

DETERMINING THE DEGREE OF AEROBIOSIS IN COMPOSTING MATERIALS

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1. ABSTRACT

A laboratory test rig was constructed to investigate the possible use of exhaust gas O₂ concentration, the microbial respiratory quotient, and oxygen consumption rate, in evaluating the degree of aerobiosis of a composting matrix. This laboratory study involved trials with two batches of source-separated household organic waste, including yard waste, incubated at 50°C and 65°C, and at variable forced-aeration rates to achieve exhaust gas O₂ concentrations in the range of 1-17 % (v/v). The outcomes of this study indicated that any of the aforementioned parameters would not, in isolation, be sufficient for evaluating the degree of aerobiosis of a composting matrix. Comparatively speaking, the oxygen consumption rate was found to be the most useful for this purpose. A more extensive degree of aerobiosis was observed at RQ values less than 0.8.

2. INTRODUCTION

Automatic process control for composting has principally involved feedback control actions based on temperature of the material and/or macropore oxygen concentration considerations. Macropore oxygen concentration has conventionally served as an indicator of compost matrix aerobiosis owing to, among others, the lack of alternative practical means for measuring the degree of aerobiosis. In this work, the term aerobiosis refers to whether the oxygen amounts solubilised, and thus available to the micro-organisms present in the biofilm, are capable of supporting aerobic metabolism. Further, various degrees of aerobiosis may be defined, zero being the one which corresponds to absolute lack of aerobic microbial metabolism.

Oxygen macropore concentration is certainly a determinant of matrix aerobiosis, by virtue of its impact on the oxygen diffusion driving force, i. e., the oxygen concentration differential between the biofilm and macropore environments. However, other factors are of an equal, if not a greater, importance. Compost particle thickness, porosity (as affected by the amount of free water and particle size) and temperature are additional factors thought to substantially influence the degree of aerobiosis of a composting matrix (Richard, 1997; Haug, 1993).

The microbial respiratory quotient (RQ = mole CO₂ produced/mole O₂ consumed) is known to be different under aerobic rather than under anaerobic conditions and thus may be a lumped parameter for monitoring matrix aerobiosis (Moore, 1958; Glathe and Farkasdi, 1964; Richard 1997).

Oxygen uptake rate depends on the structural and chemical characteristics of the substrate, the substrate's availability, and the intensity of the microbial activity. Oxygen consumption represents that part of substrate oxidised to carbon dioxide and water as well as the fraction converted to cell substances (Varma and Raid, 1965).

The aim of this work was to investigate the utility of the exhaust gas O_2 concentration, and the microbial RQ and oxygen consumption rate (OCR) in evaluating the degree of aerobicisation of a composting matrix.

3. MATERIALS AND METHODS

3.1 Experimental System

The reactor system, shown in Figure 1, was designed to maintain targeted environmental conditions throughout the composting material. Cylindrical stainless steel vessels with a diameter of 21,5 cm, a height of 50 cm and a working volume of approximately 14 litres were used as reactors.

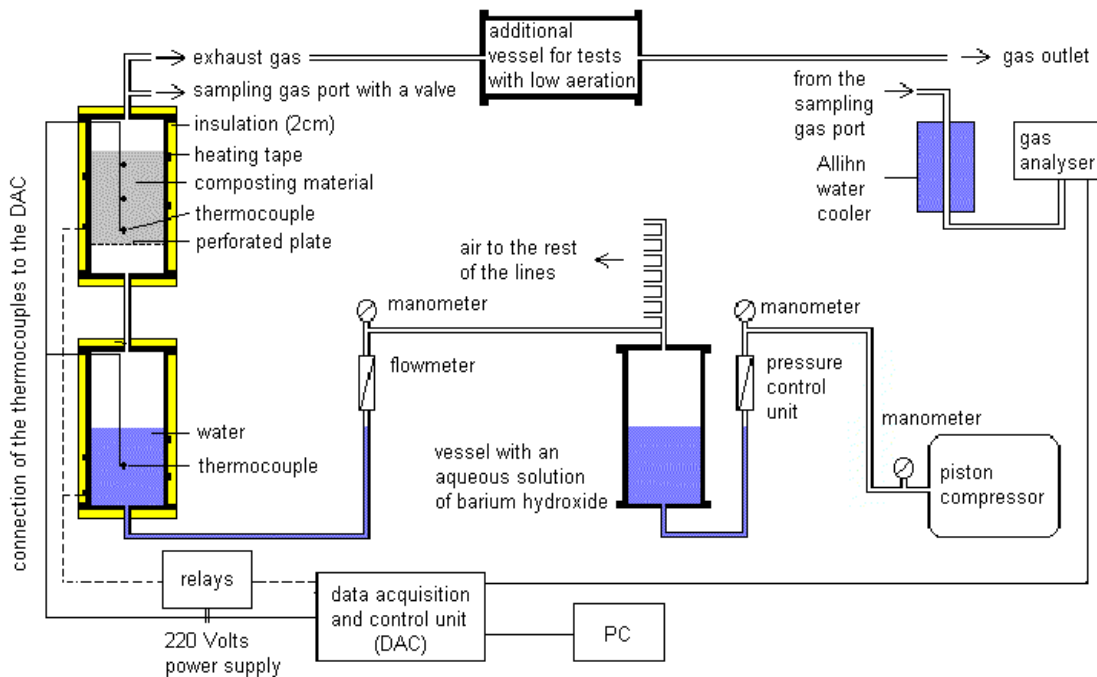


Figure 1. Schematic representation of the experimental system

The container walls of all vessels were wound with heating tape (type WB/202/100/0027, output 300 W), and then wrapped with an ISOVER™ rockwool layer. An orifice on the base served as the air inlet and another orifice on the lid of the vessel served as the exhaust gas outlet.

These reactors were arranged in eight lines (Fig. 1). Each line consists of two air-tight containers connected to each other by insulated plastic tubes. Each lid and base were made air-tight by using screws. All pipes connecting the air pre-conditioning vessels with the reactors were insulated with tube insulation material. The air flow rate was separately adjusted

for each line by using manually-adjusted flow meters with different ranges (purgemeter, model 10A4161F, tube FP-1/4-41-G-P-3/37, float FP-SS-14 with a range from 4 to 38 l/min; tube FP-1/8-20—P-3/37, float FP-CA-18 with a range from 0.6 to 4.4 l/min; and tube FP-1/8-08-P-3/37, float FP-CA-18 with a range of 0.15 to 1.3 l/min). Manometers to observe and adjust the incoming air pressure were also used. Oxygen was supplied as air, employing a piston compressor.

The compressed air had to bubble through a separate vessel filled with approximately 16 litres of saturated aqueous solution of barium hydroxide to remove the carbon dioxide content of the incoming air. In a subsequent vessel, the incoming air was saturated with water and brought to the temperature level of the material contained in the reactor into which air was subsequently introduced. The temperatures in the pre-conditioning vessels was slightly higher (2 - 4°C) to compensate for heat losses.

The reactor vessels were equipped with three thermocouples. They carried a perforated plate 10 cm above the base to support the composting material and also assist in evenly distributing the inlet air through this material. The rim of this plate touching the side wall of the vessel was made air-tight by silicone to avoid preferential airflow paths through the composting material and along the reactor walls.

Each exhaust gas pipe had a junction, using a valve, (2/2 way magnetic valve 1/4 M214) to drive the sampling gas to an oxygen and carbon dioxide analyser (TAD Ltd. model GD02 O₂ and GD02 CO₂). The sampling port valves were connected to relays to control automatically the sampling frequency and duration by using a PC.

All thermocouples and heating tapes were connected to the data acquisition and control unit (HP 3852A) and from this unit to the same PC.

The data acquisition unit operated the flow-through valves by relays which successively sampled the reactors on a given time interval.

The software program Labview™ was employed to monitor, control and record experimental data on oxygen and carbon dioxide concentrations as well as temperature measurement and control.

3.1 Materials and Experimental Trials

The material used for the experiments originated from a commercial composting plant. The plant treated a mixture of source-separated household organic waste and green waste in 7-day period in tunnel-like containers featuring an automatic temperature and oxygen control regime. Shredded wood bark was added to the mixture of household organic and green waste (20% on a volume basis) to improve the structural characteristics of the feedstock.

For the requirements of the laboratory tests, the processed material was brought to the laboratory and stored there for 12 to 72 hours thinly spread on a plastic pad on the floor, under ambient conditions. Before launching a trial, the processed waste was manually re-mixed and its moisture content was adjusted to the desired level. If necessary, additional wood chips, up to 10 % (v/v), were added to improve its porosity and structural integrity.

Usually 4.5 to 6,0 kg, i.e. approximately 10 to 12 litres, of material were placed in each reactor. Some major characteristics of the starting and treated material of the trials are given in Table 1. At the end of the trials the material had similar moisture content levels to those at the start. This indicated that the humidifying system was working adequately. Initial and final pH values are shown in Table 1.

A first series of trials (T1) examined variable oxygen content. These trials were carried out at a temperature of 65°C and with oxygen concentrations in the range between 2 and 18 % (v/v). An amount of 10 % (v/v) wood chips was used as a bulging agent. The moisture content of the starting material was adjusted to approximately 54 % (Table 1).

A second series of trials (T2) was made featuring oxygen concentrations ranging from 2 to 18 % (v/v) and a starting material moisture content of 52 %. No bulking agent was added to the starting material in T2 trial series. In addition the material originated from a batch different than that of trial T1. T2 investigations took place at 50°C.

The work reported here is part of an extensive study which examined the impact of different moisture and temperature conditions as well as variable oxygen exhaust gas concentration on the RQ (Klauss, 1999). This paper discusses two selected runs which were considered to offer representative data.

Aeration and heating started immediately after closing the containers. Air supply was regulated manually so that certain oxygen concentrations in the exhaust gas were achieved. The experiments were carried out for 72 to 140 hours. Temperatures, oxygen and carbon dioxide levels were measured continuously and recorded in files at one-hour intervals. Temperature readings involved the average value of the readings of a set of three thermocouples located at different locations along the height of material during those one-hour intervals (Fig. 1).

To calculate the desired parameters, the following formulae and sources were used:

$$RQ = \frac{CO_{\text{evolved}}}{O_{\text{consumed}}} = \frac{CO_{2,\text{out}}}{20.95 - O_{2,\text{out}}} \quad [1]$$

where:

RQ is the Respiratory Quotient;

$CO_{2,\text{out}}$ is the exhaust gas CO_2 concentration in % (v/v); and

$O_{2,\text{out}}$ is the exhaust gas O_2 concentration in % (v/v).

$$OCR = \frac{100 - \frac{O_{2,\text{out}} \cdot 100}{20.95}}{100} \cdot \frac{O_{2,\text{in}} \cdot 1000}{m \cdot VS / 100} \quad \text{in} \left[\frac{\text{mg } O_2}{\text{g VS} \cdot \text{h}} \right] \quad [2]$$

where:

OCR is the oxygen consumption rate;

$O_{2,\text{out}}$ is the volumetric exhaust gas oxygen concentration in per cent;

m is the mass of input material in grams; and

VS is the percentage of volatile solids initially present in dry matter.

$$O_{2, in} = \text{air}_{in} \cdot t \cdot \rho \cdot x \quad [3]$$

where:

air_{in} is the amount of air in litres per minute;

t are 60 minutes per hour;

ρ is the density of air: 1.197g/l at 1.0 bar and 18°C; and

x is the content of oxygen in environmental air: 23.15 [% mass].

Table 1. Characteristics of the material

Trial	Initial moisture content [%] ¹	Final moisture content [%] ¹	Initial pH	Final pH	Initial VS [%] ²	Final VS [%] ²
T1.1 (15-16%) ³	53.7	57.8	8.8	9.0	53.0	46.8
T1.2 (11-14%) ³	53.7	49.7	8.8	9.0	53.0	49.9
T1.3 (7-12%) ³	53.7	56.2	8.8	9.2	53.0	47.1
T1.4 (6-9%) ³	53.7	53.8	8.8	9.1	53.0	52.6
T1.5 (4-6%) ³	53.7	49.9	8.8	7.9	53.0	52.3
T2.1 (15-17%) ³	52.1	52.1	8.6	8.8	57.2	54.6
T2.2 (3-8%) ³	52.1	50.8	8.6	9.4	57.2	53.2
T2.3 (5-8%) ³	52.1	52.4	8.6	9.3	57.2	53.0
T2.4 (1-7%) ³	52.1	49.3	8.6	9.1	57.2	56.6
T2.5 (1-2%) ³	52.1	50.4	8.6	9.1	57.2	53.4

1. On wet matter basis.

2. On dry matter basis.

3. The values in brackets indicate the range of O_2 concentration in the exhaust gas for a given trial.

Moisture and volatile solids contents as well as other standard measurements were carried out and calculated according to FCQAO (1994).

The T1 runs were carried out for 83 hours. The corresponding inlet air flow rates are shown in Table 2.

Table 2. Aeration rates of the T1 trials (litres per minute)

Time period [hours] ¹	T1.1 (15-16%) ²	T1.2 (11-14%) ²	T1.3 (7-12%) ²	T1.4 (6-9%) ²	T1.5 (4-6%) ²
0 - 3	3,52	1,32	0,44	0,88	0,68
3 - 6	3,96	1,32	0,88	0,88	0,68
6 - 8	4,46	1,32	0,88	0,88	0,68
8 - 14	4,40	1,32	0,88	0,88	0,68
14 - 17	4,40	0,88	0,88	0,88	0,54
17 - 38	3,08	0,88	0,88	0,88	0,27
38 - 83	1,76	0,66	0,44	0,66	0,27

1. Time from the onset of a trial, i.e., following the end of the microbial acclimatisation period.

2. The values in brackets indicate the range of O_2 concentration in the exhaust gas for a given trial.

The T2 experiments were executed for 74 hours. Employed inlet air flowrates are listed in Table 3.

Table 3. Aeration rates of the T2 trials (litres per minute)

Time period [hours] ¹	T2.1 (15-17%) ²	T2.2 (3-8%) ²	T2.3 (5-8%) ²	T2.4 (1-7%) ²	T2.5 (1-2%) ²
0 - 5	1.98	0.88	1.32	0.68	0.54
5 - 19	3.08	0.88	1.32	0.68	0.54
19 - 51	3.08	0.88	1.32	1.08	0.54
51 - 66	2.64	0.88	1.32	0.54	0.54
66 - 74	2.64	0.88	1.32	0.54	0.27

1. Time from the onset of a trial, i.e., following the end of the microbial acclimatisation period.

2. The values in brackets indicate the range of O₂ concentration in the exhaust gas for a given trial.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 T1 Trials

Figure 2 shows the RQ profile between the 12th and the 40th hour of the T1 trials. The first 12 hours were supposed to be needed for the adaptation of the microbial population to the conditions in the reactors while after the 40th hour the RQ remained mainly in the same range (data not shown). The material with different oxygen exhaust gas concentrations had RQ levels mostly between 0.6 and 0.9. This may well indicate a high degree of aerobiosis according to other investigations (Wiley and Pierce, 1955; Schulze, 1960; Atkinson, 1996).

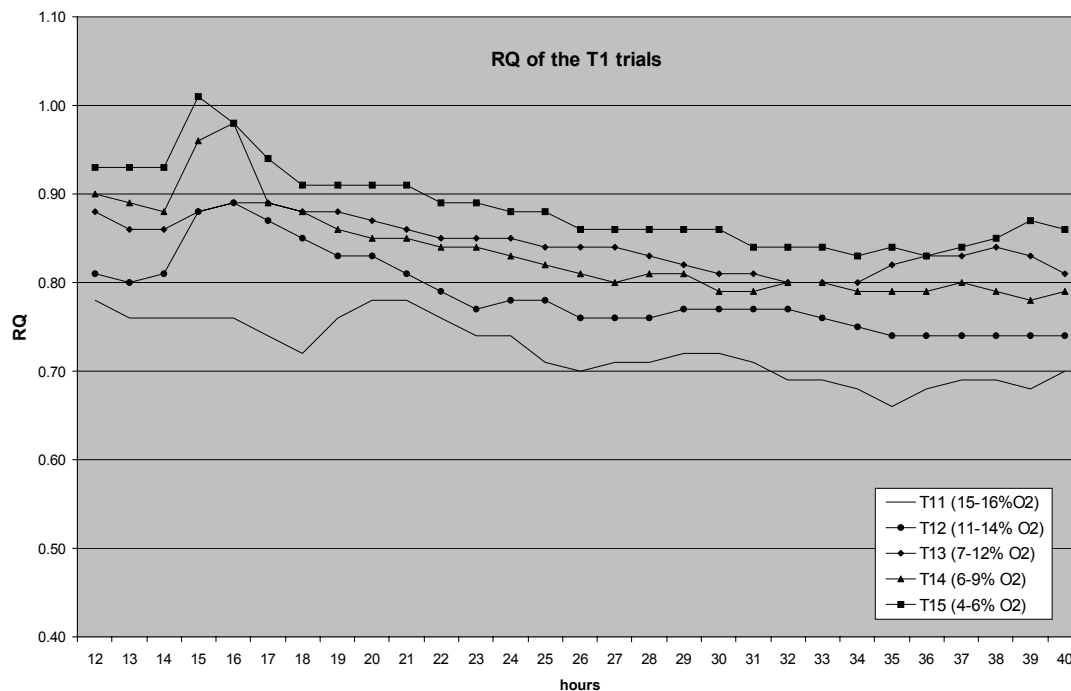


Figure 2. RQ evolution of the T1 trials

However, even material supplied with a relatively low amount of air (i.e., 0.3 to 0.7 litres per minute) did not achieve RQ values above one that would indicate anaerobic conditions for this stage of a composting process (Glathe and Farkasdi, 1960). It is interesting to note that the RQ peaks which occurred for oxygen concentrations between 4 and 14% (v/v), early during the trials, were not observed in the run featuring an exhaust gas oxygen con-

centration of 15 to 16% (v/v). Further, the RQ for the trial at approximately 15 % O_2 concentration was the lowest compared to the RQ readings in the trials conducted at an O_2 concentration less than approx. 13 %. This fact, along with the fact that the OCR of the 15 % O_2 concentration trial was distinctively higher than the OCRs of the trials conducted at an O_2 concentration less than approx. 13 %, indicates that exhaust gas O_2 concentrations less than 13 % resulted to a relatively lower degree of aerobiosis, under the conditions of this study.

Instant OCR peaks in Figure 3 indicate a change of aeration intensity. The highest OCR were achieved by the material treated with an oxygen exhaust concentration of around 15% (v/v) that achieved a plateau value of around 4.5 $mg O_2 / (g VS h)$ following a 20 hour processing period. The OCR of experiments conducted at oxygen concentrations between 6 and 14% O_2 did not differ significantly and achieved values between 2.5 and 3.5 $mg O_2 / (g VS h)$. These results may indicate that the microbial activity despite the different oxygen (macropore) conditions was nearly identical for this range of oxygen concentration. At oxygen exhaust concentrations between 3 and 6 % (v/v) very low OCRs of around 1 $mg O_2 / (g VS h)$ were reached indicating a substantially lower aerobic microbial activity. In this case, examining the RQ value, in isolation to the OCR, would lead to an imprecise judgement of the degree of aerobiosis of the matrix.

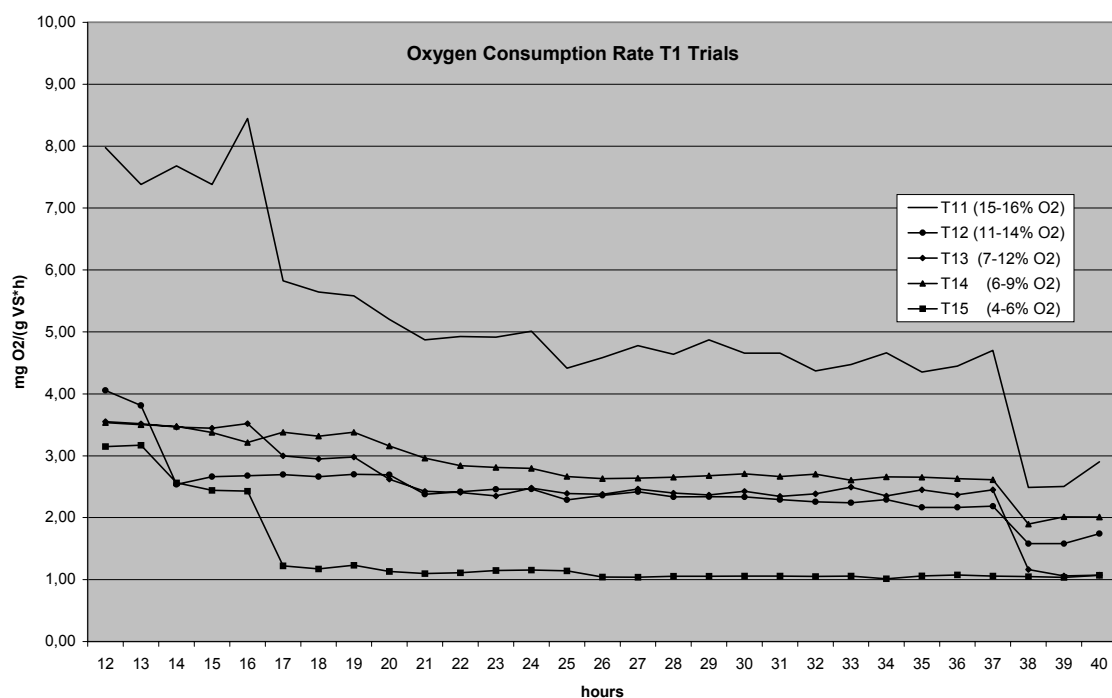


Figure 3. OCR evolution of the T1 trials

It was to be expected that material with high aeration rates would have a higher decomposition expressed in the OCR than the material with a very low oxygen concentration but the oxygen consumption rates did not change significantly at oxygen exhaust concentrations between 6 and 14%. This may indicate that exhaust gas oxygen concentrations between 6 and 14% (v/v) influence the aerobic microbial activity in a similar way. Taking into account the differences in the oxygen uptake rate between reactors featuring an oxy-

gen concentration higher than 13% (v/v) and those less than 13% (v/v) and also the RQ differences of the same reactors it was concluded that the process inhibitions for this material occurred at oxygen exhaust gas concentrations less than 13% (v/v). This may be attributed to the fact that, despite O_2 concentrations in the exhaust gas being similar, oxygen and carbon dioxide concentrations may deviate considerably at microsite level (Harper et al., 1992).

As expected, volatile solids loss was generally lower with lower aeration.

4.2 T2 Trials

RQ levels between 0.90 and 1.0 were achieved for all lower oxygen concentrations, the experiment with high oxygen exhaust concentrations of around 16% (v/v) achieved the lowest RQ levels of around 0.7 which confirms aerobic processing (Fig. 4). Even though the RQ levels of the experiments conducted at O_2 concentrations in the range of 1-8 % did not exceed the value of 1 one, their considerable difference to the RQ of the trial conducted at an O_2 concentration of approx. 16 %, strongly indicates a reduced degree of aerobiciosis. This assumption was confirmed by odour production and the lumpy structure of the material observed on emptying the reactor.

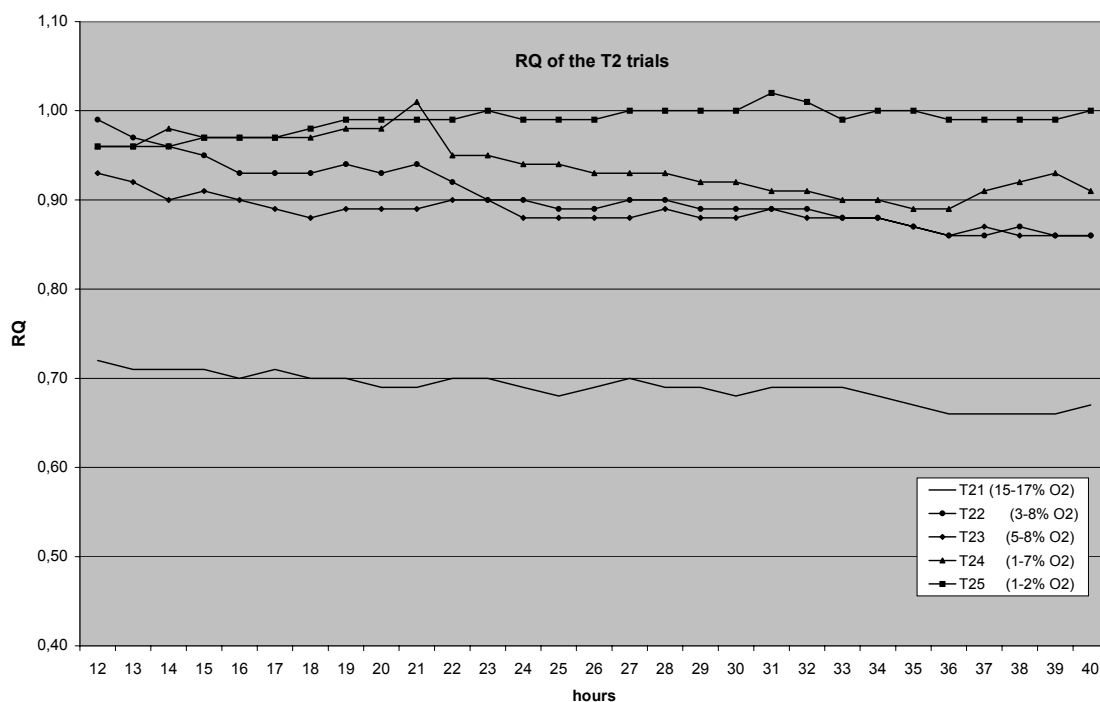


Figure 4. RQ evolution of the T2 trials.

Oxygen consumption rates between 3 and 6 mg O_2 / (g VS h) were achieved which decreased slowly with the processing time (Fig. 5). The material with an oxygen exhaust concentration of approximately 16 % (v/v) achieved, a lower OCR than the materials processed with half of this oxygen concentration. This may have been caused by channelling of

the air between the material outer surfaces and the reactor walls, thus resulting in oxygen starvation within the material.

The relatively high RQ values of this trial may be explained by assuming that the carbon dioxide is slowly released from the macropores as a result of a poor air penetration.

The occurrence of lower oxygen uptake rates at relatively high oxygen exhaust gas concentrations was also observed in several other trials carried out alongside these experiments (Klauss, 1999).

Similarly to trial T1, the T2 trials indicated a lack of preciseness of the RQ in judging the degree of aerobiosis, when the RQ was not considered in conjunction with the OCR.

The loss of volatile solids of the T2 trials was higher at intermediate exhaust oxygen concentrations (Table 1).

Concerning the assessment of the degree of aerobiosis by merely examining the exhaust gas O_2 concentration, both the T1 and T2 trials indicated that this parameter would not be sufficiently precise.

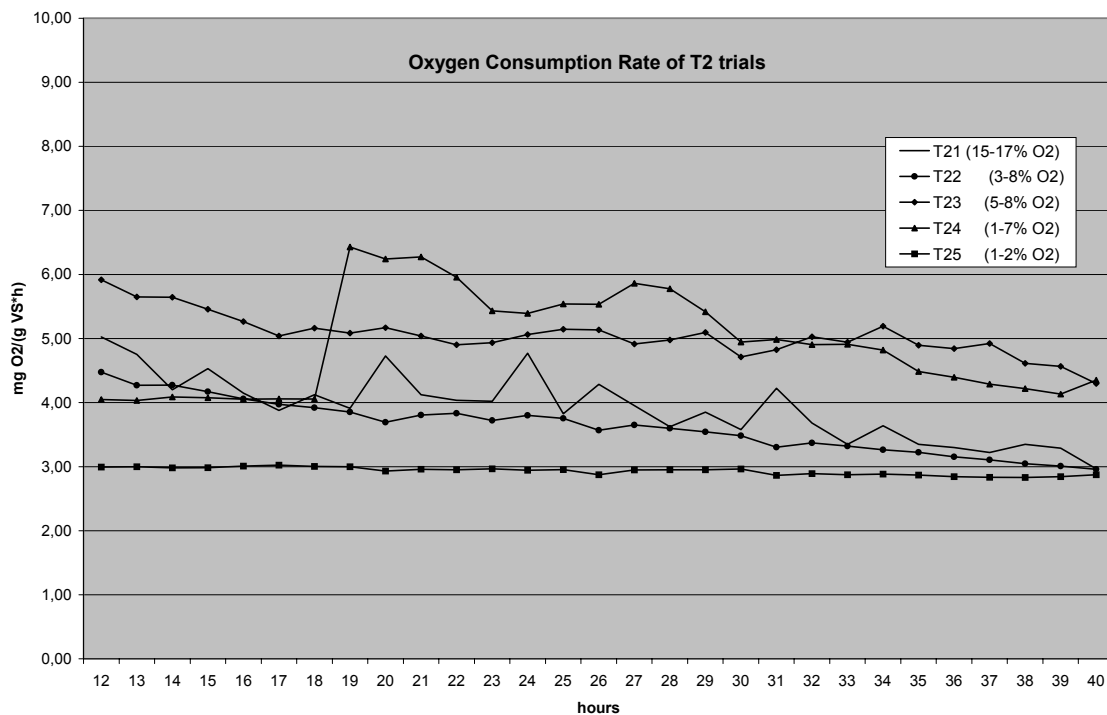


Figure 5. OCR evolution of the T2 trials

5. CONCLUSIONS

Using the exhaust gas O_2 concentration, the RQ, or the OCR, in isolation to each other, to evaluate the degree of aerobiosis may lead to incorrect deductions. However, the OCR seems to have a higher sensitivity and preciseness for this purpose, compared to the exhaust gas O_2 concentration and the RQ.

For the conditions of this study, a higher degree of aerobiosis occurred at RQ levels less than 0.80.

6. ACKNOWLEDGEMENTS

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