# A scientific approach to wastewater recovery and reuse in the textile industry

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**Abstract** Wastewater recovery and reuse in industries requires all the basic steps of quality management. It should involve a comprehensive in plant survey of processes with wastewater generation, identification of recoverable streams, and treatment requirements for reuse. It should equally undertake evaluation of wastewater quality remaining after segregation of the recovered portion, with specific emphasis on technological implications of appropriate treatment and compliance with effluent limitations. In this study, all these factors were experimentally assessed and evaluated for a knit fabric processing textile plant.

**Keywords** Biological treatment; characterization; COD fractionation; knit fabric processing; pollution profile; process kinetics; recovery and reuse; textile industry

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## Introduction

Wastewater recovery and reuse is an important feature of the total quality management for industrial activities. It requires a thorough life cycle analysis and a stepwise assessment of all parameters involved, including process and pollution profiles, leading to the identification of recoverable wastewater streams and additional treatment technology needed for reuse. It should equally involve evaluation of wastewater quality remaining after segregation of the recovered portion, with specific emphasis on technological implications with regard to appropriate treatment and compliance with effluent limitations.

Wastewater recovery and reuse is particularly significant for the textile industry, generally characterized with a high water consumption. In the knit fabric subcategory the unit water usage is reported to range from 20 to 100 $m^3$ per ton of fabric processed (Germirli Babuna *et al.*, 1998; 1999). It is often a major problem to find water with the required quantity and quality for individual plants and operations. Therefore, water is an important economical asset within the overall production scheme and requires appropriate management. Wastewater minimization, with possible recovery and reuse of a significant portion should be viewed as an integral part of water management and pollution control in the textile industry. On the other hand, textile effluents are subjected to stringent limitations for discharge to receiving waters and often require full biological treatment for compliance. Non-biodegradable organics, either initially present in the wastewater or generated as residual microbial products during biological treatment often pose significant problems in meeting the effluent COD requirements. Segregation of a relatively less polluted portion for reuse is likely to leave a stronger wastewater with higher levels of residuals, and consequently less compatible with biological treatment. This paper outlines selected results of a comprehensive experimental study on waste minimization and wastewater reuse for a knit fabric textile plant, emphasizing assessment of stream segregation and treatment need for recovered and remaining wastewater fractions.

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## Materials and method

### Plant description

The study generated and evaluated data from a textile plant located at Ayazağa/Istanbul, processing cotton and synthetic knit fabrics and their blends. The plant operates 6 days a week, 250 days a year, employing 165 people in 3 shifts a day. The process requires an average of 751 $m^3$ of water per day, supplied partly from local wells and the remaining portion by tankers, with a water balance fully justifying the need for wastewater recovery and reuse. It houses a wastewater treatment plant, composed of an equalization basin, a neutralization tank and an activated sludge system with a 24 h hydraulic retention time, providing full treatment to the plant effluents before discharge into an adjacent creek.

### Methods

All analyses for conventional characterization were performed as defined in *Standard Methods* (1998). 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.

The particulate and soluble inert COD components, $X_{I1}$ and $S_{I1}$ of the wastewater were determined according to a recently proposed experimental procedure by Orhon *et al.* (1999a). Respirometric procedures were used for the assessment of the readily biodegradable COD, $S_{S1}$ (Ekama *et al.*, 1986), together with the heterotrophic yield coefficient, YH, the maximum heterotrophic growth rate, $\hat{\mu}_H$ (Kappelar and Gujer, 1992) and the endogenous decay coefficient, $b_H$ (Ekama *et al.*, 1986). OUR measurements were conducted with a WTW OXI DIGI 2000 oxygen meter. For the determination of other kinetic coefficients for biological treatability, curve fitting to experimentally obtained OUR profiles was performed through model simulation. An AQUASIM (Reichert, 1994) computer software program was used for modeling and curve fitting procedures.

For the ozonation experiments, ozone 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 l in a 1.5 l 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 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 1 N NaOH and $H_2SO_4$ solutions.

## Experimental evaluation

### Process profile

The selected plant sets a very representative example for the knit fabric textile subcategory as it handles cotton, viscose rayon, polyester, polyamide knit fabrics together with cotton/polyester, polyester/viscose rayon and viscose rayon/cotton knit blends. The plant operation involves 20 different processes, all in batch systems. The striking feature of the operation, almost typical for this subcategory, is that the plant functions on fluctuating demands from the textile sector. Consequently, while a small group of processes are performed almost routinely, most others are much less frequent and the daily plant output, as far as production distribution and related wastewater generation hardly ever reflects the entire process spectrum of the plant. Therefore, the process profile of the plant, yielding the correlation between the amount of fabric processed and the rate of wastewater generated was evaluated as the daily averages of an in-plant survey for a period of more than a year. As outlined in Table 1, the average capacity of the plant was calculated as 10 tons of fabric per day with a wastewater rate of around 751 $m^3d^{-1}$, corresponding to a unit wastewater

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**Table 1** Process profile of the plant

| Processes | | Unit wastewater generation [l.(kg fabric)$^{-1}$] | Average daily production [kg fabric.d$^{-1}$] | Wastewater flow [m$^3$.d$^{-1}$] | [%] |
|---|---|---|---|---|---|
| Cotton knit fabric | | | | | |
| [1] | Raw Fabric Washing | 17.8 | 100 | 1.78 | 0.24 |
| [2] | Sugar Bleaching | 67.0 | 100 | 6.70 | 0.89 |
| *[3] | Optical Brightening | 40.0 | 1700 | 68.00 | 9.05 |
| [4] | 60°C Reactive (Remazol) Dyeing with Bleaching | 214.3 | 300 | 64.29 | 8.56 |
| *[5] | 60°C Reactive (Remazol) Dyeing with Kiering | 90.9 | 700 | 63.64 | 8.47 |
| *[6] | 95°C Reactive (Procion) Dyeing with Bleaching | 96.8 | 2300 | 222.58 | 29.63 |
| [7] | 95°C Reactive (Procion) Dyeing with Kiering | 99.0 | 100 | 9.90 | 1.32 |
| Mercerized cotton knit fabric | | | | | |
| [8] | Sugar Bleaching After Mercerization | 50.6 | 100 | 5.06 | 0.67 |
| Viscose rayon knit fabric | | | | | |
| [9] | 60°C Reactive (Remazol) Dyeing | 104.8 | 400 | 41.91 | 5.58 |
| *[10] | 95°C Reactive (Procion) Dyeing | 112.5 | 500 | 56.25 | 7.49 |
| Polyester+viscose rayon knit blend | | | | | |
| [11] | Single Bath Dyeing | 59.4 | 400 | 23.76 | 3.16 |
| [12] | Double Bath Dyeing | 94.8 | 400 | 37.92 | 5.05 |
| Polyester knit fabric | | | | | |
| [13] | 110°C Dyeing with Carrier | 42.8 | 100 | 4.28 | 0.57 |
| [14] | 130°C Light Color Dyeing | 24.0 | 800 | 19.20 | 2.56 |
| [15] | 130°C Dark Color Dyeing | 25.6 | 800 | 20.48 | 2.73 |
| Cotton+polyester knit blend | | | | | |
| [16] | Single Bath Dyeing | 59.4 | 400 | 23.76 | 3.16 |
| [17] | Polyester Double Bath Dyeing | 94.8 | 400 | 37.92 | 5.05 |
| [18] | Dyeing with Cleaning | 54.5 | 400 | 21.80 | 2.90 |
| Polyamide knit fabric | | | | | |
| [19] | Polyamide Dyeing | 37.7 | 300 | 11.32 | 1.51 |
| Sugar bleched, mercerized cotton knit fabric | | | | | |
| [20] | Reactive Printing | 107.1 | 100 | 10.71 | 1.43 |
| **Total** | | | **10,000** | **751** | **100** |

* Selected processes for pollution profile

generation of 75 m$^3$ per ton of fabric processed, a value quite compatible with the range reported in the literature (Germirli *et al.*, 1990; 1998).

An important task at this stage is the selection of processes/waste streams that are likely to represent the overall plant effluent for further experimental evaluation. In this study, four of the 20 processes in the plant were selected, namely, *optical brightening, 60ºC kiered remazol dyeing, 95ºC bleached procion dyeing* of the cotton knit fabrics and *95ºC procion dyeing* of viscose rayon knit fabrics, mainly because they all appear in day to day operation of the plant, greatly affect the quality of the overall plant effluent and discharge a total of 410 m$^3$d$^{-1}$ of wastewater, corresponding to 55% of the average total daily volume.

### Wastewater characterization and selection of recoverable fractions

This part of the experimental survey involved characterization of the effluents from the selected processes in terms of conventional parameters that are relevant for both treatment and reuse. The survey separately covered all the successive steps in each process. The results are outlined in Table 2. As expected, significant quality fluctuations and differences

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**Table 2** Conventional characterization of selected process effluents

| **Processes** | **pH** | **COD [mg.l$^{-1}$]** | **Color [Pt-Co unit]** | **TKN [mg.l$^{-1}$]** | **TP [mgP.l$^{-1}$]** | **TSS [mg.l$^{-1}$]** | **TDS [g.l$^{-1}$]** | **Alkalinity [mg CaCO$_3$.l$^{-1}$]** |
|---|---|---|---|---|---|---|---|---|
| Cotton knit fabric | | | | | | | | |
| [3] Optical Brightening | | | | | | | | |
| [3].1 Optical Brightening | 10.6 | 6830 | 470 | 30 | 10 | 85 | 5.05 | 1160 |
| [3].2 Softening | 5.9 | 2645 | 180 | 10 | 15 | 55 | 1.77 | 205/75** |
| [5] 60°C Reactive Dyeing with Kiering | | | | | | | | |
| [5].1 Kiering | | | | | | | | |
| [5].1.1 Kiering | 10.1 | 2500 | 450 | 70 | 11 | 130 | 5.8 | 2250 |
| *[5].1.2 Neutralization | 7.8 | 100 | 35 | 6 | 8 | 30 | 1.6 | 300 |
| [5].2 Remazol Dyeing | | | | | | | | |
| [5].2.1 Dyeing | 11.7 | 2750 | 25800 | 35 | 29 | 290 | 12.04 | 5700 |
| [5].2.2 First Rinse | 10.4 | 240 | 3750 | <5 | 17 | 65 | 11.24 | 900 |
| [5].2.3 Second Rinse | 9.7 | 145 | 2790 | <5 | 10 | 25 | 2.69 | 350 |
| [5].2.4 Neutralization | 7.1 | 280 | 765 | <5 | 12 | 25 | 1.11 | 190 |
| [5].3 Washing | | | | | | | | |
| [5].3.1 Soaping | 8.7 | 360 | 1620 | 85 | 7 | 20 | 1.29 | 210 |
| [5].3.2 First Rinse (95°C) | 8.4 | 1200 | 1290 | 20 | 2 | 25 | 1.11 | 210 |
| [5].3.3 Second Rinse (95°C) | | | | | | | | |
| [5].3.4 Third Rinse (60°C)8.2 | 360 | 410 | 7 | 3 | 15 | 0.92 | 180 | |
| *[5].3.5 Softening | 6.4 | 345 | 30 | <5 | 4 | 20 | 1.07 | 110 |
| [6] 95°C Reactive Dyeing with Bleaching | | | | | | | | |
| [6].1 Pre-Bleaching | | | | | | | | |
| [6].1.1 Pre-Bleaching | 11.4 | 2365 | 155 | 15 | 15 | 55 | 39 | 1295 |
| *[6].1.2 Neutralization | 2.5 | 235 | 15 | 8 | 19 | 35 | 1.69 | 400** |
| [6].2 Procion Dyeing | | | | | | | | |
| [6].2.1 Dyeing | 10.6 | 1500 | 640 | 15 | 20 | 195 | 55 | 13625 |
| [6].2.2 First Rinse | 10.0 | 80 | 80 | 8 | 8 | 35 | 4.5 | 900 |
| [6].2.3 Second Rinse | | | | | | | | |
| [6].3 Washing | | | | | | | | |
| [6].3.1 Soaping | 8.3 | 50 | 40 | 13 | 18 | 12 | 1.8 | 345 |
| [6].3.2 First Rinse (95°C) | | | | | | | | |
| [6].3.3 Second Rinse (95°C) | | | | | | | | |
| *[6].3.4 Third Rinse (60°C) | 7.7 | 35 | 15 | 4 | 3 | <10 | 0.82 | 240 |
| *[6].3.5 Softening | 6.4 | 440 | 30 | 4 | 2 | 75 | 0.75 | 100 |
| Viscose rayon knit fabric | | | | | | | | |
| [10] 95°C Reactive Dyeing | | | | | | | | |
| [10].1 Viscose Floss-Washing | | | | | | | | |
| [10].1.1 Pre-Washing | 8.7 | 1820 | 495 | 21 | 24 | 45 | 1.4 | 210 |
| [10].2 Procion Dyeing | | | | | | | | |
| [10].2.1 Dyeing | 10.0 | 340 | 30 | 7 | 36 | 20 | 10.1 | 1225 |
| [10].2.2 First Rinse | 10.0 | 735 | 30 | 7 | 30 | 30 | 11.0 | 1200 |
| [10].2.3 Second Rinse | | | | | | | | |
| [10].3 Washing | | | | | | | | |
| [10].3.1 Soaping | 9.5 | 320 | 40 | 40 | 18 | 20 | 2.0 | 350 |
| [10].3.2 First Rinse (95°C) | | | | | | | | |
| [10].3.3 Second Rinse (95°C) | | | | | | | | |
| *[10].3.4 Third Rinse (60°C) | 8.4 | 45 | 15 | 8 | 51 | <10 | 0.7 | 200 |
| *[10].3.5 Softening | 4.3 | 1110 | 20 | 10 | 33 | 60 | 1.1 | 600** |

*Effluents selected as recoverable fraction

**Acidity

were depicted, best illustrated by an observed range of 35– 6830 mgl$^{-1}$ for COD, 30– 25800 Pt-Co unit for color and 2.5 – 11.7 for pH, for different wastewater streams.

This type of an evaluation by sampling from every batch discharge, also enabled identification of 7 different recoverable effluent fractions, basically associated with low COD and color contents as indicated in Table 2. The magnitude of the recoverable effluent was calculated as 92 m$^3$d$^{-1}$, corresponding to 22% of the total wastewater volume selected for evaluation.

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**Table 3** Pollution profile of the plant

| Wastewater | Flowrate | COD | | TSS | | TDS | | TP | | TKN | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | [m$^3$.d$^{-1}$] | [mg.l$^{-1}$] | [kg.d$^{-1}$] | [mg.l$^{-1}$] | [kg.d$^{-1}$] | [g.l$^{-1}$] | [kg.d$^{-1}$] | [mgP.l$^{-1}$] | [kg.d$^{-1}$] | [mg.l$^{-1}$] | [kg.d$^{-1}$] |
| Overall Wastewater | 410 | 1180 | 483.9 | 65 | 26.65 | 9.00 | 3690.0 | 15 | 6.15 | 14 | 5.741 |
| Reusable Wastewater | 127 | 350 | 44.42 | 30 | 3.81 | 1.05 | 133.4 | 13 | 1.65 | 4 | 0.508 |
| Effluent After Reuse | 283 | 1475 | 417.7 | 80 | 22.64 | 12.5 | 3537.5 | 16 | 4.53 | 18 | 5.098 |
| Treatment Plant Influent* | 751 | 910 | 682.5 | 65 | 48.8 | – | – | 4 | 3.0 | 20 | 15.00 |

* Average

Flow proportional composite samples were also prepared and analyzed, to represent the *overall wastewater* from the selected processes shown in Table 1, the recovered and potentially *reusable wastewater* and the *remaining wastewater* after the recovered portion. At the same time, the average composition of the plant total effluent was measured at the inlet of the treatment plant. The results are summarized in Table 3.

The overall wastewater was observed to exhibit the typical character of knit fabric textile effluents, with a high COD level of 1180 mgl$^{-1}$, and a low SS and nutrient content with respect to domestic sewage (Orhon *et al.*, 1999b). It provides a conservative basis for evaluation as it is slightly stronger than the treatment plant influent. The table also shows that the segregation of the reusable fraction with a COD concentration of only 350 mgl$^{-1}$, is likely to leave behind a wastewater of different quality, roughly 25% stronger (COD: 1475 mgl$^{-1}$) in terms of conventional parameters.

### Achievable quality for the reusable wastewater fraction

There is no clear-cut quality requirement for reuse of textile effluents in the process. Generally, color is cited as the major concern, together with total dissolved solids (TDS) and total hardness. As shown in Table 4, knit fabric processing in the plant studied, imparted to the wastewater around 9 gl$^{-1}$ of TDS, 1180 mgl$^{-1}$ of COD and 720 Pt-Co unit of color. Recoverable streams were selected with specific care to minimize the level of these pollutants; in the study, the TDS content was adjusted as 1.05 gl$^{-1}$, below the 1.5 gl$^{-1}$ level to avoid costly membrane treatment, but still with a COD of 350 mgl$^{-1}$ and a color level of 25 Pt-Co unit, requiring polishing before reuse.

In the study, two sets of ozonation experiments, with different ozone feeding rates, were conducted on the reusable effluent fraction for the removal of color and COD. In the first run, set with an ozone feeding rate of 27.65 mg(min)$^{-1}$, complete removal of color was observed after 1 minute, and COD dropped to only 250 mgl$^{-1}$ after 15 minute contact time. During this 15 min experiment 20% ozone utilization was observed. The second run was adjusted for a 38.10 mg(min)$^{-1}$ ozone feeding and a total of 120 min contact time; a gradual and slow decrease in the COD concentration was experienced from 350 mgl$^{-1}$ to a final value of 95 mgl$^{-1}$ still higher than the 50 mgl$^{-1}$ level recommended in the literature for reuse at end of the contact time (Table 5).

### Biological treatability of the wastewater before and after reuse

The plant effluent, like other textile wastewaters, requires effective treatment to comply with stringent effluent limitations. Although a common application, chemical treatment usually proves unreliable for this purpose; this is especially true for the textile plant investigated, as more than 80% of the wastewater COD is of soluble nature and consequently, the existing treatment plant is built as an activated sludge system. The evaluation should then focus on biological treatability, and this involves, within the framework of the current understanding and interpretation of activated sludge behavior, *COD fractionation* and the experimental assessment of relevant *kinetic and stoichiometric coefficients*.

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**Table 4** Evaluation of wastewater quality for reuse

| Parameters | Reuse Criteria<br>Hoehn, (1998) | <br>From manufacturer | <br>Process water | Wastewater quality<br>Overall wastewater | Reusable wastewater<br>Raw | <br>After ozonation** |
|---|---|---|---|---|---|---|
| PH | 6.5–7.5 | – | 7.38 | 10.28 | 5.16 | 7.5 |
| COD (mgl$^{-1}$) | <50 | – | – | 1180 | 350 | 250 |
| TSS (mgl$^{-1}$) | 0 | – | 25 | 65 | 30 | – |
| TDS (gl$^{-1}$) | – | <1.5 | 0.67 | 9 | 1.05 | 1.19 |
| Chloride (mgl$^{-1}$) | <150 | – | 135 | 3460 | 320 | – |
| Total Hardness (mg $CaCO_3$. l$^{-1}$) | 90 | <50 | 20 | 36 | 20 | – |
| Color (Pt–Co unit) | 0 | 0 | 10 | 720 | 25 | 0 |

* Acidity; ** 15 min contact time

**Table 5** Results of ozonation experiments

| Contact time [min] | Ozone<br>Feeding rate [mg.min$^{-1}$] | <br>Output [mg] | pH* | COD<br>Total [mgl$^{-1}$] | <br>Filtered [mgl$^{-1}$] | <br>Removal [%] |
|---|---|---|---|---|---|---|
| 0 | – | – | 5.16 | 350 | 200 | – |
| 5 | 27.65 | 22.46 | 7.70 | 285 | 180 | 19 |
| 10 | 27.65 | 23.30 | 7.58 | 265 | 175 | 24 |
| 15 | 27.65 | 23.04 | 7.45 | 250 | 175 | 29 |
| 120 | 38.10 | N.D. | 4.05 | 95 | 80 | 73 |

N.D.: not measurable due to extended ozonation time

* after ozonation

**Table 6** COD fractionation of wastewaters

| COD | Overall wastewater<br>[mg.l–1] | <br>[%] | Effluent after reuse<br>[mg.l–1] | <br>[%] |
|---|---|---|---|---|
| Readily Biodegradable COD | 118 | 10 | 132 | 9 |
| Hydrolyzable COD | 752 | 64 | 958 | 65 |
| Initial Soluble Inert COD | 247 | 21 | 307 | 21 |
| Initial Particulate Inert COD | 63 | 5 | 78 | 5 |
| **Total COD** | **1180** | | **1475** | |

The concept of differentiating COD fractions based on biodegradability was developed and tested primarily for domestic sewage (Henze, 1992; Orhon *et al.*, 1997). It was only recently that reliable information for industries, and especially for textile effluents were derived and reported in the literature (Orhon *et al.*, 1999b; 1999c). Table 6 summarizes similar experimental data generated in this study: The results reflect the specific character of the *overall wastewater* before reuse, with a biodegradable COD ratio of around 75%, a readily biodegradable COD ratio of 10%, the same level normally encountered in domestic sewage, and a predominantly soluble slowly biodegradable COD fraction of 65%. This may be considered as a specific COD fingerprint for the plant investigated. The significant feature of the observation, as shown in Table 6, is that the segregation of the reusable portion did not affect this fingerprint, as the *remaining wastewater* after reuse, although stronger, could be associated with practically the same COD fractions.

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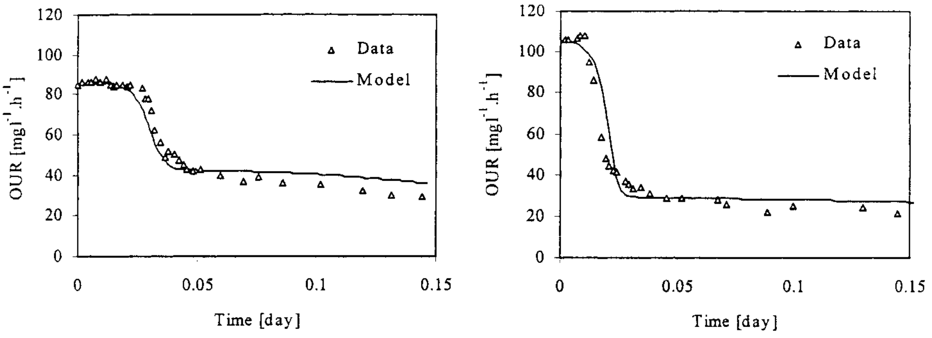
**Table 7** Kinetic and stoichiometric constants of effluents

| Parameter | Overall wastewater | Wastewater after reuse |
|---|---|---|
| Maximum heterotrophic growth rate, $\hat{\mu}_H$ [day$^{-1}$] | 4.1 | 3.6 |
| Half saturation constant, $K_S$, [mg COD.l$^{-1}$] | 6 | 10 |
| Endogenous decay rate, $b_H$, [day$^{-1}$] | 0.12 | 0.12 |
| Heterotrophic yield coefficient, $Y_H$, [g cell COD(g COD)$^{-1}$] | 0.67 | 0.67 |
| Maximum hydrolysis rate, $K_h$, [day$^{-1}$] | 3.6 | 2 |
| Hydrolysis half saturation constant, $K_X$, [g COD(g COD)$^{-1}$] | 0.2 | 0.35 |
| Soluble inert fraction of endogenous biomass, $f_{ES}$ | 0.12 | 0.13 |
| Particulate inert fraction of endogenous biomass, $f_{EX}$ | 0.17 | 0.23 |

Evaluation and modeling of activated sludge behavior of organic carbon removal requires appropriate values for eight constants, namely, $\hat{\mu}_H$, $K_S$,, $b_H$, $Y_H$, $k_h$, $K_X$, $f_{ES}$ and $f_{EX}$. The coefficients $Y_H$, and $b_H$ were determined by OUR measurements, $f_{ES}$ and $f_{EX}$ were calculated by mass balance from the specific experiments and $K_S$, $k_h$ and $K_X$ could only be calculated by curve fitting the model to experimental OUR profiles. Table 7 lists experimentally computed values of these coefficients for both the overall wastewater and the remaining fraction after reuse. As shown in this table, a $Y_H$ value of 0.67 g cell COD(g COD)$^{-1}$ and a bH value of 0.12 d$^{-1}$ were found to characterize both wastewaters, as typical levels equally associated with domestic sewage and most other industrial effluents; the same would apply to $f_{EX}$, with a quite accepted default value of 0.20. The maximum heterotrophic growth rate, $\hat{\mu}_H$ of 4.1 d$^{-1}$ experimentally assessed for the overall wastewater is slightly lower than the average value of 4.8 d$^{-1}$ characterizing domestic sewage (Orhon *et al.*, 1997); it further drops to 3.6 d$^{-1}$ after segregation of the reusable fraction, possibly due to the accumulation and increased effect of inhibitory compounds likely to be present in the wastewater.

On the basis of currently accepted models of activated sludge, the growth process ($\hat{\mu}_H$, $K_S$), directly related to readily biodegradable COD, is not so important in systems operated solely for organic carbon removal, as compared to the hydrolysis of the slowly biodegradable COD which practically governs the COD removal efficiency. In this context, the maximum hydrolysis rate, $k_h$, was observed to decrease from 3.6 d$^{-1}$ to 2.0 d$^{-1}$, in the remaining wastewater fraction after reuse; a similar change was also found for the hydrolysis half saturation constant, $K_X$. A single hydrolysis mechanism was applicable to both wastewater samples as shown in Figure1, indicating that there is no need to assign different hydrolysis rates for the soluble and particulate portions of the slowly biodegradable COD.



*a) Overall wastewater*

*b) Effluent after reuse*

**Figure 1** OUR profiles of effluents

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Specific attention should be devoted to soluble inert COD initially present ($S_{I1}$) or generated as microbial products($S_P$); as it is generally the decisive factor in meeting the effluent COD limitations; $S_{I1}$ was calculated as 20% of the initial total COD, much higher than the 5% level usually associated with domestic sewage. Combined with an equally high $f_{ES}$ value of 0.12 defining the expected magnitude of residual microbial products, the soluble inert COD accumulation appears to be a major problem for the wastewater to be treated after reuse.

## Conclusions

Significant points, derived from experimental results and evaluations, may be outlined as follows, as the concluding remarks of this study.

Knit fabric textile plants, as the one investigated in this study, usually involve a large package of different processes utilized at varying frequencies, based on demand. Selection of reusable wastewater streams should be made from processes with the highest utilization frequency in daily operation. In this context, seven wastewater streams, amounting to 92 $m^3d^{-1}$ and constituting only 12% of the total daily water use, were selected as recoverable fractions, within the four major processes identified in the plant; as they generated 410 $m^3d^{-1}$ of wastewater, the recovery ratio, within these selected processes could be calculated as 22%.

From a quality standpoint, the selection of the recoverable streams should be made in a way to minimize additional treatment before reuse; accordingly, they were selected to have a TDS and a hardness content below acceptable levels and with lowest possible color and COD contents. Ozone treatment proves very effective for complete removal of color but provided only partial treatment for COD at economically acceptable doses. Partial ozone treatment for reuse was found satisfactory as the need for complete COD removal is not required and therefore justified in practice.

Segregation for reuse was observed to generate a stronger wastewater with a slower mechanism for the breakdown and the removal of the slowly biodegradable COD, necessitating larger treatment volume. Reuse was evaluated to impart around 25% increase of the already high soluble residual COD level associated with the wastewaters from the plant and this aspect should deserve significant consideration in meeting the effluent COD limitations after reuse.

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