellent feedstock material.
- Se report 16

No. 16

Title:

Characteristics of Composts Derived from Waxed Corrugated Cardboard

- D.A. Raymond, R.P. Voroney & C. Chong, Grace Bioremediation Technologies, Mississauga, Ontario, Canada; Department of Land Resource Science, University of Guelph, Ontario, Canada; Ontario Ministry of Agriculture, Food and Rural Affairs, Horticultural Research Institute of Ontario, Vineland Station, Ontario, Canada
- Compost Science & Utilization, (1997), Vol. 5, No.3, 60-70

Objectives

No. 16

To evaluate the effects of including waxed corrugated cardboard (WCC) on the quality of composts produced in combination with spent mushroom substrate (SMS) and pulverized wood wastes

Materials and methods

12 different composts containing, by volume,

- spent mushroom substrate (SMS, 5O%),
- waste waxed corrugated cardboard (WCC, 0 %, 25 % or 5O %), and/or
- pulverized wood wastes (WW, 5O%, 25 % or 0 %)

were produced in outdoor heaps and were measured during two separate windrow composting periods (12-16 weeks).

- Supplemental N was added to some of the composts in the form of poultry manure, and/ or soybean processing wastes.
- Each of the composts contained 50 m^3 of material and all were heaped in piles 3m high and 7 m in diameter
- Each of the composts were aerated by mixing with a front-end loader two to three times weekly during the thermophilic stage of composting
- During composting, triplicate 5 kg samples were collected 1m inside and 1-1.5 m above ground at three equally spaced locations around each compost heap at various intervals (weeks)

Materials and methods

Formulation of the 12 experimental composts

Ingredient	Compost 1	2	3	4	5	6	7	8	9	10	11	12
	Feedstock											
SMS[1]	50	50	50	50	50	50	50	50	50	50	50	50
WCC	0	50	25	0	50	25	0	50	25	0	50	25
WW	50	0	25	50	0	25	50	0	25	50	0	25
	N-supplement											
PM[2]	-	-	-	+	+	+	-	-	-	+	+	+
SBW[3]	-	-	-	-	-	-	+	+	+	+	+	+

Test results

Chemical characteristics of the compost feedstock and N-supplements

	Feedstock						N-supplement			
	SMS		WW		WCC		SBW		PM	
Property	1	2	1	2	1	2	1	2	1	2
H_2O (%)	64	62	39	17***	26	21	72	78	27	24
EC(dS·m^{-1})	22	21	4.3	6.3**	3.8	3.5	26	38	28	42***
pH	7.5	7.6	7.5	7.4	7.2	7.2	5.1	4.9	7.4	7.4
Nitrogen (%)	1.6	1.7	0.9	0.4**	0.1	0.3	4.3	6.0	3.9	4.5**
NH_4^+-N (mg- ·kg^{-1})	51	52	144	41***	4.4	4.4	103	595***	476	564***
NO_3+NO_2-N (mg- ·kg^{-1})	7.2	5.9	2.5	4.3	0.2	0.6	5.2	6.0	24	30*
Carbon (%)	26	23	36	44	51	46*	47	47	41	43
Organic Carbon (%)	23	21	34	44	51	46*	47	46	40	43
Volatile Solids (%)	51	44	73	83	97	84**	86	82	88	85
Phenolics[1]	56	34***	47	22***	79	16***	121	286***	225	486***
P(mg- ·kg^{-1})	-[2]	0.5	-	0.02	-	0.04	-	0.8	-	1.4
K(mg- ·kg^{-1})	-	1.5	-	0.2	-	0.2	-	1.9	-	1.8
Ca (%)	-	10.0	-	1.9	-	1.6	-	1.7	-	2.8
Mg (%)	-	2.4	-	0.5	-	0.6	-	0.6	-	0.7

[1] mg Phenolic-C·kg^{-1} -compost, expressed as tannic acid equivalents
*,**,*** indicates significant difference between batches at p≤0.05, p≤0.01, and p≤0.001, respectively
[2] Not determined

- During the first eight to 10 weeks,

Test results

Influence of WCC level on organic matter reduction (OMR) during composting

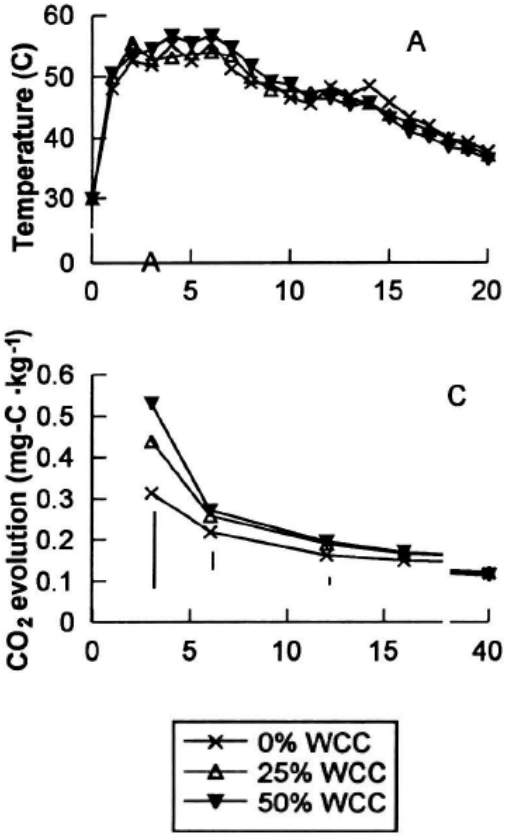
WCC (% by vol)	Week 12	Week 40
	% OMR	
0	53c[1]	62c
25	61b	68b
50	69a	77a

[1] Values in each column followed by the same letter are not significantly different at $p \leq 0.05$

Increased organic matter reduction (OMR) in composts with 50 percent waste waxed corrugated cardboard (WCC) suggests that WCC promoted the decomposition of the feedstocks and it was readily decompostable.

Test results

- During the first eight to 10 weeks, composts containing 5o percent WCC tended to reach and maintain the highest temperatures, but subsequently cooled most rapidly. Microbial activity (C02 evolution) also was initially highest in these composts but fell by the twelfth week to levels comparable to composts containing lower levels of WCC.
- The paraffin wax in WCC containing composts was almost completely degraded (>95 percent).



No. 16

Conclusions

- The study demonstrated that Waxed corrugated board (WCC) was easily decomposed during composting and, in this regard, is an excellent feedstock material.
- The paraffin wax present in the coating of wee was also readily decomposed.

Report No. 14

Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills

No. 25, 26, 18, 16, 14, 15, 47, 58

No. 14

Summary of report 14

- In the report "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills" the objectives was to characterize the anaerobic biodegradability of municipal refuse components by measuring methane yields, the extent of cellulose and hemicellulose decomposition. The material components selected for study were the major biodegradable components of refuse and included different packaging materials. Coated paper represent (4,2%), old newsprint (6,6%), old corrugated containers (12,2%), office paper (3,3%).
- The results from the study demonstrate that the extent of decomposition for old corrugated cardboard was 54,4%, and similar for office paper 54,6%. Coated paper was 39,2%, old newsprint 31,1%.
- This study show that the decomposition of old corrugated cardboard are equal to the decomposition of uncoated paper which indicate that corrugated cardboard also must be a compostable material.
- Se report no. 14

No. 14

Title:

Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills

- WILLIAM E. ELEAZER, WILLIAM S. ODLE, YU-SHENG WANG, AND MORTON A. BARLAZ
- Environ. Sci. Technol. **1997**, 31, 911-917

No. 14

Objectives

- To characterize the anaerobic biodegradability of municipal refuse components by measuring methane yields, the extent of cellulose and hemicellulose decomposition

No. 14

Materials and methods

The material components selected for study were the major biodegradable components of refuse and included

- grass (G), leaves (L), branches (B), food waste (F), coated paper (CP), old newsprint (ONP), old corrugated containers (OCC), and office paper (OFF) as well as mixed residential refuse (MSW)

Experiments were conducted in quadruplicate in 2-L reactors

- Coated paper represent (4,2%), old newsprint (6,6%), old corrugated containers (12,2%), office paper (3,3%) of municipal refuse as generated
- Corrugated containers contain both mechanical and chemical pulp,

Test results

- **The extent of decomposition** is the measured methane yield divided by the yield calculated assuming conversion of 100% of the cellulose and hemicellulose (and protein in the case of food waste) to methane and carbon dioxide.
- The extent of decomposition for old corrugated cardboard was 54,4%, for office paper 54,6%, coated paper 39,2%, old newsprint 31,1%
- For OCC 64% and 62% of the initial cellulose and hemicellulose, respectively, were degraded by the end of the 470-day monitoring period
- **Measured methane yields** for old corrugated containers was 152,3, for coated paper 84,4 for old newsprint 74,3 and for office paper 217,3 mL of CH4/ dry g.

Methane Yield and Initial and Final Solids Composition

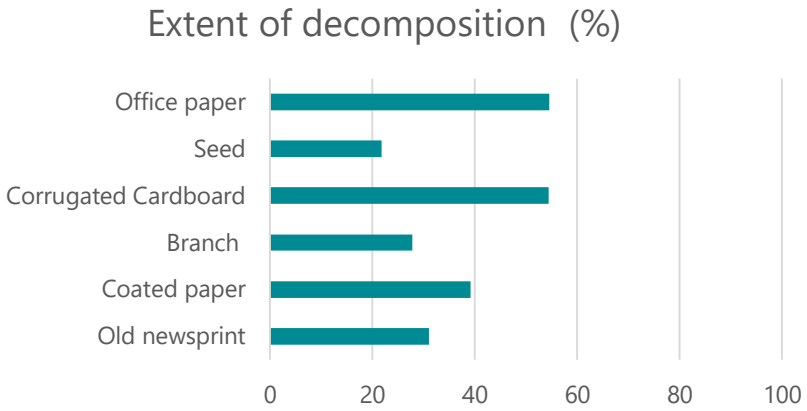
reactor series	yield (mL of CH_4/ dry g)	cellulose (%)	hemi-cellulose (%)	lignin (%)	volatile solids	MC[b]	MH[b]	ML[b]	methane potential recovery[c]	extent of decom-position[d]	chl/vs[e]
seed	25.5	23.4	4.7	22.5	48.2	0.18	0.36	0.83	43.4 (47.3)	21.8	1.05
SD	5.7					0.02	0.03	0.07	3.5		
seed-2	5.8	18.3	3.7	22.1	42.4	0.34	0.69	0.85	46.6 (49.6)	6.3	1.05
SD	0.6					0.01	0.11	0.01	1.8		
grass	144.4	26.5	10.2	28.4	85.0	0.19	0.42	0.78	89.3 (93.1)	94.3	0.77
SD	15.5					0.01	0.06	0.07	5.5		
grass-2	127.6	25.6	14.8	21.6	87.8	nm[f]	nm	nm	nm	75.5	0.71
SD	21.8										
leaves	30.6[g]	15.3	10.5	43.8	90.2	0.43	0.68	0.90	75.2 (77.7)[g]	28.3[g]	0.77
SD	8.6					0.05	0.10	0.10	5.5		
branch	62.6[g]	35.4	18.4	32.6	96.6	0.52	0.59	0.93	82.8 (85.0)[g]	27.8[g]	0.89
SD	13.3					0.05	0.02	0.08	4.2		
food	300.7	55.4	7.2	11.4	93.8	0.24	0.58	0.80	77.4 (80.7)	84.1	0.99[h]
SD	10.6					0.02	0.04	0.07	4.2		
coated paper	84.4	42.3	9.4	15	74.3	0.54	0.58	1.03	83.7 (85.4)	39.2	0.90
SD	8.1					0.01	0.06	0.03	2.5		
old newsprint	74.33	48.5	9	23.9	98.5	0.73	0.46	0.99	98.0 (99.2)	31.1	0.83
SD	6.8					0.05	0.06	0.06	3.0		
old corrugated containers	152.3	57.3	9.9	20.8	98.2	0.36	0.38	0.93	87.7 (90.9)	54.4	0.90
SD	6.7					0.01	0.01	0.00	1.2		
office paper	217.3	87.4	8.4	2.3	98.6	0.02	0.09	0.95	55.5 (60.3)	54.6	0.99
SD	15.0					0	0.01	0.18	3.5		
MSW	92.0	28.8	9.0	23.1	75.2	0.25	0.22	0.95	87.9 (91.8)	58.4	0.81
SD	4.1					0.03	0.05	0.02	3.2		

The ratio of the cellulose (MC), hemicellulose (MH),

No. 14

Test results

- The extent of decomposition is the measured methane yield divided by the yield calculated assuming conversion of 100% of the cellulose and hemicellulose (and protein in the case of food waste) to methane and carbon dioxide.
- The extent of decomposition for old corrugated cardboard was 54,4%, for office paper 54,6%, coated paper 39,2%, old newsprint 31,1%



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Conclusions

The anaerobic biodegradability of municipal refuse components was characterized by measuring methane yields, the extent of cellulose and hemicellulose decomposition.

The methane yield increased as the cellulose plus hemicellulose content increased,

The degree of lignification of a particular component was not a good predictor of the extent of biodegradation.

There is a general trend of more extensive cellulose biodegradation(MCdecreasing) in the less lignified substrates e.g., food and office paper

Report No. 15

HALL COUNTY WAXED CORRUGATED CARDBOARD COMPOSTING PILOT PROJECT

No. 25, 26, 18, 16, 14, 15, 47, 58

No. 15

Summary of report no. 15

- In the report ”Hall county waxed corrugated cardboard composting pilot project” the objective was to evaluate the compostabilitiy of old waxed corrugated cardboard from the poultry industry, using poultry manures and broiler litter as nitrogen amendments.
- The results from the study demonstrate that waxed corrugated cardboard is a very good source of carbon and may be composted with broiler litter or hen manure successfully. The combination of these two waste streams that have mutually compatible characteristics can be effectively used in composting to produce an end-product of good quality.
- The evaluated method has the potential to eliminate a substantial amount of the solid waste stream from poultry industry in Georgia. There is currently no practical disposal alternative for waxed corrugated cardboard.
- Se report no. 15

No. 15

Title:

HALL COUNTY WAXED CORRUGATED CARDBOARD COMPOSTING PILOT PROJECT

- Richard Foote Hall County Resource Recovery Gainesville, GA and K.C. Das, Ph.D. University of Georgia Athens, GA. USA 1996

No. 15

Objectives

- The objective was to evaluate the compostabiltiy of old waxed corrugated cardboard from the poultry industry, using poultry manures and broiler litter as nitrogen amendments.
- Initial laboratory screening identified the mixes to use and characttrized the products of composting.
- A full scale composting demonstration was to be performed based on the laboratory study and scale up factors and products were to be evaluated

No. 15

Materials and methods

It is possible to use high rates of poultry manure in the mixes and reach a stable product in 60 days. Composting was performed in 30 gallon steel drums.

The vessels were aerated using a temperature feedback control with an adjustable set point that was set at a temperature of 55°C.

Properties of materials used in the composting trials

Material	Moisture (%)	Carbon (%)	Nitrogen (%)	Density (lbs/yd^3)
Waxed Corrugated Cardboard	6,2	55,1	0,1	251
layer manure- fresh	64	8	6	1300
Layer Manure - old	64	6	2	1300
Broilder litter	26	18	3,5	750

No. 15

Test results

- Waxed corrugated cardboard is a very good source of carbon and may be composted with broiler litter or hen manure successfully.
- Good composing practices should apply with this material as well as any other of this type.
- Do not see any problems that would limit the use of the compost. The finished material may be marketed in the horticultural as well as the agricultural area and used at normal application rates without problem.
- The project has the potential to eliminate a substantial amount of the solid waste stream from poultry industry in Georgia. There is currently no practical disposal alternative for waxed corrugated cardboard.

- Waxed corrugated cardboard is high in carbon and can absorb moisture once shredded and mixed with other materials. An existing waste stream from the poultry industry is the poultry manures and litter which can form an excellent nitrogen amendment.
- The combination of these two waste streams that have mutually compatible characteristics can be effectively used in composting to produce an end-product of quality.

No. 15

Conclusions

The anaerobic biodegradability of municipal refuse components was characterized by measuring methane yields, the extent of cellulose and hemicellulose decomposition.

The methane yield increased as the cellulose plus hemicellulose content increased,

The degree of lignification of a particular component was not a good predictor of the extent of biodegradation.

There is a general trend of more extensive cellulose biodegradation(MCdecreasing) in the less lignified substrates e.g., food and office paper

Report No. 47

Biodegradation of paper waste under controlled composting conditions

No. 25, 26, 18, 16, 14, 15, 47, 49, 58

Summary of report no.47

No. 47

- In the report " Biodegradation of paper waste under controlled composting conditions" the objective was to determine the last aerobic biodegradability (LAB) of paper and cardboard of the type that wrapping and packaging are made from. In particular, to widen understanding of the various groups of paper such as: white writing and printing paper, newspaper, bleached recycled writing and printing paper, tissue paper, cardboard, and kraft paper (brown) in container lids.
- The method used was designed to reproduce the conditions for the creation of aerobic compost of a typical mixed MSW. All the tests were carried out under EN 14046:2003 standard corresponding to ISO 14855 and ISO 14852.
- The standard EN14046 contains a method to be used when evaluating the biodegradability of packaging materials. The title of the standard is *"Evaluation of the ultimate aerobic biodegradability and disintegration of packaging materials under controlled composting conditions - Method by analysis of released carbon dioxide"*
- When standard EN13432 "Requirements for packaging recoverable through composting and biodegradation" was developed the parts of the results from the work reports became the standard EN 14046. In the annex D of the standard EN 14046 , there is information about a test method for biodegradability of packaging materials that is published in a report "Determination *of the aerobic biodegradability of polymeric material in a lab controlled composting test" (Report no. 18)*
- The results from the study demonstrate that at 45 days, under controlled conditions, none of the papers exceeded the 70% biodegradation limit. The papers that come closest to the limit are the are the W (white printing paper) and the R (recycled printing paper), and they reach it in a retention period of a little more than 2 months. It can be observed that those materials present in packaging and wrapping are those that take longer time to biodegrade.
- The studied packaging materials are biodegradable but it is big differences in number of days to reach the biodegradation of 70%.
- The study can establish what the maximum limit of biodegradation would be for each typology of paper, based on the maximum measurement of CO2 that they generate at 45 days. (see equation in report).

No. 47

Summary of report no.47

- Number of days for biodegradation of different packaging material to 70%. The number of days are between 65 and 994 days.
- Kraft paper are considered as non-biodegradable, when using the method under EN 14046.
- All the tests were carried out under EN 14046:2003
- W= printing and writing
  K= Kraft bags
  N= Newspaper
  T= Tissue
  C= Cardboard
  R= Recycled
- Se report no. 47

Paper	Biodegradation Function	r	B_{45}	$\hat{B}_{45}$	No. days for $\hat{B}$ = 70%	Significance %
W	$y = -17.9342 + 21.0487$ lx	0.9816	65.240	62.19	65	
C	$y = -9.43339 + 16.2493$ lx	0.9875	51.699	52.42	133	
K	$y = -11.6926 + 11.8363$ lx	0.9699	36.018	33.3	994	
N	$y = 2.44352 + 12.6375$ lx	0.9677	43.342	45.60	309	
R	$y = -13.4894 + 20.0915$ lx	0.9776	61.022	62.99	64	
T	$y = -6.49205 + 15.4451$ lx	0.9836	50.084	53.302	142	5

y = % biodegradation x = No. of days.
B_{45} = actual mean % biodegradation at 45 days.
$\hat{B}_{45}$ = estimated % biodegradation at 45 days.

No. 47

Title:

Biodegradation of paper waste under controlled composting conditions

- J.V. López Alvarez *, M. Aguilar Larrucea, P. Arraiza Bermúdez, B. León Chicote
- Waste Management 29 (2009) 1514–1519

No. 47

Objectives

- The objective of the study is to determine the last aerobic biodegradability (LAB) of paper and cardboard of the type that wrapping and packaging are made from, and in particular, to widen understanding of the various groups of paper such as:
- – white writing and printing paper,
- – newspaper,
- – bleached recycled writing and printing paper,
- – tissue paper,
- – cardboard, and
- – kraft paper (brown) in container lids.

No. 47

Materials and methods

- The method used was designed to reproduce the conditions for the creation of aerobic compost of a typical OF of mixed MSW. The percentage and speed of conversion of the carbon in the material for analysis into CO2 was then produced, in such a way that the values that were obtained, being optimum, corresponded to maximum biodegradation.
- All the tests were carried out under UNE-EN 14046:2003 (AENOR, 2003) standards corresponding to ISO 14855 and ISO 14852 (AENOR, 2003).
- The method of test consisted of an optimised simulation of the intensive formation of aerobic compost and the determination of the, last aerobic biodegradability (LAB), of the material analysed under controlled conditions for compost formation.
- During aerobic biodegradation of the material analysed, carbon dioxide, water, mineral salts, and new microbial cellular constituents (biomass) were products. Incubation took place in the dark in a suitably equipped chamber at a constant temperature of 58 ± 2 _C, which was free of vapours that might inhibit microorganisms.

No. 47

Materials and methods

- The CO2 produced was measured at regular intervals during the test, together with the blank control (only compost). This was integrated in order to determine the CO2 produced by the material being analysed with the maximum quantity of CO2 that could be obtained from the material under analysis, calculated on the basis of the quantity of total organic carbon (TOC).
- The material used in the biodegradability test and its characteristics correspond to the six groups of paper waste found in the Organic fraction (OF) of municipal solid waste (MSW).
- The percent biodegradation of each type of paper was calculated from the total values of organic carbon in the recipients.
- Microcrystalline cellulose (MC) was used as the reference material.

No. 47

Test results

The results obtained, measured through the quantity of CO2 generated over 45 days, compared with the maximum that could be produced, showed that the presence of paper to a degree retards, the biodegradation of organic material in general in municipal solid waste (MSW)

The different groups of paper behave differently in the process

Group	Type	Description (% dry weight)	Grammage (g/m^2)
W	Printing and writing	White offset 33%	80
		Photocopying 33%	80
		Laser 33%	80
K	Brown (Kraft)	Kraft bags25%	125
		Kraft liner 25%	125
		Compact cardboard 50%	175
N	Newspaper	Newspaper	60
T	Tissue	Paper handkerchiefs, serviettes 50%	19.5
		tablecloths	37
C	Cardboard	Boxes and boards (*)	250
		Cardboard tubes	180
R	Recycled	Printing and writing	80
		White liner	125

Groups of papers tested that can be found in the organic fraction of MSW

Group	Mean% D. at 45 days
MC	79.337
W	65.240
C	51.699
K	36.018
N	43.342
R	61.022
T	50.084

Biodegradation of the test material at 45 days according to UNE 14046 standards

No. 47

Test results

- White paper contains some material over and above the TVS, expressed as percent dry weight, such that the theoretical biodegradable fraction over the VS of the paper is approximately 74%. At 45 days of testing under controlled aerobic conditions, 65% biodegradation was achieved, which is only 12% below the theoretical maximum value. From these results, White paper retained in the plant for 110 days and pre-treated by trituration, could be considered for this purpose as biodegradable.
- Cardboard is tremendously heterogeneous in its fibrous composition. It is made from recycled fibres but with a mixed composition that is poorly controlled. This material in many cases is not de-inked or bleached and so the presence of certain chemical materials may inhibit the biodegradation process
- Kraft is characterised by a high density and content of lignin, since in the majority of cases it is semi-bleached or untreated. This type of paper should not be accepted into the composting facilities, given that it would greatly lengthen the process and would render it ineffective.
- For recycled paper on day 45 of testing in controlled aerobic conditions 61% biodegradation was achieved, which is only 9% or 10% below the theoretical maximum value. From this point of view, recycled paper retained in the plant for 110 days and pre-treated by trituration, could be considered for these purposes as biodegradable and this would therefore be suitable for recycling

RI. SE

No. 47

Test results

- The results obtained with newspaper are surprising. Nearly all newspaper production is made on recycled paper or paper with high recycled fibre content, so the behaviour of this paper should have been better than observed. However, the lignin content over and above the volatile solids expressed as a percent of dry weight varied between 10% and 20%, according to the mixtures that were confirmed by the producers. The theoretical biodegradable fraction for this paper is 41%. Explanations for this stress the presence of lignin in this type of paper, as well as other products coming from the organic content and ink used in printing, which can retard the biodigestion process. This type of paper should be completely removed before it enters into the composting plants.
- For Tissue on day 45 of testing under controlled aerobic conditions, 50% biodegradation was achieved, which is 13% below the theoretical maximum value. From these results, T should not enter these treatment plants. This result, which produced such a low level of biodegradation, was surprising. This was due, to the organic additives present in the manufacturing or finishing process and, above all, to the behaviour of the material during the test where particles of paper tended to form “balls” in the test containers, due to their absorption of humidity and the swelling of fibres. The effect of this was that the surface in contact with the inoculant was reduced and the process of biodigestion was retarded. In the plant at the end of the composting process, this type of material was observed to have formed doughy masses.

RI. SE

No. 47

Test results

- The papers tested will never achieve the same level of biodegradation at 45 days as the MC tested
- As the standard establishes that the reference material, in this case crystalline cellulose, must exceed the 70% biodegradation limit in 45 days, we can establish this level as the reference for paper, above which it would be possible to consider biodegradation as being effective.

Paper	Biodegradation Function	r	B_{45}	$\hat{B}_{45}$	No. days for $\hat{B} = 70\%$	Significance %
W	$y = -17.9342 + 21.0487\ lx$	0.9816	65.240	62.191	65	5
C	$y = -9.43339 + 16.2493\ lx$	0.9875	51.699	52.422	133	5
K	$y = -11.6926 + 11.8363\ lx$	0.9699	36.018	33.357	994	5
N	$y = 2.44352 + 12.6375\ lx$	0.9677	43.342	45.663	309	5
R	$y = -13.4894 + 20.0915\ lx$	0.9776	61.022	62.992	64	5
T	$y = -6.49205 + 15.4451\ lx$	0.9836	50.084	53.302	142	5

y = % biodegradation x = No. of days.
B_{45} = actual mean % biodegradation at 45 days.
$\hat{B}_{45}$ = estimated % biodegradation at 45 days.

No. 47

Conclusions

- At 45 days, under controlled conditions, none of the papers exceeded the 70% biodegradation limit.
- The papers that come closest to the limit are the W and the R, and they reach it in a retention period of a little more than 2 months, if the controlled conditions are kept unchanged.
- By contrast, it can be observed that those materials present in packaging and wrapping are those that take the longest to biodegrade.
- We can establish what the maximum limit of biodegradation would be for each typology of paper, based on the maximum measurement of CO2 that they generate at 45 days. (see equation in report)

No. 47

Conclusions

- For the W and recycled group it would be sufficient to lengthen the retention time in the plant.
- For the groups C, T and N, the degradation depends on the structure and disposition of the fibres and the variability of the materials that are present. For this group, in addition to lengthening their retention time in the case of C, it would be necessary to also treat the group with micro-organisms.
- T and N would be difficult to biodegrade unless the manufacturing process was changed.
- The paper K can be considered as non-biodegradable

Report No. 49

Characterization of selected municipal solid waste components to estimate their biodegradability

No. 25, 26, 18, 16, 14, 15, 47, 49, 58

No. 49

Summary of the reports 49

- The objective of the study no 49, Characterization of selected municipal solid waste components to estimate their biodegradability, was to investigate the biodegradability of several household waste fractions and materials and the possible correlations between quantitative and qualitative variables commonly used to characterize waste materials. 8 fractions were predominantly organic and were therefore selected for the present study.
- The biodegradation yield of the different fraction varied from 9% to 85%.
- For corrugated board it was 69,7%.
- Conclustion from the study is that 'Biological treatments of Residual Municipal Solid Waste (RMSW) allow to divert biodegradable materials from landfilling and instead recover valuable alternative resources.
- The biodegradability of the waste components needs however to be assessed in order to design the bioprocesses properly.
- (se table next page)

Summary of the reports 49

No. 49

Waste fractions	Aerobic bioassays		Anaerobic bioassays	
	Biochemical Oxygen Demand BOD_{28} (mg O_2 g^{-1}_{TS}) [a]	Biodegradation yield BD_{Aero} % [b]	Biomethane potential BMP_{60} (NmL_{CH4} g^{-1}_{TS}) [c]	Biodegradation yield BD_{Anae} % [b]
Food waste (FW)	933 ± 40 [d]	70.2	268 ± 11	57.5
Mix of green waste (GW)	360 ± 23	47.6	69 ± 5	26.1
Fine Fraction (FF)	747 ± 38	82.1	199 ± 6	62.4
Newsprints (NP)	708 ± 17	65.7	142 ± 5	37.6
Office papers (OP)	901 ± 36	84.7	273 ± 6	73.0
Magazines (MP)	422 ± 30	60,6	157 ± 8	64.4
Corrugated board (CB)	789 ± 39	69.7	221 ± 8	55.8
Cotton textiles (COT)	780 ± 31	66.1	275 ± 9	66.6
Sanitary textiles (SAN)	680 ± 22	54.8	266 ± 2	61.4
Diapers (DIA)	578 ± 26	37.8	221 ± 21	41.3
Wood (WOO)	129 ± 11	9.4	16 ± 1	3.3
Composites (COM)	576 ± 12	42.3	148 ± 20	31.1
MIX_{exp}	656 ± 15	65.4	148 ± 3	46.4

BD_{Aero}: Bioconversion yield in aerobic condition; BD_{Anae}: Bioconversion yield in anaerobic condition.

[a] Biological Oxygen Demand expressed in mg of O_2 consumption per g of dry solid sample.

[b] Bioconversion yield expressed in % of solid Chemical Oxygen Demand (COD).

[c] Bio-Methane Potential expressed in Normal mL of CH_4 production per g of dry solid sample.

[d] Average of triplicates with standard deviation.

Se report no. 49

No. 49

Title:

Characterization of selected municipal solid waste components to estimate their biodegradability

- R. Bayard*, H. Benbelkacem, R. Gourdon, P. Buffiere, Univ Lyon, INSA Lyon, DEEP Laboratory, EA7429, F-69621, Villeurbanne cedex, France
- Journal of Environmental Management 216 (2018) 4e12 , 2017

No. 49

Objectives

- The objective of the study was to investigate whether correlations could be observed in selected fractions constitutive of Residual Municipal Solid Waste (RMSW) between the results obtained from different procedures of characterization aiming at the determination of their biodegradability.
- Biochemical Oxygen Demand (BOD) and anaerobic BMP bioassays were conducted on aqueous suspensions of crushed solid waste materials obtained from each fraction. Different complementary protocols were used for quantitative and qualitative analysis of organic matter, including leaching tests, soluble fraction, hemicelluloses-like, cellulose-like and lignin-like components.

No. 49

Materials and methods

- A representative sample of 500 kg of RMSW was collected from a MBT plant located in the south east of France. The sample was sorted into fractions.
- 8 of the 13 fractions were predominantly organic and were therefore selected for the present study . Some of them were further divided into sub-fractions and ultimately a total of 12 organic fractions and sub-fractions were considered in the present study,

MODECOM® categories	MSW (% w/w_{DM})	Sub-categories	Designation	MIX Waste (% w/w_{DM})
Putrescible matters	11.5	Food waste	FW	6.2
		Mix of green waste (yard, leaves, branches)	GW	12.5
Fines (< 20 mm)	21.6	Fine Fraction	FF	34.9
Papers	9.7	Newsprints	NP	8.3
		Office papers	OP	6.4
		Magazines	MP	6.4
Cardboards	9.0	Corrugated board	CB	15.5
Textiles	0.3	Cotton textiles	COT	0.5
Sanitary tissues	2.3	Sanitary textiles	SAN	3.0
		Diapers	DIA	0.8
Non Classified Combustibles	3.1	Wood	WOO	5.1
Composites	1.5	Composites like "Tetrabricks"	COM	0.5
		Non-biodegradable like plastic "yoghurt cup"		
+				100

Categories and subcategories of residual MSW collected for the study, and composition of the reconstituted MIX waste.

Test results

No. 49

Waste fractions	Aerobic bioassays		Anaerobic bioassays	
	Biochemical Oxygen Demand BOD_{28} (mg O_2 g^{-1}_{TS}) [a]	Biodegradation yield BD_{Aero} % [b]	Biomethane potential BMP_{60} (NmL_{CH4} g^{-1}_{TS}) [c]	Biodegradation yield BD_{Anae} % [b]
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MIX_{exp}	656 ± 15	65.4	148 ± 3	46.4

BD_{Aero}: Bioconversion yield in aerobic condition; BD_{Anae}: Bioconversion yield in anaerobic condition.

[a] Biological Oxygen Demand expressed in mg of O_2 consumption per g of dry solid sample.

[b] Bioconversion yield expressed in % of solid Chemical Oxygen Demand (COD).

[c] Bio-Methane Potential expressed in Normal mL of CH_4 production per g of dry solid sample.

[d] Average of triplicates with standard deviation.

No. 49

Test results

The fractions with the lowest aerobic biodegradability was the Wood fraction (9.4%), and, to a lesser extent, diapers (38%) and composites (42%).

Lignin provides a physical and chemical protection to the microbial attacks of cellulose and hemicelluloses due to its 3-D hydrophobic structure. This protective effect is likely to increase in waste fractions with high contents lignin-like substances, explaining the correlations observed in this studies

Experimental results of aerobic and anaerobic bioassays for each organic fraction or sub-fraction and the reconstituted MIX waste.

Waste fractions	Aerobic bioassays		Anaerobic bioassays	
	Biochemical Oxygen Demand BOD_{28} (mg O_2 g^{-1}_{TS}) [a]	Biodegradation yield BD_{Aero} % [b]	Biomethane potential BMP_{60} (NmL_{CH4} g^{-1}_{TS}) [c]	Biodegradation yield BD_{Anae} % [b]
Food waste (FW)	933 ± 40 [d]	70.2	268 ± 11	57.5
Mix of green waste (GW)	360 ± 23	47.6	69 ± 5	26.1
Fine Fraction (FF)	747 ± 38	82.1	199 ± 6	62.4
Newsprints (NP)	708 ± 17	65.7	142 ± 5	37.6
Office papers (OP)	901 ± 36	84.7	273 ± 6	73.0
Magazines (MP)	422 ± 30	60,6	157 ± 8	64.4
Corrugated board (CB)	789 ± 39	69.7	221 ± 8	55.8
Cotton textiles (COT)	780 ± 31	66.1	275 ± 9	66.6
Sanitary textiles (SAN)	680 ± 22	54.8	266 ± 2	61.4
Diapers (DIA)	578 ± 26	37.8	221 ± 21	41.3
Wood (WOO)	129 ± 11	9.4	16 ± 1	3.3
Composites (COM)	576 ± 12	42.3	148 ± 20	31.1
MIX_{exp}	656 ± 15	65.4	148 ± 3	46.4

BD_{Aero}: Bioconversion yield in aerobic condition; BD_{Anae}: Bioconversion yield in anaerobic condition.
[a] Biological Oxygen Demand expressed in mg of O_2 consumption per g of dry solid sample.
[b] Bioconversion yield expressed in % of solid Chemical Oxygen Demand (COD).
[c] Bio-Methane Potential expressed in Normal mL of CH_4 production per g of dry solid sample.
[d] Average of triplicates with standard deviation.

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Test results

The present study investigated the **biodegradability of several household waste fractions** and materials and the possible correlations between quantitative and qualitative variables commonly used to characterize waste materials.

No correlations were observed however between the results from either aerobic or anaerobic biodegradation tests and the quantitative or qualitative variables used to characterize the waste fractions, except their contents in lignin-like substances which was found to be negatively correlated with biodegradability results. It was concluded that the analytical parameters commonly used (OM contents, soluble fractions, cellulose and hemicelluloses contents, leaching behavior) were not relevant to predict biodegradability because they were not able to provide any information on the structure of the analyzed organic matter, which however controls its bioavailability and thereby its actual biodegradation in the bioassays

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Conclusions

- Biological treatments of Residual Municipal Solid Waste (RMSW) allow to divert biodegradable materials from landfilling and recover valuable alternative resources.
- The biodegradability of the waste components needs however to be assessed in order to design the bioprocesses properly.

Report No. 58

BIODEGRADABILITY DETERMINATION OF MUNICIPAL WASTE: AN EVALUATION OF METHODS

No. 25, 26, 18, 16, 14, 15, 47, 49, 58

Summary of the report 58

Pek 58

- The report " Biodegradability determination of municipal waste: An evaluation of methods"
- The objective was to evaluate several methods identified in a review of organic waste characterization methods.
- The study has evaluated several methods for characterizing municipal organic wastes according to their relative biodegradable content.
- The study concludes that general waste characterization in terms of dry matter (DM) and organic matter (LOI) content is essential.
- To evaluate the biodegradability of the waste, the most promising biological tests evaluated are the DRI and BMP methods and a cellulase enzymic hydrolysis method that may provide a rapid surrogate measure of relative biodegradability.

Comparison of results from anaerobic BMP and aerobic DRI and SOUR tests on selected organic wastes.

Waste sample	BMP Biogas	DRI AT4value	SOUR Peak rate	Percentage waste carbon mineralized (%)		
	(l /kg LOI)	(mg O_2/kg LOI)	(mg O_2/kg LOI.h)	BMP	DRI (96h)	SOUR (90h)
Cellulose	136	84900	20	16.9	7.59	0.07
Newspaper	76	76600	150	8.5	6.05	0.13
Corrugated paper	320	125000	660	37.8	10.3	1.83
Grass	225	119000	2880	33.1	12.3	16.30
Twigs	93	57100	13900	10	4.29	4.34
Vegetables	312	137000	24700	40.6	12.5	45.5
Meat	633	150000	12600	61.7	10.3	30.5
Cotton	26	12900	530	2.6	0.91	0.39

Se report no. 58

Pek 58

Title:
BIODEGRADABILITY DETERMINATION OF MUNICIPAL WASTE: AN EVALUATION OF METHODS

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Objectives

- The objective of this research project is to derive a means of assessing the biodegradable content of MSW that has been removed by treatment (and that which remains) prior to that waste being landfilled.
- This paper describes the results from an experimental evaluation of several methods identified in a review of organic waste characterization methods

Materials and methods

Pek 58

- The Environment Agency is required to monitor the diversion of biodegradable municipal waste (BMW) from landfill. Reliable methods are needed to measure the biodegradability of municipal waste, both as mixed municipal waste and as individually separated fractions. An evaluation of several methods was carried out using a variety of organic materials typically found in municipal solid waste.

- Evaluation of non-biological methods
  - Gravimetric methods
  - Elemental composition
- Evaluation of biological methods
  - Anaerobic biochemical methane potential (test method BMP)
  - Aerobic waste biodegradation test methods (three main method types SRI, DRI, SOUR)

Materials and methods

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- This study has evaluated several methods for characterizing municipal organic wastes according to their relative biodegradable content.
- The study concludes that general waste characterization in terms of dry matter (DM) and organic matter (LOI) content is essential. In addition, TOC is also a useful measurement as it provides a cross-check of the organic content. The LOI and TOC tests do not characterize the relative biodegradability of the waste.

- Anaerobic biochemical methane potential (BMP)
- This test measures waste biodegradability under anaerobic methanogenic conditions by measuring the amount of biogas, methane and carbon dioxide (CH4 + CO2) or specifically CH4 produced.

Test results

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Comparison of results from anaerobic BMP and aerobic DRI and SOUR tests on selected organic wastes.

Waste sample	BMP Biogas	DRI AT4value	SOUR Peak rate	Percentage waste carbon mineralized (%)		
	(l /kg LOI)	(mg $O_{2?}$/kg LOI)	(mg $O_{2?}$/kg LOI.h)	BMP	DRI (96h)	SOUR (90h)
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Cotton	26	12900	530	2.6	0.91	0.39

- Aerobic waste biodegradation test methods
- Several aerobic waste biodegradability test methods exist as well as different monitoring techniques and ways of expressing results. They can be categorized into three main method types; static respiration index (SRI), dynamic respiration index (DRI) and liquid systems such as the specific oxygen uptake rate (SOUR) method.

Conclusions

Pek 58

- Several methods for characterizing municipal organic wastes has been evaluated according to their relative biodegradable content.
- The study concludes that general waste characterization in terms of dry matter (DM) and organic matter (LOI) content is essential. TOC is also a useful measurement as it provides a cross-check of the organic content.
- To evaluate the biodegradability of the waste, the most promising biological tests evaluated are the DRI and BMP methods and a cellulase enzymic hydrolysis method that may provide a rapid surrogate measure of relative biodegradability.

Thanks

Cathrine Löfgren
RISE