Pergamon

Wat. Sci. Tech. Vol. 29, No. 7, pp. 81–90, 1994.

0273–1223/94 $7·00 + 0·00

0273-1223(94)00159-6

SEQUENCING BATCH REACTOR: A TOOL FOR WASTEWATER CHARACTERIZATION FOR THE IAWPRC MODEL

M. Torrijos*, R.-M. Cerro*, B. Capdeville**, S. Zeghal***, M. Payraudeau† and A. Lesouef***

** IDE Environnement, Av. G.-Latécoère, BP 4204, 31031 Toulouse Cedex, France*
*** URTB, Department GPI, INSA, Avenue de Rangueil, 31077 Toulouse Cedex, France*
**** Anjou-Recherche, Chemin de la Digue, BP 76, 78600 Maisons Laffitte, France*
† OTV, Le Doublon, 11 Avenue Dubonnet, 92407 Courbevoie Cedex, France

ABSTRACT

The use of a sequencing batch reactor (SBR) for wastewater characterization requires the interpretation of the total respirometric response obtained in batch culture with primary settled water. In a first step and with the aim of understanding this total response, the water was divided by filtration into three fractions,the respirometric responses of which were analysed separately. This paper presents the results of the study of the biodegradability and of the specific respirometric responses of the soluble and colloidal fractions of an urban wastewater during batch cultures with a high concentration in pre-acclimatized activated sludges (low So/Xo ratio). For the water studied, the soluble fraction could be divided in two fractions of equal size : a readily biodegradable fraction and an inert fraction. Ultra-filtration of the soluble fraction during the cultures allowed stating the specific evolution of the soluble organic compounds according to their Molecular Weight. For the colloidal fraction, the observed behaviour was totaly different. Indeed, the colloidal organic matter disappeared very quickly from the liquid phase according to a physical phenomenon but without any important biological oxidation during the first 5 hours of a batch culture. Latest work concerns the study of the particulate organic matter and the interpretation of the total respirometric response knowing the specific response of the three fractions.

KEYWORDS

Sequencing Batch Reactor, Urban wastewater, Characterization, Activated sludge, IAWPRC model No 1, Mathematical modelling, Respirometry, Biodegradability, Ultrafiltration.

INTRODUCTION

The simulation models of activated sludge systems, such as the IAWPRC model (Henze et al, 1987) or the SIMBAD model (Lesouef et al, 1992), are structured on the basis of the division of the wastewater into various fractions according to the physical state of the components (soluble and particulate) and to their biodegradability. The following fractions can be defined : soluble readily biodegradable, particulate slowly biodegradable, soluble and particulate unbiodegradable fractions, etc.

The use of the simulation models requires the characterization of the wastewater including, especially, an estimation of the concentration of the various fractions and the assay of a number of stoichiometric and kinetic parameters. It appears from the use of the models that the results of the simulations achieved with the models are tighly linked to the estimation of the concentration of the fractions. The existing methods for wastewater characterization are often based on lengthy respirometric techniques which generally require the utilisation of continuous pilot plants with demanding maintenance.

This work, the first results of which are published here, was carried out in the framework of a research program aimed at developing an experimental method which would allow the characterization of a wastewater in a short time and with a low sample volume, by the use of a Sequencing Batch Reactor (SBR). By successive batch cultures with biomass reuse, this reactor allows the activated sludge to become acclimatized to the effluent during the first batch cultures then, in a second step, the degradation of the organic matter to be studied from the respirometric response.

To understand and interpret the total respirometric response obtained during a batch culture with primary settled wastewater, and with the aim of characterizing the various fractions from this total respirometric response, the organic matter of the wastewater was divided according to the Molecular Weight of its compounds, by filtration. The biodegradability of the organic matter of each sub-fraction was studied from the respirometric response and, when possible, by following the organic matter concentration. Three fractions were defined : (i) the soluble fraction (<0.1 µm) (ii) the colloidal fraction (0.1 µm< <50 µm) (iii) the particulate fraction (>50 µm). The thresholds of filtration were chosen according to the data in the literature (Levine *et al.*, 1985; Amy *et al.*, 1987; Nielsen *et al.*, 1992) and according to the filtration capacity of the existing filtration apparatus most commonly used in practice.

The results presented in this paper were obtained during separate studies of the biodegradability of the soluble and colloidal fractions of a settled urban wastewater. This study was achieved after the automation of the SBR and the determination of the optimal operating conditions.

MATERIAL AND METHODS

Sequencing batch reactor :The SBR pilot unit included an agitated, aerated, thermostatically controlled reactor. The total volume was 6.8 litres and the working volume 3 litres. With the aeration and stirring conditions used, the k_La of the batch cultures was close to 25 h^{-1}. The reactor was connected to a computer for data acquisition and reactor monitoring.

Continuous reactor : The reactor had a working volume of 7 litres. It was connected to a secondary settling tank. This reactor was used as source of activated sludge for the batch cultures in the Sequencing batch reactor. The main operating conditions were : Sludge age : 3 days ; hydraulic retention time : 3.5 hours ; mass load : 0.45 gCOD/gSS.d.

Organic substrate preparation : Prior to any experiment, the raw wastewater drawn at the treatment plant was primary settled at the laboratory.

Soluble fraction : the primary settled water was first centrifugated at 4 500 rpm for 5 minutes and then ultra-filtrated on a tangential ultra-filtration Ultrasart mini modulus equipped with a polyolefin membrane of cut off threshold : 0.1 µm. The inlet pressure was 1 bar.

Colloidal fraction : The primary settled water was filtrated at 50 µm through a Sartopure PP capsule (Sartorius) then ultrafiltrated (UF) at 0.1 µm. When the UF filtrate reached 80% of the initial volume, the retentate was diluted with BOD_5 water up to the initial volume (washing) then ultra-filtrated again. After 3 successive ultra-filtrations and two washings, the retentate was recovered then diluted to the initial volume with BOD_5 water and served as the substrate for the batch cultures. The proportion of soluble compounds in the retentate was then negligible.

Ultrafiltration : Ultrafiltration of the samples withdrawn during the batch cultures was achieved with a 350 ml Amicon stirred cell equipped with Amicon-Diaflo membranes of the following cut off thresholds : 100 000, 50 000 and 3000 Daltons.

Measurements and analysis: Dissolved oxygen was measured with a YSI oxymeter model 58 equipped with a YSI probe model 5750, and pH with a Genos pHmeter model 3671 equipped with a Schott probe reference Gerät H6380. CO_2 concentration in the outlet gas was measured by a Fuji Electric infra-red analyser. The input air flow was controlled by a Bumskhort mass flowmeter. The COD concentration was measured according to the micro-method of Jirka et al (1975) and the suspended solids (SS) and volatile suspended solids (VSS) according to Standard Methods. TOC concentration was measured with a Dohrman DC 180 COT-meter. The kLa is measured in dynamic conditions according to the method used by Mota (1985).

RESULTS

The water which served as standard urban wastewater for this study came from the inlet of the wastewater treatment plant of the town of Labège (département of Haute-garonne, France) the capacity of which is 5000 inhabitant/equivalent. This water is an urban water without any food processing or industrial component. The primary settling of 2 hours was performed in a measuring cylinder, at the laboratory.

Beforehand, three successive batch cultures with sludges from the continuous pilot plant unit, run in the same operating conditions with biomass re-use (Sequencing batch cultures), had given identical respirometric responses. This result confirmed that the sludges from the continuous reactor fed with the wastewater of Labège were perfectly acclimatized to this water. The biodegradability of the soluble and colloidal organic matter was studied during the first culture in a stirred, aerated, thermostatically controlled reactor. The k_La measured for each culture was close to 25 h^{-1}. The initial loading rate of the batch cultures was between 0.05 and 0.1 mg COD/ mg SS.

Study of the Biodegradability of the soluble organic matter

The soluble fraction of the urban wastewater was made up of the filtrate obtained after tangential ultrafiltration of the water with a membrane of 0.1 μm porosity.

Figures 1 to 4 show an example of the results obtained during the biodegradation of the soluble fraction of the wastewater by activated sludges.

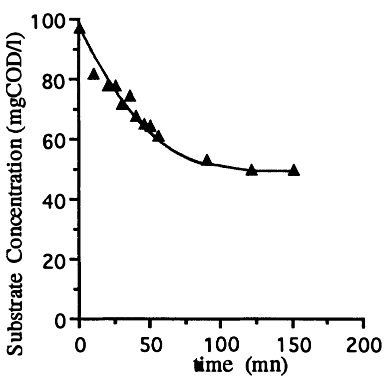

Fig. 1. Substrate concentration versus time for the soluble fraction.

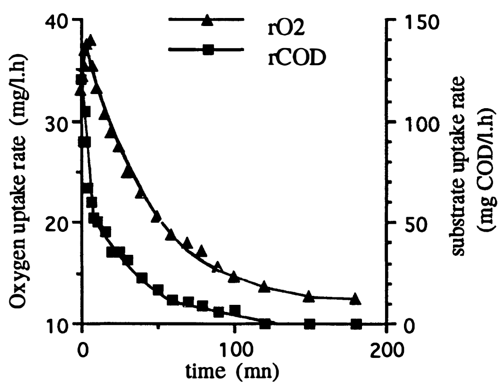

Fig. 2. Substrate and oxygen uptake rates versus time for the soluble fraction.

The changes of the soluble organic matter concentration (figure 1) and of the oxygen uptake rate (figure 2) versus time showed no latency period at the beginning of the culture. This confirmed that the activated sludges from the continuous pilot plant were perfectly acclimatized to the wastewater studied.
The initial concentration of soluble substrate was 97 mg COD/l. Globally, the consumption of biodegradable organic matter lasted between 120 and 150 minutes. Beyond this time, the soluble substrate concentration was constant (50 mg COD/l) and the oxygen uptake reflected the sole oxygen demand for endogeneous respiration.
With the high activated sludge concentration used in these cultures and the low initial concentration in organic substrate, (low ratio So/Xo), bacterial growth was negligible and the rate of consumption of the organic matter and the oxygen uptake rate were maximum during the first few minutes after seeding.

The curve representing the oxygen uptake rate versus the substrate uptake rate (figure 3) showed that at the beginning of the culture, the rate of disappearance of the substrate from the aqueous phase was higher than the rate of consumption of oxygen. This reveals that a part of the soluble substrate disappeared from the liquid phase according to a physical pattern either of adsorption on the flocs or of absorption by the bacteria but, in this case, without biological oxidation. Nevertheless, this phenomenon only concerned a very small proportion of the organic matter.

The regular decrease with decreasing concentration of biodegradable substrate, except for the first 5 minutes, of the curve of figure 4, which represents the changes of the specific uptake rate of oxygen versus the remaining quantity of biodegradable organic matter, shows that the degradation of the organic matter occurred in quite a regular manner. This suggests that, contrary to what was observed by Sollfrank and Gujer (1991) for wastewater from Switzerland, the soluble fraction of the wastewater from Labège did not contain compounds with a low degradation rate (soluble, slowly biodegradable compounds).

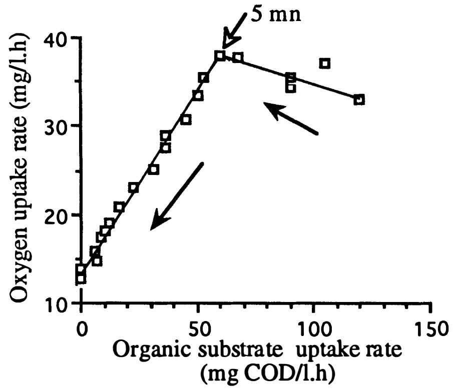

Fig. 3. Correlation between the oxygen and substrate uptake rates for the soluble fraction.

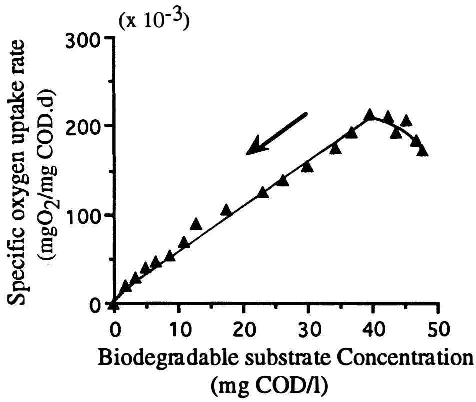

Fig. 4. Specific oxygen uptake rate versus the quantity of biodegradable substrate for the soluble fraction.

The characterization of the soluble organic matter of the urban wastewater of Labège was repeated 4 times with waters drawn over a period of one month, with the aim of establishing the average behaviour of the soluble fraction during its biodegradation by activated sludges. Table 1, which presents the main results, shows that : (i) the soluble organic matter was only slightly biodegradable since, on average, 51 % of the organic compounds were refractory even though the activated sludges were pre-acclimatized in a continuous pilot plant ; (ii) the distribution of the organic matter according to a criterion of biodegradability varied very little from one sample to another although the distribution of the size of the molecules was very different for the various samples (see table 2 below) ; (iii) the average biomass yield of 0.61 mg COD/mg COD, which was measured during these experiments, is very close to the values generally quoted in the literature for urban wastewaters : 0.666 (Ekama *et al.*, 1986) or 0.64 (Sollfrank and Gujer, 1991).

TABLE 1 Mean Results Obtained during Biodegradation of the Soluble Fraction

Initial quantity of soluble organic matter	104 mg COD/l (σ_n^* = 6)
Final quantity of soluble organic matter	53 mg COD/l (σ_n^* = 7)
Quantity of biodegradable organic matter	51 mg COD/l (σ_n^* = 5.3)
Quantity of oxygen consumed	19.6 mg O_2/l (σ_n^* = 2.8)
Quantity of organic matter consumed / Quantity of oxygen consumed	2.58 (σ_n^* = 0.15)
Y_H	0.61 (σ_n^* = 0.022)

* σ_n = Standard deviation

The study of the organic matter of the wastewater of Labège, which contains compounds of size smaller than 0.1 μm showed that this fraction in fact contained two fractions according to the IAWPRC or SIMBAD model : a biodegradable fraction in which the organic matter behaved in quite a homogeneous way and which, from the reaction kinetics can be qualified as rapidly biodegradable ; and a non-biodegradable or inert fraction. These results are in total agreement with the hypotheses which were made about the soluble organic matter when the IAWPRC model was devised (IAWPRC Activated sludge model, Report No 1, 1986).

Although the filtration thresholds used by various authors to define the upper limit of the soluble fraction are lower than the threshold that we used (0.1 μm), the homogeneous behaviour observed during the biological oxidation of the biodegradable organic matter showed that the threshold chosen was quite acceptable in the framework of our application and did not need to be re-defined.

Detailed study of the biodegradability of the soluble organic matter according to the Molecular Weight of the compounds

The soluble fraction defined previously contains molecules of variable sizes, including large molecules close to the colloidal state and very small dissolved molecules. All these compounds are likely to show great differences in their biodegradability. However, the measurements of the COD concentration of the soluble fraction only give global information on the behaviour of the soluble organic matter and do not allow any conclusion to be drawn about the specific biodegradability of the organic compounds.
Therefore, during the experiments described in the first part, the biodegradation of the organic compounds was studied more precisely by fractionation on ultrafiltration membranes. Ultrafiltration is a suitable technique for studying the distribution of the organic matter of urban wastewaters since it does not require any pre-treatment likely to bias the results (for example, by precipitation of some molecules).
An agitated Amicon type 8400 cell was used with ultra-filtration membranes of 100 000, 50 000 and 3 000 Daltons. This allowed 4 sub-fractions to be defined : (i) 0.1 μm-100 000 Da (ii) 100 000-50 000 Da (iii) 50 000-3 000 Da (iv) < 3 000 Da.
The samples withdrawn during the batch cultures were successively ultrafiltrated on the 3 membranes by decreasing porosity. After each ultrafiltration, the quantity of organic matter remaining in the filtrate was measured. The quantity of organic matter retained on the membrane was determined by difference of the concentrations before and after ultrafiltration.

Table 2 shows, for three batch cultures, the distribution of the soluble compounds of the urban wastewater of Labège according to the Molecular Weight , before biodegradation and after 3 hours of biological oxidation by activated sludges.
With reference to the wastewater organic matter before biological treatment,it appears that : (i) the distribution of the Molecular Weights of the soluble compounds can vary considerably for the wastewater of the same water treatment plant (ii) The molecules of Molecular Weight lower than 3 000 Daltons always account for a large fraction of the organic matter (between 45 and 90 %) (iii) the soluble organic matter also contains compounds with a high Molecular Weight in a fraction that can be considerable. However, the sub-fractions 100 000-50 000 Daltons and particularly 50 000-3 000 Daltons generally represent a small fraction of the total soluble carbon.

TABLE 2 Initial and Final Composition of the Soluble Fraction

		A	B	C	D
	< 0.1 µm	37.3	59 (<0.45µm)	37.8	41.5
Initial	0.1 µm-100 K	9.5 (25%)	12.3 (21%)		6.9 (17%)
Composition	100 K-50 K	3.6 (20%)	17.2 (29%)	3.6 (9.5%)	2.1 (5%)
(mg TOC /l)	50 K- 3 K	1 (3%)	2.9 (5%)		2.1 (5%)
	< 3 K	23.3 (62%)	26.6 (45 %)	34.2 (90.5%)	30.4 (73%)
	< 0.1 µm	18	16	19.4	24.1
Final	0.1-100 K	3.9 (21.5%)	3.2 (20%)		2.6 (11%)
Composition	100K-50K	1.1 (6%)	4.5 (28%)	3.4 (17.5%)	1.5 (6%)
(mg TOC/l)	50 K- 3 K	1 (6%)	0 (0%)		0 (0%)
	< 3 K	12 (66.5%)	8.4 (51%)	16 (82.5%)	20 (83%)

After 3 hours of biodegradation in aerobic conditions, the total concentration of the soluble organic matter had been reduced by half, but the distribution of the refractory organic compounds was always very close to the initial distribution of the organic matter before biological oxidation. The changes with time of the carbon concentration of the 4 sub-fractions defined by ultra-filtration (figure 5) demonstrated this phenomenon. The sub-fractions evolved with the same pattern and, therefore, the proportion of each sub-fraction in the total concentration remained constant at any time. Table 3 shows that the amount of organic matter degraded in the various sub-fractions only depends on the initial concentration. Furthermore, the level of participation of high Molecular Weight compounds (over 50 000 Daltons) in the global biodegradability of the soluble fraction of the wastewater , although variable, was generally not negligible and could account for up to 50 %.
It appears, then, that the small molecules are not preferably degraded and that the residual organic matter is not mainly made up of high Molecular Weight molecules.
Beyond 3 hours , the concentration of the liquid phase did not vary significantly. This showed that the biological reaction was over.

For the organic compounds with a size smaller than 0.1 µm,the results show clearly that the Molecular Weight parameter plays only a minor role in the determination of the biodegradability. This suggests that other parameters, such as the chemical nature and the molecular structure have a much more important impact on biodegradability.

TABLE 3 Distribution of the Biodegradable Organic Matter of the Soluble Fraction.

		A	B	C	D
Organic matter	> 50 K	8.1 (42%)	21.8 (51%)	0.2 (1%)	4.1 (28%)
consumed (mg TOC/l)	< 50 K	11.2 (58%)	21.1 (49 %)	18.2 (99%)	12.5 (72%)

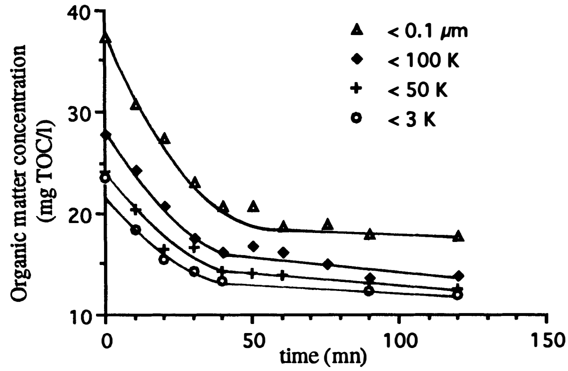

Fig. 5. Organic matter concentration after ultrafiltration versus time.

Study of the biodegradability of the colloidal organic matter

The colloidal fraction of an urban wastewater was defined as the fraction containing compounds having sizes between 0.1 µm and 50 µm. In a first step, the biodegradability of the colloidal organic matter was studied in batch culture with the colloidal fraction alone (retentate obtained after ultrafiltration at 0.1 µm of water prefiltered at 50 µm). In a second step, the study of the soluble and colloidal fractions (water filtered at 50 µm) and the comparison with the results obtained with the soluble fraction alone allowed us to check the conclusions of the study of the colloidal fraction alone.

For samples taken during the batch culture, organic matter was systematically measured after prefiltration on Prolabo 08 32-01764 filters (concentration of soluble and colloidal compounds) and after filtration at 0.1 µm (concentration of soluble compounds).

The response obtained when the colloidal fraction alone, concentrated twice, was brought into contact with activated sludges is shown in figures 6 to 8.

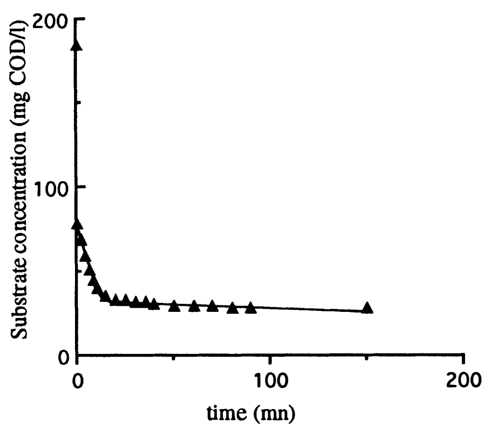

Fig. 6. Concentration of organic matter versus time for the colloidal fraction.

At the beginning of the culture, the colloidal organic matter disappeared very rapidly from the aqueous phase. This is shown by a sudden drop of the COD concentration from 184 mg/l to 35 mg/l in 15 minutes. This phenomenon is clearly demonstrated by the turbidity measurement. Indeed, it drops from 102 NTU before the addition of the activated sludges to 36 NTU immediately after seeding, then to 20 NTU at t = 50 minutes, the aqueous phase then being perfectly limpid.

At the beginning of the culture, the rate of disappearance of colloidal organic matter (600 mgCOD/l/h on the average for the first fifteen minutes) was much higher than the rate measured during the biological oxidation of the soluble organic matter (70 mgCOD/l/h on the average for the first fifteen minutes). This result is in agreement with the results published by Bunch and Griffin (1987) and suggests that the colloids disappear from the liquid phase according to a physical pathway, probably of adsorption on the flocs. The kinetics of this pathway are much faster than that of biological oxidation. Monitoring of the oxygen shows very low consumption. The oxygen used represents less than 10 % of the quantity of oxygen necessary for the biological oxidation of the organic matter which disappeared from the liquid phase. This shows that the colloidal organic matter did not undergo any great oxidation, at least during the first 5 hours.

The cultures performed with the wastewater containing both the soluble and colloidal fractions (filtered water at 50 µm), and the comparison with those with the soluble fraction alone confirmed the previous conclusions. In fact, the changes in the soluble and colloidal organic matter with the oxygen consumption showed that the curve obtained with the water filtered at 50 µm is very different from the curve obtained during the study of the soluble fraction alone (figure 7). On the other hand, still in the case of the water filtered at 50 µm, if only the soluble organic matter was taken into account, the correlation between the two previous parameters would be very close to the correlation obtained with the soluble fraction alone (Figure 8). These curves show that the surplus of oxygen consumed owing to the presence of the colloidal organic matter is very low and thus, that an important fraction of the colloidal compounds is not rapidly oxidized by the micro-organisms.

These results as a whole allow us to conclude that the colloidal compounds disappear from the liquid phase as soon as they are brought into contact with the activated sludges according to a very rapid physical pathway. During the first few hours, they participate only very little in the total oxygen demand for the oxidation of the biodegradable organic matter. More than 90 % of the oxygen consumed is used for the oxidation of the soluble organic matter. The proportion of rapidly biodegradable organic matter in the colloidal fraction is then very low.

The specific study of the biodegradation of the colloidal compounds for longer culture times (several hours or even several days) with the aim of assaying the concentration of slowly biodegradable organic matter of this fraction was not possible during these experiments. On the one hand the direct measurement of the concentration of the organic colloidal matter after adsorption on the flocs was not possible. On the other hand, the indirect assessment of the consumption of colloidal organic matter by monitoring the consumption of oxygen is not feasible in practice because of the low colloidal organic matter concentration in the wastewater (about 90 mgCOD/l) and the slow degradation rate of the colloidal compounds. These two parameters did not allow the oxygen demand for the oxidation of the colloidal organic matter to be separated from the oxygen demand for endogeneous respiration for long culture times.

The slowly biodegradable organic matter of the colloidal fraction will be studied next at the same time as the particulate fraction.

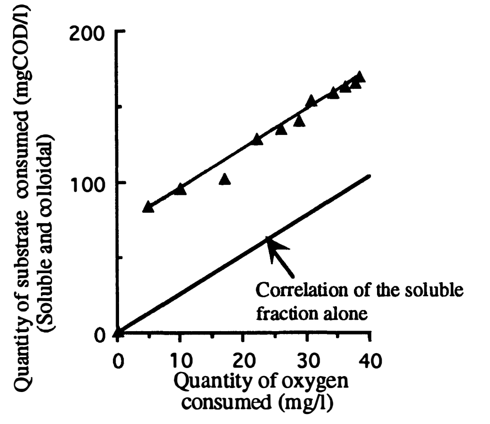

Fig. 7. Correlation between the total quantity of substrate (soluble and colloidal) and the quantity of oxygen consumed (wastewater filtered at 50 µm).

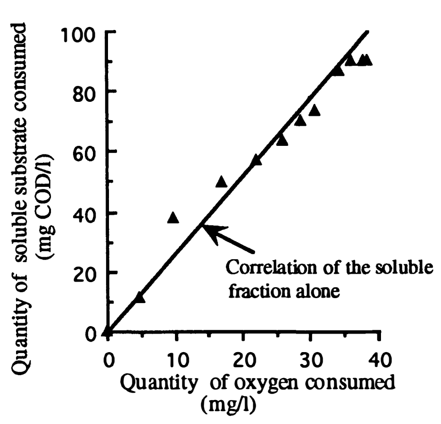

Fig. 8. Correlation between the quantity of soluble substrate and the quantity of oxygen consumed (wastewater filtered at 50 µm).

CONCLUSION

For the soluble fraction of the urban wastewater from the water treatment plant of Labège, which was isolated by filtration at 0.1 µm, two fractions could be defined according to the IAWPRC model for organic matter : (i) a non biodegradable fraction ; (ii) a biodegradable fraction which, from the kinetics of biodegradation measured could be qualified as rapidly biodegradable. These two fractions each account for about 50 % of the total soluble organic matter.

During the biological treatment, although half the organic matter was eliminated, the distribution of the organic matter of the urban wastewater according to the Molecular Weights of the compounds varied only very slightly. The soluble molecules of low Molecular Weight (< 3 000 Daltons), which always make up an important portion of the soluble organic matter, were not preferentially used as a carbon and energy source by the micro-organisms contained in the activated sludge. The compounds with Molecular Weights higher than 3 000 Daltons could represent up to 50 % of the initial biodegradable soluble organic matter.

With regard to the colloidal fraction, it was demonstrated that the colloids are eliminated very rapidly from the liquid phase at the very beginning of the culture according to a physical pathway, a priori of adsorption on the activated sludge flocs, without undergoing any important biological oxidation during the first hours of a batch culture.

Our most recent work shows that the colloidal and particulate compounds make up the slowly biodegradable fraction of the urban wastewater. Knowing the separate response of the three fractions, it is possible to interpret the global respirometric response obtained in batch culture with primary settled urban wastewater and thus to characterize the wastewater studied.
Further studies will focus on the acclimatization phenomenon using successive batch cultures. We aim at the validation of this tool for the characterization of urban wastewater .

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