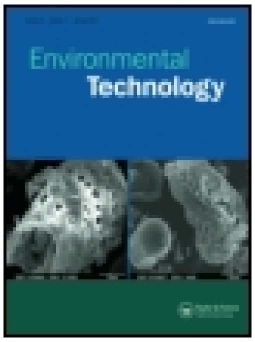

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EFFECT OF OZONATION ON THE BIOLOGICAL TREATABILITY OF A TEXTILE MILL EFFLUENT

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ABSTRACT

Ozonation, applied prior to biological processes, has proved to be a very effective chemical treatment step mostly for colour removal when soluble dyes are used in textile finishing operations. Its impact on biological treatability however has not been fully evaluated yet. This study evaluates the effect of ozonation on the quality of wastewater from a textile mill involving bleaching and reactive dyeing of cotton and synthetic knit fabric. The effect of ozonation on COD fractionation and kinetic coefficients defining major biological processes is emphasised. The results indicate that the extent of ozone applied greatly affects the remaining organic carbon composition in the wastewater. The relative magnitude of different COD fractions varies as a function of the ozone dose. Ozonation does not however exert a measurable impact on the rate of major biological processes.

Keywords: Biological processes, COD fractionation, ozonation, process kinetics, textile wastewater

INTRODUCTION

Appropriate treatment technology for textile mill effluents is generally defined as biological treatment or a sequence of chemical/ biological treatment, depending on the quality of the wastewater generated. The application of chemical treatment prior to biological treatment is used generally for two reasons: some types of dyes exert toxic effect on biological treatability [1, 2] or some may have low biodegradability. Reactive dyes are an example for the group of dyes which have a high inert fraction [3-5]. Recent studies have shown that ozonation increases the biological treatment efficiency by breaking down the molecular structure of dyes which resist biological degradation [3, 6-9]. Apart from easing the biological degradability [5-9], high colour removals can also be achieved with ozonation [10-15].

The concept of biological treatability has changed during the last decade. The determination of inert and biodegradable chemical oxygen demand (COD) fractions and the respirometric assessment of the coefficients of microbial growth kinetics in the context of multi-component activated sludge modelling gained an increasing importance. However, the effect of ozonation on biological treatability, on different COD fractions and its impact on biological processes incorporated into current activated sludge models has not been investigated. The main objective of the paper is to investigate the effect of ozonation on the biological treatability of wastewater from a textile mill involving bleaching and reactive dyeing of cotton and synthetic knit fabric. In this context, the fate of major COD fractions and especially inert COD components was studied. The effect of ozonation on the rate of major biological processes was experimentally evaluated using respirometry. The OUR profiles obtained in aerated batch reactors, before and after different ozone doses, were interpreted using model simulation. A multi-component model based on endogenous decay was used for this purpose.

PLANT DESCRIPTION

The investigated textile mill, is a plant that processes cotton and synthetic knit fabric and their blends. The main finishing operations involved in the production processes can be listed as; bleaching, kiering, reactive dyeing (with procion™ and remazol® dyes), disperse dyeing, soaping and softening. The annual production data based on the type of fabric manufactured is given in Table 1. All of the processes present in the plant are batch operations and seasonal variations are observed in terms of the amount and types of the fabric processed in the plant.

The detailed process profile of the mill has already been presented in the literature [16]. The plant involves 20 different processes, among which the following four were selected to

Table 1. Annual production data.

Production	Type of Knit Fabric Produced					
	Cotton	Viscose rayon	Polyester	Polyamide	Cotton-polyester blends	Polyester-viscose rayon blends
Amount (ton year^{-1})	1375	225	425	75	300	200
%	53	9	16	3	11	8

represent the overall effluent for this study: [A] *Cotton Knit Fabric Optical Brightening,* [B] *Cotton Knit Fabric 60 °C Remazol Dyeing with Kiering,* [C] *Cotton Knit Fabric 95 °C Procion Dyeing with Bleaching* and [D] *Viscose Rayon Knit Fabric 95 °C Procion Dyeing*. These four processes all appeared in day to day operations, corresponding to 55 % of the average total daily volume. The wastewater generation of the plant is given in Table 2. The average daily production was 10 tons and the water consumption was about 750 m^3 d^{-1}, with a wastewater generation of 72 l kg^{-1} fabric processed, in agreement with the values given in the literature [17, 18].

MATERIALS AND METHODS

Source-based wastewater samples were collected from each batch of the selected processes. A detailed wastewater characterisation was conducted on the segregated effluents in order to obtain the pollution profile. Two composite wastewater samples representing different dyes were prepared for characterisation, as mixtures of segregated wastewater streams in proportion to their relative flow rates in the processing scheme. The treatability experiments were conducted on one of the samples (sample no.2).

All analyses for conventional characterisation were performed as defined in *Standard Methods* [19]. Filtrates of samples subjected to vacuum filtration by means of Millipore membrane filters with a pore size of 0.45 µm were defined as "*soluble fractions*". The Millipore AP40 glass fiber filters were used for suspended solids (SS) and volatile suspended solids (VSS) measurements. COD measurements were accomplished by ISO 6060 [20] method.

Ozone used for the ozonation experiments was produced by means of a laboratory ozone generator PCI GL1. The experiments were conducted at 15 psi (103.45 kPa), using a sample of 1 litre in a 1.5 litres semi-batch bubbled gas washing bottle reactor with an effective depth of 23 cm. Ozone gas was supplied at the bottom of the reactor through a sintered glass plate diffuser. Two gas washing bottles, connected in series, containing 2 % KI solution were connected to the reactor for the determination of ozone output. All experiments were conducted at room temperature. pH adjustments were made by NaOH or H_2SO_4 solutions.

Biological treatability studies for the determination of COD fractions and kinetic coefficients were conducted on raw

Table 2. Wastewater generation.

PROCESS	Daily Production (kg fabric day^{-1})	Wastewater Generation (l (kg fabric)$^{-1}$)	(m^{3}d^{-1})	(%)
Cotton Knit Fabric				
[A] Optical Brightening*	**1700**	**40.0**	**68**	**9.1**
[B] 60°C Remazol Dyeing with Kiering*	**700**	**90.9**	**64**	**8.5**
[C] 95°C Procion Dyeing with Bleaching*	**2300**	**96.8**	**223**	**29.8**
Others	600	136.7	82	10.9
Mercerised Cotton Knit Fabric	100	50.6	5	0.7
Viscose Rayon Knit Fabric				
[D] 95°C Procion Dyeing*	**500**	**114**	**57**	**7.6**
Others	400	105	42	5.6
Polyester-Viscose Rayon Knit Blend	800	77.5	62	8.3
Polyester Knit Fabric	1700	25.3	43	5.8
Cotton-Polyester Knit Blend	1200	68.3	82	10.9
Polyamide Knit Fabric	300	36.7	11	1.4
Sugar Bleached, Mercerised Cotton Knit Fabric	100	110	11	1.4
TOTAL	**10400**	**72**	**750**	**100**

*Investigated processes

composite wastewater and on composite samples ozonated at three different doses. The particulate and soluble inert COD components, X_{I1} and S_{I1} of the wastewater were determined according to a recently proposed experimental procedure [21]. A method based on respirometric measurements was used for the assessment of the readily biodegradable COD, S_{S1} [22]. The respirometric experiments were conducted as batch tests with the seed biomass taken from a fill and draw reactor operated at a sludge age of 10 days and fed with a mixture of raw and ozonated wastewaters. The experiments were conducted in parallel sets of batch reactors having approximately the same F/M ratio of 0.6 g VSS (g COD)$^{-1}$. The pH in the reactors, was adjusted to approximately 7-7.5 and sufficient aeration was supplied in order to attain unlimited oxygen concentrations. OUR measurements were conducted with a WTW OXI DIGI 2000 oxygen meter. The determination of kinetic coefficients related to hydrolysis, were performed by curve fitting to experimental OUR profiles. AQUASIM [23] computer software program was used for modelling.

EXPERIMENTAL RESULTS

Conventional Wastewater Characterisation

Conventional characterisation was carried out on two composite samples prepared from individual process effluents mixed in proportion to their respective discharge rates. With sample no.1, the study was also conducted on single source-based samples of the selected four processes as well as on the composite mixture. Sample no.2 was subjected to further analysis for treatability. The results of the characterisation survey are given in Table 3.

The table shows that over 70 % of the wastewater total COD is of soluble (filterable) nature and the wastewater may be considered as nitrogen and phosphorus deficient, as is most similar textile effluents [16, 24]. The effect of two dyeing processes with dyes of different colours, represented in these composite samples is illustrated by their corresponding colour and chloride contents. In fact, the manufacturing scheme, where the amount of salt (sodium chloride) used is increased when dyes with darker colours are used clearly reflects on the character of the wastewater generated.

Ozonation Studies

Ozonation studies were performed in two stages. First, experiments were conducted on short ozone feeding times (5 minutes) at different ozone fluxes to identify the optimum ozone dosages for pre-ozonation application. The results of these studies [25] are summarised in Table 4.

The results in the Table indicate a threshold of utilised ozone level with respect to COD removals achieved. In fact, a total COD removal of 6 % was achieved with a utilised ozone of up to115 mg l^{-1}. When this level was increased to above 125 mg l^{-1}, a similar COD removal increase to 12 % was obtained. Therefore, an ozone flux of 62 mg min^{-1}, providing a utilised ozone level equal to or above 125 mg l^{-1}, was selected as the optimum value. As shown in Table 4, ozonation of the wastewater resulted in a high colour removal in the range of 25 to 86 % depending on the selected ozone flux, but the corresponding COD removal remained in the limited range of 4 to 14 %, indicating the existence of selectivity in ozone reactions.

In the second stage of the ozonation studies, experiments were conducted at four different ozone feeding times; 5, 10, 15 and 30 minutes at the selected optimum ozone flux (62 mg min^{-1}), as shown in Table 5. The long feeding time of 30 minutes was applied to illustrate the effect of extreme ozone dosage.

Table 5 shows that, as the ozone doses increase, a colour removal efficiency from 83 % to 94 % is achieved, on the other hand only a limited total COD removal is observed,

Table 3. Conventional wastewater characterisation.

PARAMETER	Composite 1					Composite 2
	Segregated Streams -Processes-				General Discharge	
	[A]	[B]	[C]	[D]		
Flow rate (m^3 d^{-1})	68	64	223	57	412	412
Total COD (mg l^{-1})	4740	830	670	730	1125	955
Soluble COD (mg l^{-1})	N.D	N.D	N.D	N.D	870	675
Colour (Pt-Co unit)	240	3695	140	105	720	540
TSS (mg l^{-1})	70	65	60	30	65	105
VSS (mg l^{-1})	60	30	35	30	40	80
Chloride (mg l^{-1})	240	6890	4195	1765	3460	1915
TKN (mg l^{-1})	20	22	10	16	14	14
TP (mg l^{-1})	12.5	10	12	32	13	15
pH	N.D	N.D	N.D	N.D	10.25	9.68

N.D: not determined

Table 4. Results of ozonation studies.

Ozone Flux (mg min^{-1})	Ozone feeding time (min)	Utilised Ozone (mg)	pH*	Total COD (mg l^{-1})	Total COD removal (%)	Colour (Pt-Co)	Colour removal (%)
-	-	-	9.68	955	-	540	-
7	5	30	9.60	920	4	405	25
14	5	55	9.47	915	4	340	37
18	5	60	9.52	915	4	270	50
29	5	75	9.44	910	5	200	63
38	5	85	9.49	905	5	150	72
44	5	100	9.50	895	6	130	76
48	5	105	9.46	905	5	115	79
57	5	115	9.53	900	6	100	81
57	10	220	9.29	805	16	55	90
62	5	125	9.40	845	12	100	81
65	5	130	9.45	830	13	80	85
68	5	145	9.39	825	14	75	86

*After ozonation

Table 5. Second stage ozonation studies.

Ozone Flux (mg min^{-1})	Ozone feeding time (min)	Utilised ozone (mg)	pH*	Total COD (mg l^{-1})	Total COD Removal (%)	Soluble COD (mg l^{-1})	Colour (Pt-Co Unit)	Colour Removal (%)
-	-	-	9.68	955	-	675	540	-
62	5	130	9.35	850	11	580	90	83
62	10	235	8.85	775	19	545	45	92
62	15	465	8.69	750	21	525	35	94
62	30	1385	8.08	650	32	480	30	94

*After ozonation

increasing from 11 % up to 32 %. This situation can be explained by the information given in the literature for the ozonation of textile finishing wastewaters, where the dominant mechanism of ozonation above pH 10.5 is the formation of radicals, leading to a non-selective oxidation [26, 27]. However, when the pH value is below 10.5 as in this case study, oxidation is achieved by the direct molecular reaction of ozone with organic compounds. Textile dyes, especially reactive dyes, have chromophore groups, which are linked to the dye molecule with C=C double bonds and molecular ozone initially reacts with this double bond selectively. Therefore, ozonation results in colour removal primarily, which is then followed by the removal of COD [8, 15].

The results may be further interpreted for the effect of ozone on soluble and particulate COD fractions. At a 5 minutes ozone contact time, the soluble COD achieved is 14 %, while that of particulate COD remains at 4 %. Increasing the ozone contact time to 30 minutes appears to affect more the particulate COD with a 39 % reduction, a higher level than 29 % associated with soluble COD.

Biological Treatability Studies

COD fractionation

This part of the experimental study aimed to identify the COD fractions in raw composite and ozonated samples in terms of their biodegradation characteristics. In this context, the total influent COD, C_{T1}, has been generally divided into two major components; the total inert COD and the total biodegradable COD. The total inert COD may be further subdivided into soluble inert COD, S_{I1}, and particulate inert COD, X_{I1}, both by-passing the system without affecting any biochemical reactions in the reactor. On the other hand, the subdivision of the total biodegradable COD covers basically two parts: the readily biodegradable COD, S_{S1} and the slowly biodegradable COD, which consists of soluble, S_{H1} and particulate parts X_{S1} based on dual hydrolysis models [28, 29]. Total and soluble COD fractions of the wastewater can be expressed with the following mass balance equations:

$$C_{TI} = S_{SI} + S_{HI} + S_{II} + X_{SI} + X_{II} \qquad \text{(i)}$$

$$S_{TI} = S_{SI} + S_{HI} + S_{II} \qquad \text{(ii)}$$

The experiments conducted for the determination of the inert fractions resulted in the simultaneous formation of colloidal particles in wastewater under aerobic conditions, thus increasing particulate organic matter concentrations were observed. This phenomenon was investigated by a set of experiments conducted on raw and filtered samples (through 0.45 μm cellulose acetate membrane filters), where one set of the samples was aerated while the other set was not, for 8 days without inoculation. At the end of the experiment, a particulate COD accumulation of 305 mg l^{-1} in the aerated reactor and 265 mg l^{-1} in the reactor without aeration was observed for the raw wastewater. For the filtered wastewater, the corresponding particulate COD increase was measured as 210 mg l^{-1} and 205 mg l^{-1} respectively. The observed particulate matter generation was suspected to have occurred as a result of interactions between chemicals used in different processes, although this remains to be clarified with further studies. Consequently, experimental assessment of the initial particulate inert COD, X_{I1} was not possible, due to particulate matter formation mentioned above and the experiment remained limited with the assessment of the initial soluble inert COD fraction, S_{I1}. Reported experimental data show, as given in Table 6, that the X_{I1}/C_{T1} ratio for similar wastewaters was small enough to be neglected in the evaluation of the OUR profiles through model simulation.

Since very close removal efficiencies were obtained for 10 and 15 minutes of ozonation, biological treatability experiments were conducted on 5, 10 and 30 minutes ozonated samples. The OUR profiles obtained for this study are shown in Figures 1, 2, 3 and 4. For the assessment of S_{S1} the heterotrophic yield coefficient was accepted as 0.7 g COD (gr COD)$^{-1}$ according to the results of previous studies conducted on the same wastewater [30].

Table 6. COD fractions in textile industry.

	C_{T1}	S_{S1}/C_{T1}	S_{H1}/C_{T1}	S_{I1}/C_{T1}	X_{S1}/C_{T1}	X_{I1}/C_{T1}	References
Polyester Knit Fabric	1985	0.15	0.39	0.21	0.19	0.06	[17]
Cotton Knit Fabric	1470	0.23	0.39	0.18	0.19	0.01	[17]
Cotton-Polyester Blend Knit Fabric	2400	0.07	0.53	0.10	0.25	0.05	[17]
Cotton Knit Fabric	2300	0.18	0.57	0.07	0.16	0.02	[31]
Cotton Knit Fabric	955	0.09	0.28	0.34	0.29	-	This study

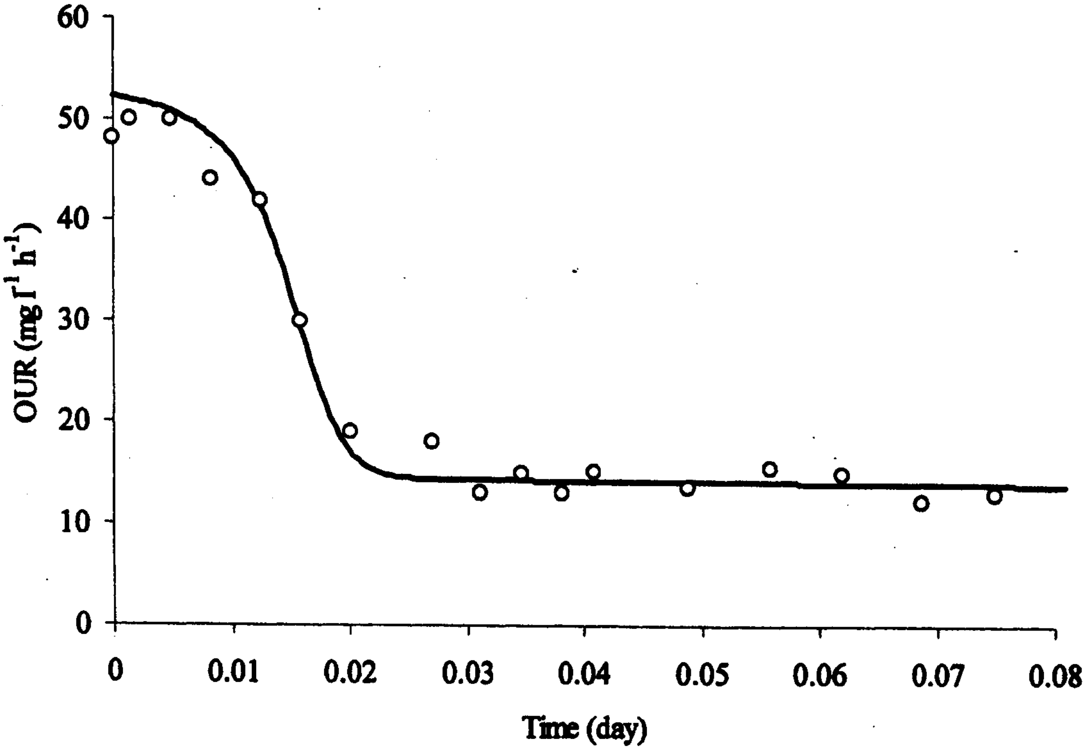

Figure 1. OUR profile for the raw composite wastewater (data o; model —).

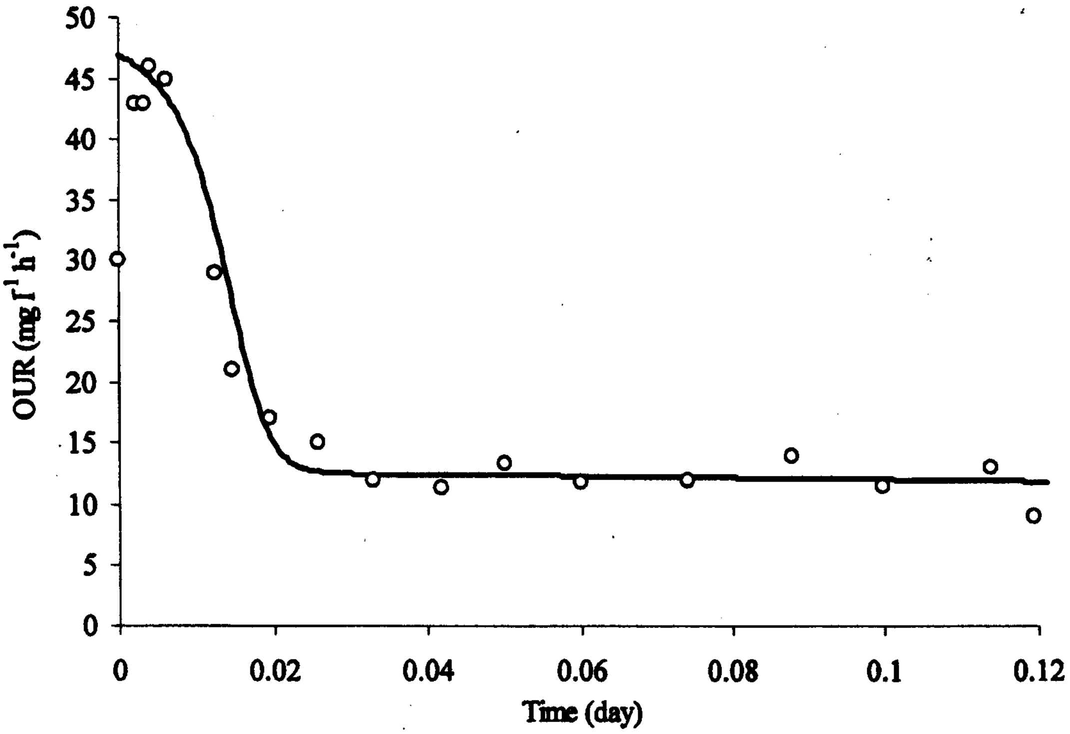

Figure 2. OUR profile for the 5 min. ozonated sample (data o; model —).

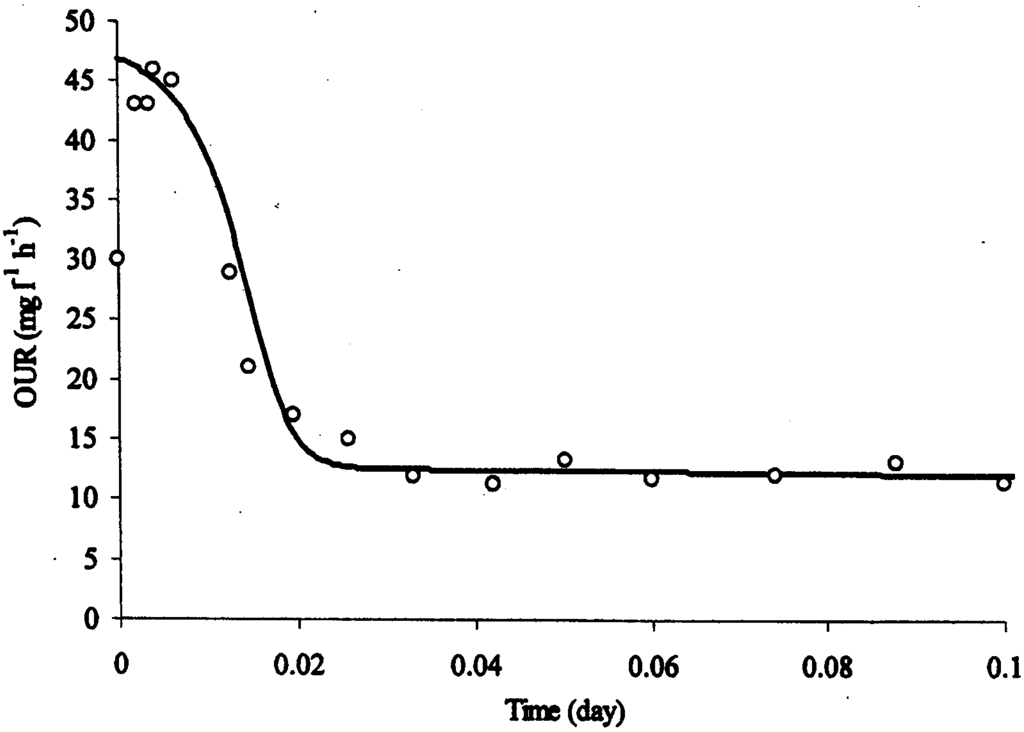

Figure 3. OUR profile for the 10 min. ozonated sample (data o; model —).

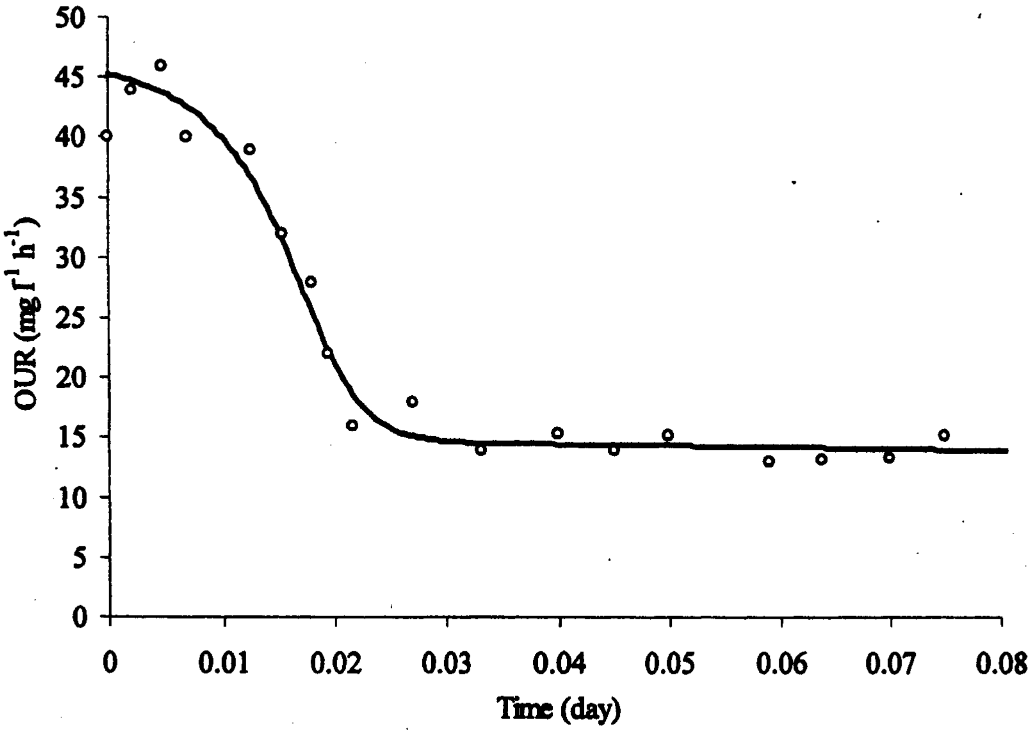

Figure 4. OUR profile for the 30 min. ozonated sample (data o; model —).

Table 6 summarises the COD fractions of raw wastewater, together with literature data for comparative evaluation. The soluble and particulate slowly biodegradable organic matters have been calculated with the above given expressions by using the experimentally determined S_{S1} and S_{I1} values.

The results show that 34 % of the raw wastewater consists of soluble inert COD, a small fraction is readily biodegradable COD, while a considerable portion is composed of slowly biodegradable organic matter. When the COD components are evaluated with respect to available data presented in Table 6, a similar trend may be observed in the sense that they all reflect a relatively significant slowly biodegradable COD fraction. The major difference is the relatively low S_{S1}/C_{T1} and the high S_{I1}/C_{T1} ratios associated with the wastewater tested in this study. It should be noted however that the latter is mainly due to the low total COD content of the wastewater and does not necessarily reflect a high S_{I1} value as compared with levels of 250, 260 and even 415 mg l^{-1} identified for similar textile operations. Nevertheless, it clearly indicates that although the COD of the wastewater studied in this work is lower than those given in the literature, it may be considered to have a character resistant to biodegradation, since its biologically inert fraction is higher.

The effect of ozonation on COD fractions is outlined in Table 7 and illustrated in Figure 5. The first observation based on the presented data is a decrease in the soluble inert COD fraction, S_{I1} with increasing ozonation times, a significant result in view of the stringent effluent requirements. An equally significant observation is the parallel increase in the inert COD ratio with longer ozone contact times. This result

Table 7. COD fractionation in raw composite and ozonated samples.

	C_{T1}	S_{T1}	S_{S1}	S_{H1}	S_{I1}	X_{S1}
Raw wastewater	955	675	90	265	320	280
5 minutes ozonation	850	580	65	215	300	270
10 minutes ozonation	775	550	50	205	295	225
30 minutes ozonation	650	480	50	165	265	170

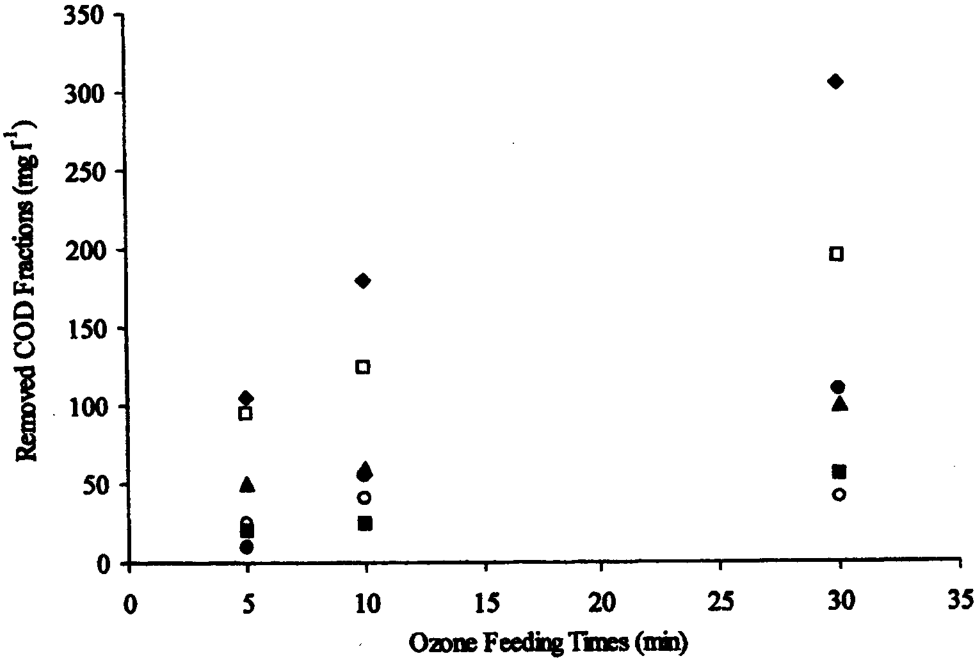

Figure 5. Effect of ozonation on COD fractions (◆C_{T1}; □S_{T1}; OS_{S1}; ▲S_{H1}; ■S_{I1}; ●X_{S1}).

predicts that ozonation is not only effective on the inert fraction but also on the other COD fractions as well. This argument is also supported by the ozone-induced decrease in the soluble COD, and particularly in the readily biodegradable COD fraction. In fact, after an ozonation of 5 minutes, around 90 % of the total COD removal achieved was of a soluble nature and the COD removed could be subdivided as 24 % S_{S1}, 48 % S_{H1}, 9 % X_{S1} and 19 % S_{I1}. As the ozone feeding time was adjusted to 10 minutes, a higher removal of particulate COD (slowly biodegradable COD) could also be observed. In this experiment the new COD fractionation was set as 22 % S_{S1}, 33 % S_{H1}, 31 % X_{S1} and 14 % S_{I1}, with only 69 % soluble portion removal. When an extremely long (30 minutes) ozone feeding time was used, the corresponding COD fractionation achieved was 22 % S_{S1}, 33 % S_{H1}, 36 % X_{S1} and 18 % S_{I1}, the slowly biodegradable COD components representing 69 % of the total COD removal. The results also indicate a gradual increase in the removal of the total slowly biodegradable COD from 57 % at 5 minutes ozone contact time to 69 % at 30 minutes contact time.

Model evaluation

Model studies were devoted to evaluate the effect of ozonation on the kinetics of substrate utilisation. For this purpose experimentally determined OUR curves were calibrated for appropriate kinetic parameters, using a multi-component model involving endogenous decay [32]. COD fractions previously determined for each ozonation experiment were used for model simulation. Coefficients associated with microbial growth and hydrolysis of slowly biodegradable organic matter were identified with specific emphases on hydrolysis, as it constitutes the rate-limiting step in substrate utilisation. In this context, a sensitivity analysis was performed for the assessment of the validity of the selected hydrolysis coefficients.

The adopted model is described in a matrix format in Table 8, indicating the basic stoichiometric relationships between model components and processes. As shown in the Table, the model identifies soluble and particulate fractions of the slowly biodegradable COD (S_H and X_S), but assigns the same rate coefficients for their hydrolysis, as reported for

Table 8. Reaction matrix of the adopted model.

Process	S_S	S_H	X_S	X_H	X_P	S_P	S_O	Reaction Rate
Growth	$-\frac{1}{Y_H}$			1			$-\frac{1-Y_H}{Y_H}$	$\hat{\mu}_H \frac{S_S}{K_S+S_S} X_H$
Endogenous Decay				-1	f_{EX}	f_{ES}	$-(1-f_{EX}-f_{ES})$	$b_H X_H$
Hydrolysis of soluble slowly Biodegradable organic matter	1	-1						$k_h \frac{S_H/X_H}{K_X+S_H/X_H} X_H$
Hydrolysis of particulate slowly biodegradable organic matter	1		-1					$k_h \frac{X_S/X_H}{K_X+X_S/X_H} X_H$

many similar textile wastewaters [17, 18, 33]. It involves generation of particulate inert organic products (X_P) as part of endogenous respiration of active biomass, X_H. Similarly, generation of soluble inert products, S_P, is incorporated into the model as a decay associated process. Only growth and endogenous decay are defined as oxygen-consuming processes.

The OUR curve obtained for the raw wastewater was calibrated for a maximum specific heterotrophic growth rate value of $\mu_H = 4.2\ d^{-1}$ and an endogenous decay rate coefficient of $b_H = 0.12\ d^{-1}$ determined previously for the same wastewater [30]. Values of $f_{EX} = 0.2$ and $f_{ES} = 0.1$ were used for all model simulations. The initial heterotrophic biomass concentration was estimated by curve fitting from the reactor fed with raw (untreated) wastewater and this value was adopted for all the experimental sets on ozonated samples, since they all used the same amount of seeding from the fill and draw reactor. The model calibration evaluations supported the assumption of the negligible initial particulate inert COD, X_{I1} in the wastewater. Model evaluation of the OUR curve obtained with the raw wastewater is plotted in Figure 1. Aside from the selected $\mu_H = 4.2\ d^{-1}$, best calibration was obtained for $K_S = 7\ mg\ l^{-1}$, $k_h = 1.9\ d^{-1}$ and $K_X = 0.2$ mg COD (mg COD)$^{-1}$. As shown in Table 9, these values are well within the range characterising different textile effluent in similar studies. Calibration results for ozonated wastewater samples are also outlined in the same Table and illustrated in Figures 2-4. They indicate that the kinetics of heterotrophic growth and hydrolysis are not affected to a significant extent by ozonation. All kinetic coefficients exhibit slight deviations around the values obtained for the raw wastewater samples and these deviations may easily be interpreted in terms of uncertainties associated with analytical measurements.

The sensitivity of the OUR profile to k_h and K_X coefficients was evaluated for the sample ozonated for 10 minutes (Figure 6). The validity of the selected k_h of 1.7 g COD (g COD.d)$^{-1}$ has been investigated within a wide range of 0.5 – 3 g COD (g COD.d)$^{-1}$. The results given in Fig.6a show that the best fit of the data has been obtained with the selected k_h value. A similar investigation for K_X confirms that the selected value of 0.2 g COD (g COD)$^{-1}$ can be accepted as the appropriate value among the tested range of 0.05-0.7 g COD (g COD)$^{-1}$.

CONCLUSION

The following observations derived from the experimental results may be outlined as the concluding remarks of this study:

Colour removal, a well-documented potential of ozonation is also successfully tested on the textile wastewater selected for the study. It provides however limited COD removal, in the range of 10 – 30 %. This result suggests that ozonation should best be considered as a preliminary conditioning step for biological treatment, rather than a competitive process for the overall COD removal.

Soluble residual COD fraction, (S_I), in the wastewater is a major problem for textile effluents in meeting the effluent COD requirements. Therefore, the conditioning provided by ozonation should be evaluated in terms of the efficiency of S_I breakdown and removal. The results indicate that at a low ozone dose, S_I removal remains limited and ozonation selectively favours the readily biodegradable COD compounds. As the ozone dose is increased, partial S_I removal is accomplished together with breakdown of the slowly biodegradable COD components. The effect of ozonation is best observed on COD fractionation.

Model evaluation of the OUR profiles obtained with raw and ozonated wastewater samples shows that ozonation does not exert a measurable impact on the rate of major biological processes.

Table 9. Kinetic and stoichiometric coefficients in textile industry.

	μ_H (d^{-1})	K_S (mg l^{-1})	k_h (d^{-1})	K_X (mgl^{-1})	References
Denim Processing	3.2	20	1	0.16	[24]
Cotton Knit Fabric Finishing	3.2	13	0.8	0.7	[19]
Polyester Knit Fabric Finishing	5.3	25	3.8	0.65	[17]
Acrylic Fibre & Yarn Finishing*	3.9	10	1.6	0.7	[18]
Organised Industrial District	3.9	10	2.0	0.38	[33]
Cotton-Polyester Blend Knit Fabric	4.2	7	1.9	0.2	This study
Ozonation - 5 minutes	4.0	6	1.6	0.2	This study
Ozonation - 10 minutes	4.0	5	1.7	0.2	This study
Ozonation - 30 minutes	4.1	6	2.1	0.2	This study

*Effluent of the partial chemical oxidation with H_2O_2

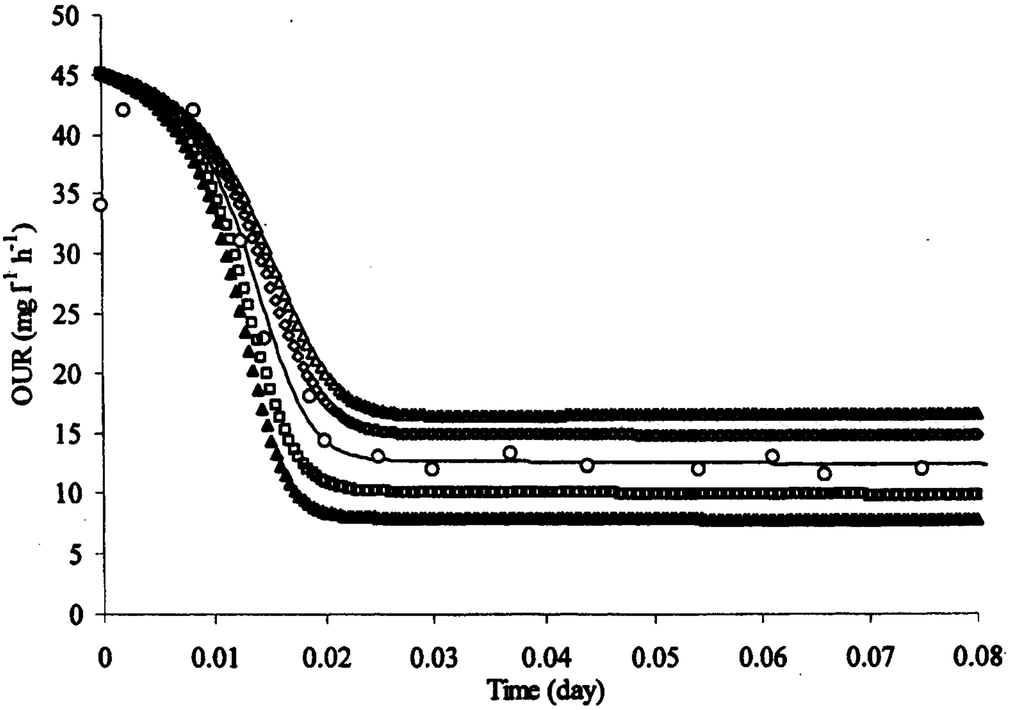

Figure 6a. Sensitivity of the parameter estimation to the half saturation coefficient for hydrolysis, K_X (k_h = 1.7; K_X = 0.05 Δ; K_X = 0.1 ◊; K_X = 0.2 □; K_X = 0.4 ▲; K_X = 0.7 —; data o).

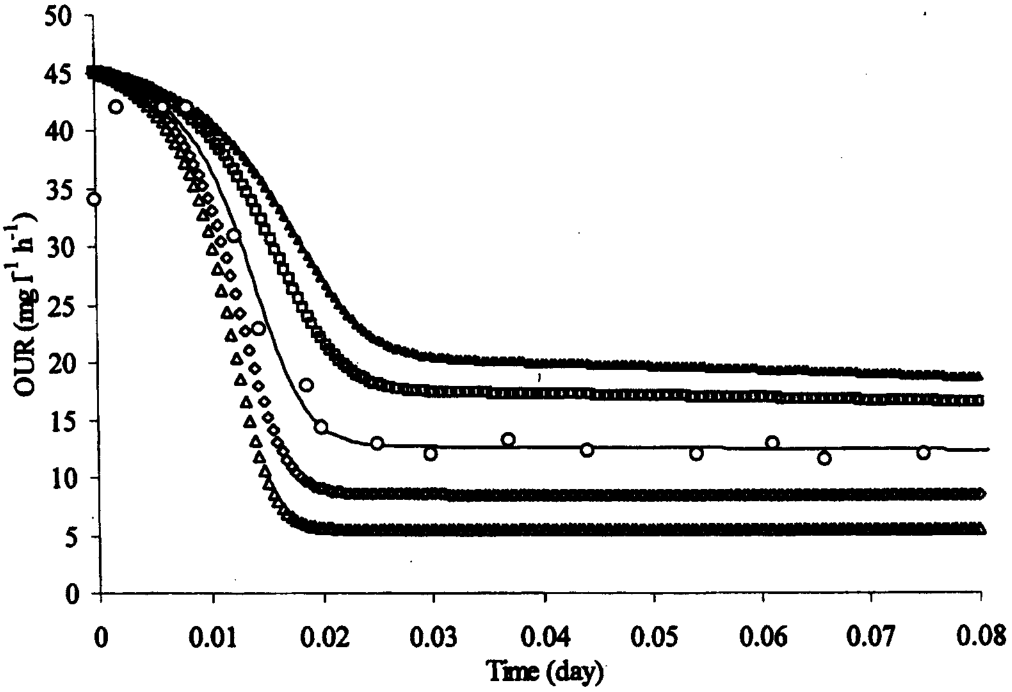

Figure 6b. Sensitivity of the parameter estimation to the maximum specific hydrolysis rate, k_h (K_X = 2.0; k_h = 0.5 Δ; kh = 1 ◊; k_h = 2.5 □; k_h = 3 ▲; k_h = 1.7 —; data o).

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