

The Biological Degradability and Compostability of Rhodia Filter Tow

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Introduction

After single use, cigarette filters are discarded and become trash to be disposed of. For dealing with such solid and other waste, biological methods are nowadays being used for general waste disposal and recycling to useful end-degradation products, and no longer just for the classical composting of purely biogenic waste (agricultural and garden waste, or municipal waste-water). Hence, knowledge about the biological degradability of manufacturing starting materials and products relevant for optimizing their recycling and ultimate reuse is becoming an important topic, also of considerable general interest.

At the national and international level methods for the testing of biodegradability have now been standardized or are draft proposals for standardization. With these procedures, it is readily feasible to investigate the biological degradability of polymeric materials in aerobic (composting) and anaerobic (fermentative) systems.

Using some of these established standards and proposed test procedures, Rhodia Filter Tow has been extensively investigated in recent years. The results obtained from these tests will be briefly presented and discussed in the following summary. The full reports with the complete presentation of the experiments will be gladly provided upon request.

To summarize, the biological degradability of Filter Tow in various environmental conditions can be characterized as follows:

- in aqueous aerobic milieu: completely degradable,
at rates from moderate to good
(under optimal conditions)
- in aqueous anaerobic milieu: readily degradable
- by composting: moderately degradable
(several cycles are necessary)

Chemical description of Rhodia Filter Tow

Rhodia Filter Tow is made of cellulose acetate filaments, usually of a fineness of 1.6 - 5 dtex (namely, weighing 1.6 to 5 g per 10,000 m of filament length). These filaments have a trilobal cross-section and a diameter of 20-40 micrometers.

Cellulose acetate (2) is formally made from cellulose (1) and acetic acid (AcOH). During this process an average of 2.5 of the 3 hydroxyl groups (alcohol groups) of each of the glucose molecules, the "monomers" of cellulose, become esterified with acetic acid (i.e., degree of substitution, DS = 2.5).

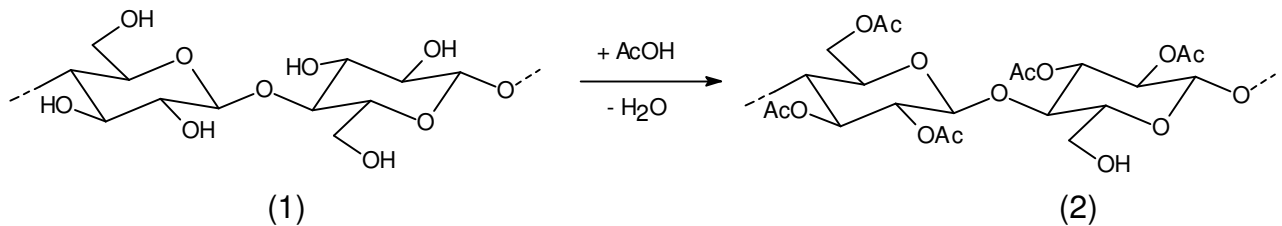


Fig.1: Formal synthesis of cellulose acetate (shown as a section of the polymeric chain with DS = 2.5)

The degree of substitution has major effects on the physical properties of cellulose derivatives, as well as the rate of their biological degradation.

On the biological degradation of cellulose acetate

The glycosidic linkage between the monomeric subunits of cellulose can be split enzymatically by a variety of microorganisms. The fragments generated can in turn be utilized by the same and other microorganisms as carbon and energy source. It turns out, however, that the cleavage of these glycosidic C-O bonds by the appropriate specific enzymes (cellulases) is sterically hindered by the neighboring acetate groups. This effect is so strong that above a degree of substitution of about 2.0 this hydrolysis becomes essentially blocked.

On the other hand, these acetate groups can themselves be cleaved off enzymatically by different, also fairly specific enzymes. Hence, the biological degradation of cellulose acetate must proceed in a series of steps, as follows:

- partial hydrolysis involving removal of the acetate groups,
- cleavage of the now accessible glycosidic bonds of the cellulose chains,
- biochemical conversion (catabolism) of the glucose-containing fragments to the terminal or so-called end-products of this process (carbon dioxide, water and, in certain situations, methane).

The first step of the sequence indicated is the critical, rate-limiting step. Here it is crucial to have precisely the right environmental conditions and the right microorganisms as inoculum. It appears that only very special, but nearly ubiquitously occurring microorganisms are able to carry out this first step efficiently.

Experimental results in aqueous test systems

Sturm Test

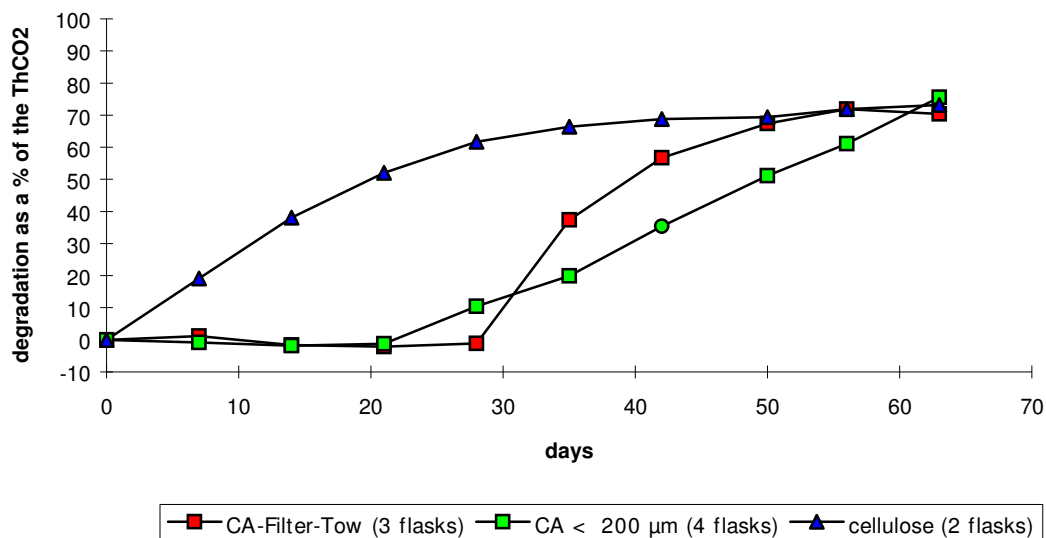
The Sturm Test was carried out according to Part 2 of the German Standard DIN 54900 (draft entitled "Prüfung der Kompostbarkeit von polymeren Werkstoffen" i.e. "Testing the compostability of polymer materials"), which is based on an older standard EN 29439).

In this aqueous test the substance being tested was incubated as the sole carbon source for an inoculum of microorganisms for up to 3 months. The only additives were inorganic nutrient salts in solution, plus aeration with carbon-dioxide-free air. Any carbon dioxide formed was expelled (flushed out) by the air bubbled in and could be trapped in the exit tube and quantified.

From the measured amount of carbon dioxide produced during the test, the biological degradation could be calculated. With some additional measurements (dry weight determinations, protein content and content of soluble organic carbon compounds in the aqueous phase), a carbon balance was made. And from this, the fate of all the starting material (further processing to additional biomass, remainder of unconverted starting material) could be estimated. The inoculum used in our tests consisted of sewage sludge from a municipal wastewater treatment plant.

Samples of Filter Tow (1.6 dtex filament titer), intact or ground-up, attained a final extent of degradation - based on the theoretical maximally producible amount of carbon dioxide - of 64-86% after treatment for 9 weeks with sewage sludge which had been preincubated for two months with cellulose acetate. Compared to cellulose powder, our reference substance, degradation of Filter Tow began 3 to 4 weeks later (7 weeks in one flask, which was therefore not further considered).

Figure 2: Degradation of CA-Filter Tow in the Sturm Test after preincubation of sewage sludge



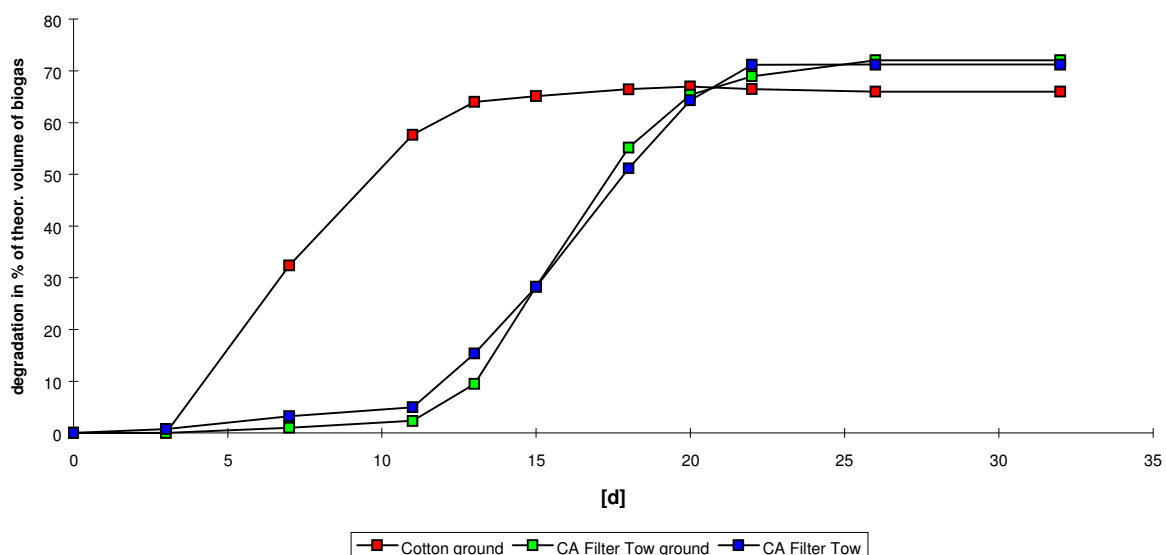
After this delay (lag phase) of ca. 3 weeks, carbon dioxide is eventually formed at a rate and to an extent which is comparable to the degradation of cellulose (see fig. 2.: time

course of the biological degradation, determined from the amount of carbon dioxide produced, normalized to the theoretically obtainable amount of carbon dioxide).¹ Corresponding experiments without preadaptation of the inoculum yielded similar results. Namely, 76% of the theoretical value was achieved after 9 weeks. However, again in one of four test sets the biological degradation had not started ². The experimental scatter of the results is an indication that only certain microorganisms participate in carrying out the first degradation step, namely the deacetylation.

Anaerobic test

For testing the anaerobic degradability the method according to the US Standard ASTM-D5210-91 was utilized. Here an anaerobic aqueous treatment of the test substance with activated sludge and nutrient medium is called for. The biological degradability of the test substance is calculated from the volume of biogas (methane) formed. As inoculum, digested activated sludge from a municipal wastewater plant was added.

Figure 3: Anaerobic degradation of cellulose-2,5-acetate



In this test, carried out under oxygen-free conditions, the digestion or wet fermentation in the digestion tower is simulated.

A degradation of 72% was measured after 22 days (mean value of the samples of intact and ground-up Filter Tow).

¹ Final Report: "Degradation of Cellulose Acetate Filter Tow in the Sturm Test" by S. Gartiser, Hydrotox GmbH contracted by Rhône-Poulenc Rhodia AG, from August 29, 1996

² Report: "Abbau von Celluloseacetat Filter Tow im Sturm Test" by S. Gartiser, Hydrotox GmbH contracted by Rhône-Poulenc Rhodia AG, from January 31, 1996.

Compared to cotton, which served as the reference substance in this test, the beginning of the formation of biogas (as the end-product of the degradation) is delayed by about one week. This lag phase can be attributed to the need for the initial biological saponification/deacetylation step (pre-treatment in aqueous medium does not shorten this lag phase measurably).^{3 4}

Results of compostability tests

In Part 3 of the proposed German Standard DIN 54900 for the "Testing the compostability of polymer materials" mentioned above, tests are recommended in both simple and technically advanced composting installations which are actually in operation. The simple composting system can also be simulated by a laboratory experimental procedure developed by the EMPA.⁵

In a thermally insulated vessel a standard mixture of solid waste consisting of untreated newspaper, potatoes, eggs and wheat straw, is aerated for 2 months. The samples in plastic frames are introduced into this garbage and then examined visually and weighed at the end of the test. During the composting process, the temperature is monitored.

It must be pointed out that while these results are not directly generalizable to the case of larger, technical-scale treatment plants, they do provide relative values, in comparison to the standard substances treated in parallel. One important difference as compared to the composting in simple installations, however, is that in the laboratory test virtually no mechanical compaction occurs.

The standard garbage mixture is reduced to 20-60% (on a dry weight basis) of its input in one cycle, whereby most of the wheat straw remains intact.

After one cycle, the samples of Filter Tow (1.5 Y 38000) were hardly touched (weight loss of-8%). But after a second run-through, the filaments of the Filter Tow samples had disappeared without any detectable trace.⁶

³ Final Report: "Anaerobic Degradation of Cellulose Acetate" by S. Gartiser, Hydrotox GmbH contracted by Rhône-Poulenc Rhodia AG, from May 5, 1995.

⁴ S. Gartiser and R. Willmund: "Untersuchungen zum Verhalten von Tabakextrakt, Zigarettstummeln und Nikotin in Kläranlagen", Korrespondenz Abwasser **43**, 1991 (1996); and "High Ratio of Degradation for Tobacco Extracts in Sewage Treatment Plants", Tobacco Journal Int. **3/97**, 54 (1997)

⁵ Eidgenössische Material Prüfungs Anstalt, i.e. the official material testing laboratory of Switzerland; P. Paschke and J.P. Kaiser: "Biotransformation und Kompostierbarkeit von Folien", Werkstoffe und Korrosion, **45**, 167 (1994)

⁶ Final Report: "Versuche zur Kompostierung von Filter Tow im Labormaßstab" by S. Gartiser, Hydrotox GmbH contracted by Rhône-Poulenc Rhodia AG, from December 4, 1996.