ASSESSMENT OF THE BIOLOGICAL STABILITY OF REFUSE DERIVED FUELS

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Abstract

Refuse Derived Fuels (RDF) are used as substitute fuels in energy intensive industries due to their low cost and non fossil and renewable carbon content (biogenic). This carbon is usually found in fractions of paper, cardboard, textiles, etc. Therefore, the High Calorific Fraction (HCF) of Municipal Solid Waste (MSW) is seen as a potential raw material for its production. However, this approach can have implications in the biological stability of RDF due to the degradability of the biogenic carbon and the presence of putrescible matter which usually impregnates HCF. In this study the effect of moisture content and water availability on RDF degradation kinetics is assessed by a static respirometric test. The influence of temperature and oxygen are also evaluated. Results show that moisture content plays an important role on the degradation of RDF and optimal values range between 65% and 90% (17ºC and 25ºC, respectively). Kinetics can be three times higher at 25ºC than at 17ºC, for optimal moisture contents. When superabsorbent is used, the degradation rate (and consequently the biostabilization) of RDF is increased. Water bioavailability is higher when these structured polymers are used due to their effect as scaffolds to biological activity. Moreover, water is directly retained by superabsorbents avoiding dissolution of potential toxins. These results suggest that storage in moderate climates (like Mediterranean) should assure moisture contents under 20% which lead to low degradation rates. If needed, superabsorbent can be used to enhance biological stabilization of HCF material for RDF production.

Keywords: waste fuels; aerobic degradation kinetics; BOD; water activity; hydrolysis.

1. INTRODUCTION

Refuse Derived Fuels (RDF) are solid fuels prepared from non-hazardous waste for energy recovery. These fuels can be prepared from industrial waste flows or from Municipal Solid Waste (MSW).

The production of RDF from MSW may be achieved by two main methods: biostabilization and, by Mechanical and Biological Treatment (MBT). In biostabilization, all the MSW is stabilized for water loss and biological inactivation. Additionally, there is an inert and contaminant removal and also some particle size reduction for homogenization (Gendebien et al., 2003).

In MBT there is a mechanical separation of some components from the mixed MSW (usually recyclables and organics) followed by a biological step to treat only the organic fraction. During the mechanical treatment, a High Calorific Fraction (HCF) is obtained and can be used for RDF production after particle size reduction and some contaminant removal (Gendebien et al., 2003). This HCF is mainly composed by plastics, paper, cardboard, textiles and other smaller fractions like wood, metals, etc. This material is also impregnated with organic matter (due to the previous contact with the organic fraction of MSW) which can play a major role in the biological stability of the RDF produced from MSW.

The biological stability of RDF is important because it influences the production of odours, degradation of the organic matter and the growth of pathogens (Iannotti et al., 1993).

The decomposition of waste(s) can be defined as the bio-oxidation of organic matter by organisms. This decomposition may be aerobic (in the presence of oxygen) or anaerobic (in absence of oxygen). The aerobic decomposition depends on the waste constitution and on factors such as moisture content, nutrient availability, self-fauna and other environmental factors (Miller and Clesceri, 2000).

In RDF composition there is some biogenic carbon, which contributes to its non-fossil and renewable character, but that can be used by the organisms as a substrate. Usually, fractions like paper and cardboard can degrade if proper conditions are established.

Oxygen may be a limiting factor in aerobic decomposition because it must be dissolved in the aqueous phase in order to be accessed by the organisms (Miller and Clesceri, 2000). As a consequence, this factor is highly related to the moisture content of the waste.

Generically, moisture content is defined as the total amount of water present in the material. Nevertheless, there are different states of water sorption in solid materials that influence its availability to organisms (Miller and Clesceri, 2000). Intrinsic water, which is inside the waste particles, is inaccessible to organisms because the energy required to extract it from the waste is too high. Some water can be loosely bound and its availability depends upon the organisms, the substrate and chemical conditions. When the water is free (around the waste particles) it means that it is available to organisms. So, from the total moisture content only the free water determines the biological stability of waste.

Waste self-fauna usually consists of bacteria, fungi and yeasts (Tchobanoglous et al 1993). This fauna is dependent on several conditions, because the organisms only develop under certain values of temperature and moisture. These conditions influence the substrate degradation. Bacteria and fungi have an important role in the initial stage of aerobic degradation, because they act in the hydrolysis process of the substrate molecules conditioning the degradation kinetics (Tchobanoglous et al 1993).

Wastes biological stability assessment has already been extensively studied within the context of composting processes (Iannotti et al., 1993, Adani et al., 2001, Gomez et al., 2006). In these studies the main goal was to help on determining the highest degradability of the substrate. Therefore optimal conditions of moisture and temperature were used to access stability. However and regarding RDF biological stability there are few published results (Adani at al., 2002) which are devoted to the RDF produced by biostabilization.

In this work the biological stability of the HCF from MSW is accessed by a static respirometric method aiming at a deeper knowledge on which factors and conditions influence its degradability. Moreover, the influence of superabsorbent for water availability control was also studied.

2. EXPERIMENTAL STUDY

The kinetics of aerobic decomposition of RDF was evaluated using the Biochemical Oxygen Demand (BOD) test, a static respirometric test where the oxygen consumption is determined by a pressure differential inside a closed vessel. When O_2 is consumed BOD measures the drop in the vessel after assuring that all the CO_2 that is formed is absorbed by a proper solution.

Tests on HCF from MSW were performed during 5 to 10 days the WTW OxiTop Control System on 1 and 2.5 L flasks. Due to the equipment limit of detection some samples were diluted. During these tests the influence of moisture and temperature was evaluated. The CO2 absorption solution was soda lime (solid granules sized between 1 and 2.5 mm)

The HCF samples came from a MBT plant near Lisbon. The material under analysis consisted of the non putrescible rejected fraction generated during the mechanical treatment of mixed MSW. This fraction is then subjected to glass and metals removal and is shredded to 30 mm. Samples were collected and provided by the waste treatment plant. The physical composition of the HCF under analysis is summarized on Table 1.

Table 1. Physical composition of the HCF from mixed MSW under study as a potential RDF.

Components	Composition (% w/w)
Paper	20.62
Cardboard	8.55
Plastics	18.19
Textiles	7.25
Hygiene wastes	8.05
Food wastes	16.57
Yard wastes	4.25
Metals	2.33
Others	14.19

For BOD tests the mass portions used varied between 23g, 2.3g (dilution 1:10) and 4.6g (dilution 1:5). For sample division the manual increment method was used (CEN/TS 15443:2006). In order to increase homogeneity of such low masses samples were shredded to 10 mm using a cutting mill (Retsch SM 2000). Polyethylene (PET) plastic (from water bottles) was used as a dilution material because beyond its biological stability it could act as a structural material promoting oxygen spreading throughout all sample.

Moisture content was measured by the weight loss at 105ºC. Moisture was adjusted to higher values by adding water through a uniform spray and to lower values by drying the sample at

40°C. Experimental essays were performed using conditions expressed in Table 2. Temperature was assured by the use of acclimatized chambers. The superabsorbent used was Stockosorb® 400 F.

Table 2. Experimental conditions used for RDF biological stability assessment.

Conditions	Dilution	Initial Moisture Content (%)	Moisture Content (%)
1g superabsorbent Stockosorb 400 F	1:2	28,0	45,5
Control sample			45,8
0.25g superabsorbent Stockosorb 400 F	1:4	7,8	49,1
Control sample			49,6
17ºC	1:5	22,0	66,4
			71,8
			ND
	1:10	22,0	86,8
25ºC	1:10	22,0	11,4
			16,4
			22,2
			80,1
			86,8

3. RESULTS AND DISCUSSION

3.1. Overview of RDF degradability by studying it hydrolysis rate

Based on physical composition of the RDF under study (Table 1) the theoretical contribution of each component to RDF hydrolysis was evaluated (Figure 1).

Given the wide range of materials that can compose food wastes and the discrepancy found among the hydrolysis rates (k_H) values both for food and hygiene wastes, two possible scenarios were investigated. On worst case scenario food wastes were considered to be composed of the materials with high k_H like rice and hygiene wastes were considered to be mainly toilet tissues. On the best case scenario lower k_H materials like diapers were regarded as the major component of hygiene wastes and food was considered to be a mixture of low degradation rate materials like cooked fish or meat, eggs, etc.

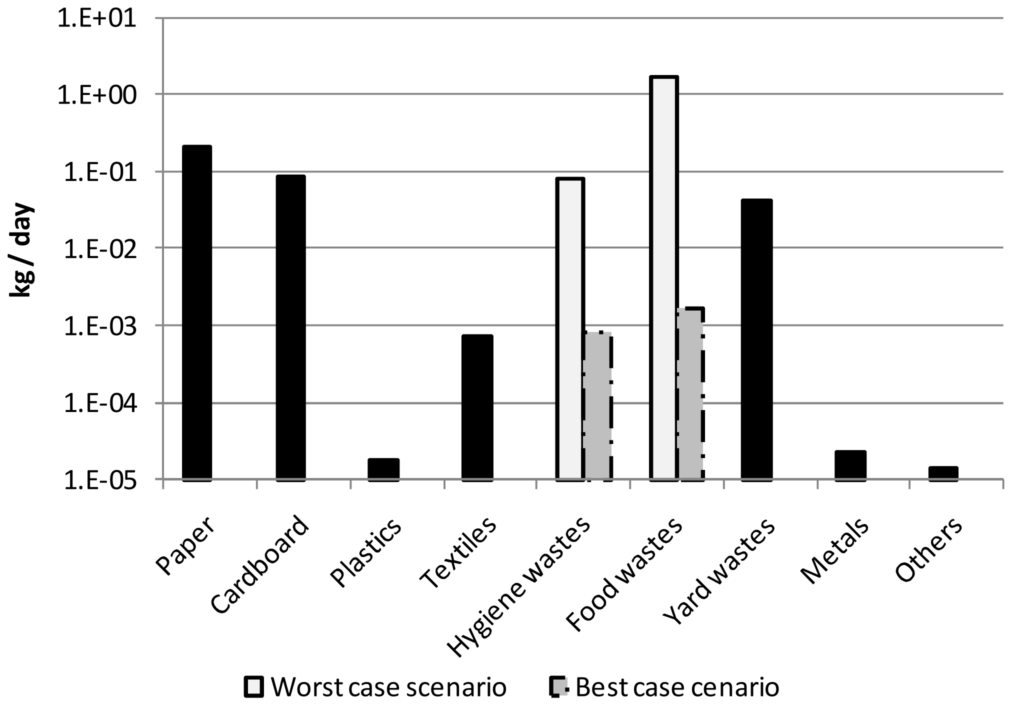

Figure 1. Theoretical contribution of the major RDF components to the aerobic hydrolysis kinetics.

Two of the components that contribute the most for RDF degradation are paper and cardboard. Though they have lower k_H values than more putrescible fractions like food or yard wastes their amount in RDF is enough to turn the hydrolysis kinetics significant. When the best case scenario is considered Figure 1 shows that food wastes are not the main responsible for the degradation of RDF.

3.2. Effect of moisture content and temperature on RDF degradation

In Figure 2 the experimental results of the influence of temperature and moisture content on the degradation kinetics of RDF produced from mixed MSW (initial moisture content of 22%) are plotted. These kinetic were determined after identification of lag phase and in the first 48h, where biological activity was more intense.

Moisture addition to RDF seems to lead to a logarithmic increase of the RDF degradation rate, which is an expected behaviour. However, Figure 1 shows that optimal degradation moistures, ranging between 65% and 90%, are higher than the ones found in literature (30% to 65%) (Adani et al, 2001).

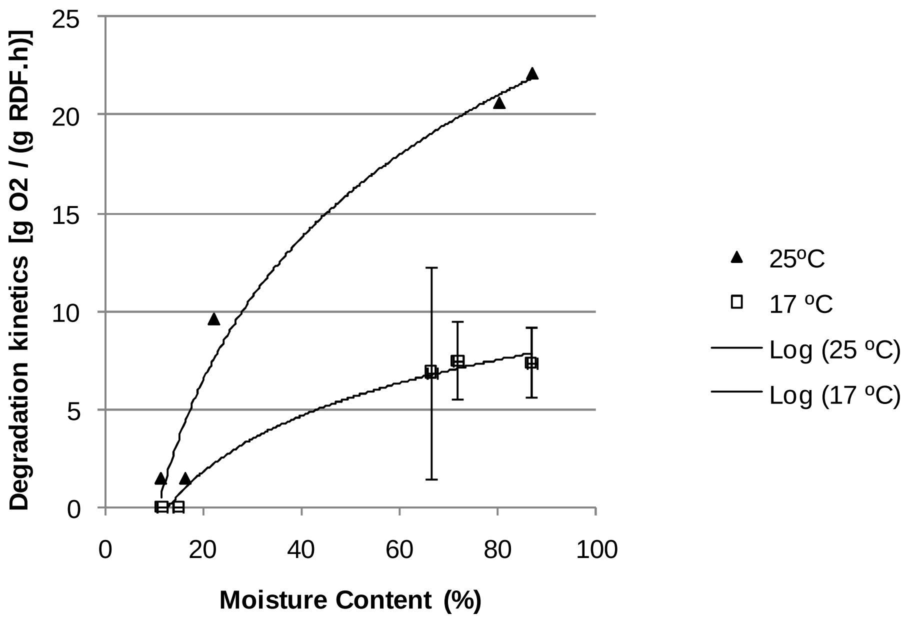

Figure 2. Influence of moisture content and temperature on the aerobic degradation kinetics of the RDF produced from mixed MSW.

This can be due to the water holding capacity of RDF which is higher than in MSW (the material under study in literature), given its physical composition (Table 1). The water holding capacity of RDF allows for the storage of high amounts of free water that seem to enhance biological activity.

It can be seen that temperature can influence the degradation kinetics. Figure 2 shows a significant increase in the biological activity for temperatures of 25ºC (almost three times higher at 80% moisture) when compared with 17ºC results. This outcome is expected since literature states that mesophilic temperatures are more effective for degradation purposes when process parameters (moisture and oxygen) are maintained in an optimal range (Adani et al, 2002).

On the other hand, at lower temperatures the degradation is only possible in samples with moisture content higher than 60% while at 25ºC biological activity exists even with low water content.

3.3. Influence of water availability on the degradation kinetics

Figure 3 shows the experimental results of the addition of superabsorbent (SA) Stockosorb® 400F on the degradation kinetics of RDF produced from mixed MSW. These results were obtained using biological activity on the first 48h.

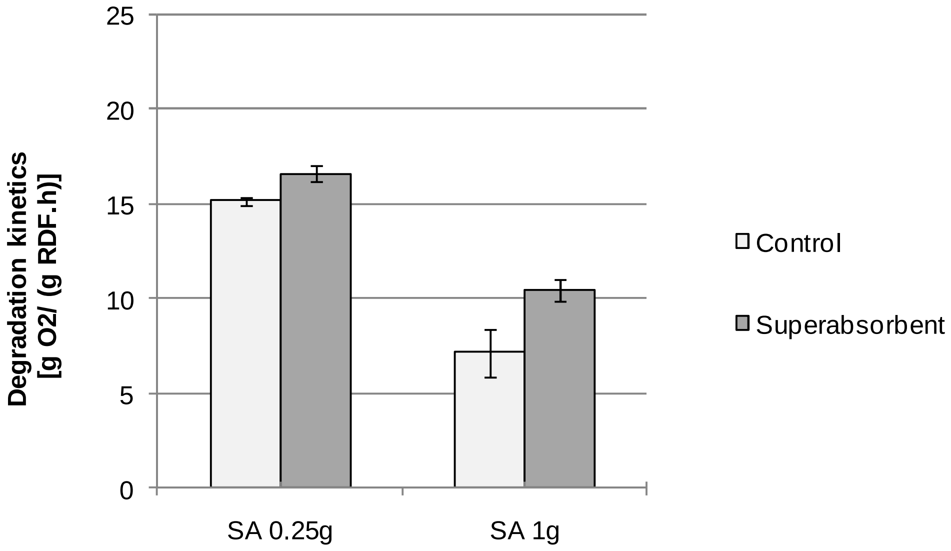

Figure 3. Influence of addition of superabsorbent (SA) on the aerobic degradation kinetics of RDF (moisture content = 46%; SA= Stockosorb® 400 F).

The addition of superabsorbent increases the degradation rate of RDF. The main reason to this phenomenon is the higher water bioavailability in the superabsorbent. In these polymers, the water molecules are retained and available in particles with a large surface to volume ratio offering good conditions for biological activity. In the waste, the water is less bioavailable since it is usually a solution containing not only the substrate but also substances that can act as toxins. Moreover water losses are higher in waste, which tends to a an equilibrium with atmospheric humidity while in the superabsorbent water is still retained.

3.4. Effect of the oxygen volume on the test flask

Figure 4 shows the BOD of RDF samples using different test flasks of 1L and 2.5L.

Results show that after a lag phase of 24h the biological activity on RDF samples is higher (9.4 g O_2/(g RDF.h)) when large test flasks are used, even though sample has a lower moisture content.

The 1L flask tests were performed after moisture increase up to 80% and according to Figure 2 degradation kinetics around 22 g O_2/(g RDF.h) should be expected. However, almost null activity (1.3 g O_2/(g RDF.h)) was detected.

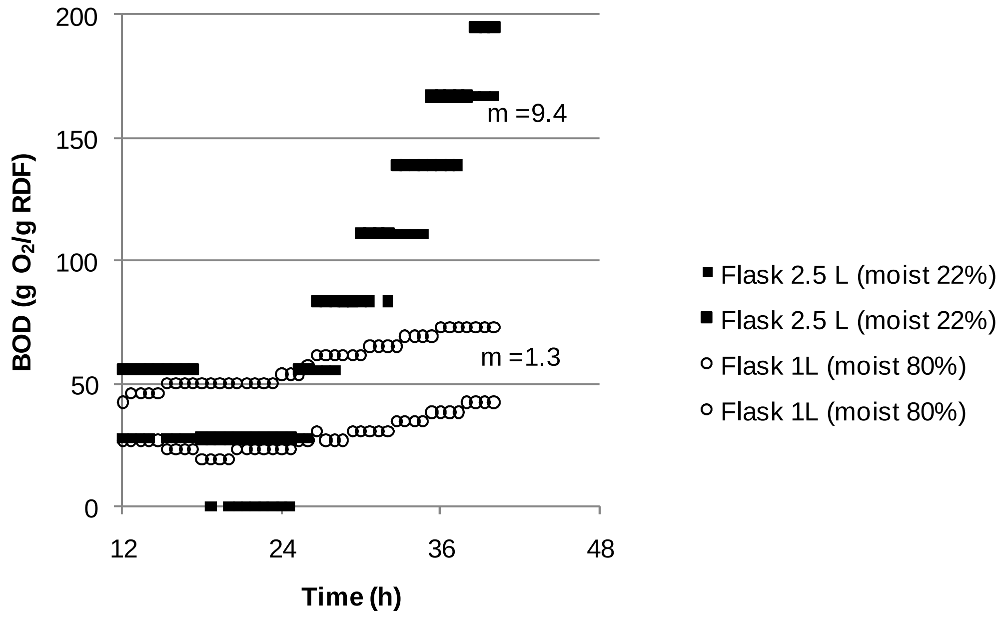

Figure 4. Influence of oxygen availability on test flasks used for BOD determination on RDF samples.

4. CONCLUSIONS

The intent of this work was to study the main factors that can influence the biological stability of RDF produced from the HCF of MSW. Initially, an overview of RDF degradability was done by studying theoretical contribution of the major RDF components to the aerobic hydrolysis kinetics. The experimental approach involved the evaluation of the effect of RDF moisture content and water availability on the degradation kinetics using BOD, a static respirometric test. The influence of temperature and oxygen were also addressed.

The analysis of hydrolysis kinetics shows that RDF from mixed MSW is expected to have biological activity. The contribution of paper and cardboard fractions to overall degradability is significant since they exist in considerable amounts. On the other hand fractions like food, hygiene and yard wastes have higher hydrolysis constants and can act like inoculums for biological degradation. Therefore quality control of RDF should include a deeper knowledge of the type of food and hygiene wastes that compose the HCF used for production.

Experimental results reveal that moisture content plays an important role on the degradation of RDF and optimal values range between 65% and 90%, according to the temperature conditions (17ºC and 25ºC respectively). The degradation rate can be three times higher at 25ºC than at 17ºC for optimal moisture contents. These results suggest that storage in moderate climates (like Mediterranean) should assure moisture contents under 20% which lead to low degradation rates.

The degradation rate (and consequently the biostabilization) of RDF is increased when superabsorbent is used. Water bioavailability is higher when these structured polymers are used due to their effect as scaffolds to biological activity. Moreover, water is directly retained by superabsorbents avoiding dissolution of potential toxins.

One of the limitations found during this work is that static respirometric tests like BOD can have some drawbacks like the oxygen limitation. This affects quantitative values found for degradation kinetics misleading results. Additionally this method only allowed for the study of biological stability in the first 48h.

Further work should include the use of dynamic respirometric methods that assure the continuous aeration of larger and representative amounts of sample overcoming oxygen diffusion and mass transfer limitations. In-depth knowledge of the possible advantages of the use of superabsorbent for RDF stabilization could also be useful.

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