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# COD fractionation based biological treatability assessment of segregated & recovered wastewater streams from denim processing plant

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## ABSTRACT

This study evaluated the biological treatability of overall wastewater generated from a denim processing plant located in Çorlu, Tekirdağ, in the NW of Turkey, before and after sub-stream wastewaters' recovery alternatives were performed in the plant processes. It was determined that there are 5 segregated sub-streams composed of 11 segregated single sub-stream wastewaters contribute overall wastewater of the plant. The plant overall wastewater reflects the typical character of denim processing effluents which have a high level of chemical oxygen demand ($COD_{Tot}$) 1200–1577 mg.l$^{-1}$ (1390 mg.l$^{-1}$), $COD_{Sol}$ 700–1210 mg.l$^{-1}$ (955 mg.l$^{-1}$), TSS 2840–6800 mg.l$^{-1}$ (4820 mg.l$^{-1}$) and quite acidic/neutral pH value such as 5.8–6.5 (6.2). According to the segregated stream characters, 6 segregated single sub-stream wastewaters fitted to be suitable for recovery. After recovery, it was observed that the remaining wastewater character changed as $COD_{Tot}$ 1750–2295 mg.l$^{-1}$(2020 mg.l$^{-1}$), $COD_{Sol}$ 1080–1695 mg.l$^{-1}$ (1390 mg.l$^{-1}$), TSS 3330–9735 mg.l$^{-1}$ (6535 mg.l$^{-1}$) and pH value 5.3–6.5 (5.9). According to the biodegradability experimental data, the soluble inert fraction ($S_I$) of the initial total (COD) ($S_I/C_T$) remain steady by the ratio 3% before and after recovery while particulate inert fraction ($X_I/C_T$) increased from 1.6% to 3.4% ratio, as it can be considered as a specific case of COD fractions for recovery. But when the all biological treatability characteristics were evaluated as a private for this plant, it was observed that there is no any difficulty for biological treatability of remaining wastewater after recovery.

*Keywords:* COD fractionation; Biological treatability; Denim processing effluents; Oxygen uptake rate (OUR); Stream segregation; Recovery

## 1. Introduction

Turkey has been one of the leading countries on the denim garment production for both design as a trademarker and with effective marketing strategies. While the share of denim garment in the total finished clothes and confection export of Turkey has been determined 5.6% for 2000, 14% for 2007 and 11.1% for 2008 [1].

Turkey being a candidate country for full membership to the EU is in the period of adopting legal requirements and sanctions of the Union. The textile and clothing industry is the largest and one of the first industries established in Turkey [2]. Currently, there are about 40,000 companies active in the Turkish textile and apparel sector; 25% of which are active exporters [3]. In the european union (EU) countries, pollution rising from industrial activities is regulated by which integrated pollution prevention and control (IPPC) Directive (96/61/EC) concentrates on the minimization of the environmental impacts of the industrial activities which are defined in the directive via best available techniques reference documents (BREF) forming guideline for each industrial sector. In this document, pollution prevention opportunities, control of raw materials, use of water and

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chemicals and their optimization, chemical substitutions, process modifications, recovery, reuse and recycle options are stated [4]. Among those defined industries in the IPPC Directive (96/61/EC), textile is a water and energy intensive one [5].

Since industries use different technologies and production processes, they show important differences in terms of pollutants' types and quantities generated. At the same time, industries are also dynamic organisations and they should be also controlled with a scientific sense and implementations alongside to update of pollutant characteristics' as parallel to new industrial developments. Textile finishing processes involve a series of washing treatments steps to remove impurities and to produce the material with desired properties in terms of aesthetic appearance. The textile industry is known as a intensive water use sector. Typically 200–400 l water are needed to produce 1 kg of fabric [6]. Therefore, one should give importance to the textile wastewater management in terms of sustainable water consumption and recovery these potential wastewaters where feasible [4,7]. There are 10 sub-categories of textile production for wet finishing processes according to EPA classification. One of them is Denim wet processing [7].

The major processing steps on the wet processing of denim garments involve desizing, stone-washing, bleaching and neutralization and softening. Desizing involves the removal of starch based sizes added during fibre processing by treating the denim with commercial α-amylase enzymes. Stone-washing is a more severe form of cellulase treatment which is essentially a degradative mechanism resulting in the loss of both the weight and strength of the fabric giving the material a worn-out appearance. Stone-washing with enzymes generally referred to as bio-stoning has gained popularity due to the reduced ecological problems normally encountered when stones are used [8]. Bleaching and neutralization steps are generally implemented to remove unwanted colour before dyeing.

Denim finishing processes are water-intensive requiring large volumes of water for processing and rinsing [9]. Furthermore, a wide variety of chemicals, detergents and softeners are also employed to improve the efficiency of each process. Since the processing and rinsing steps are conducted as batch operations and there are stringent water quality requirements for each processing step, water used is normally used once for each processing step or rinse before being discharged. This greatly increases the discharge volume and fresh water requirements for the wet processes [10]. More than 70% of the total water usage is used for dyeing and finishing processes; and the rest being used for other purposes such as steam generation, sizing, good housekeeping etc. [11,12].

In this study, a chart of denim processing plant which implements cutting, tailing, washing (include tint dyeing), drying, local worn-out with resin and ironing operations on indigo dyed denim garments was described, process and COD based pollution profile were calculated and segregated sub-stream wastewaters' characterization were made. Then according to these results, biological treatability characteristics were assessed using respirometric methods for the overall wastewater generated from investigated plant, before and after sub-stream wastewaters recovery alternatives were performed in the processes. After these assessments, additional to the other studies carried out in the related literature, characterization of every segregated sub-stream wastewaters and biological treatability evaluation based on COD fractionation which were done for remaining wastewater having high pollution load after sub-streams which have low pollution potential were recovered, can be explained as the most important finger point of this study.

## 2. Materials and methods

### 2.1. Plant production

This study was carried out in a Denim processing plant located in Çorlu industry region in Tekirdağ. The selected denim processing plant processes indigo dyed woven fabrics to denim based garment as pants. It functions six days a week with three shifts a day, employing a total of 2000 personnel. The capacity of the plant is approximately 50,400 number pants per day corresponding to around 50.4 ton of pants per day. Tailed pants made of denim fabrics are processed by using washing machines with different capacity. The general production scheme applied in the investigated plant is schematically illustrated in Fig. 1. Based on wastewater management, the plant may be classified in Jean Washing Finishing subcategory based on the classification proposed by Orhon et al. [13]. But, according to wastewater management legislation in Turkey, the plant was included in woven fabric finishing sub-category in textile industry [14].

The investigated plant shows a very representative example for the denim washing textile subcategory as it includes rinse, stone, bleaching and local washing and additional tint dyeing processes which are the typical sub-procesess of a denim processing production scheme. The plant operation involves about 16 different combination of these processes, all in consecutive batch system. The fact that more than 1500 different washing bath formulations are applied in washing processess, implying a wide variation in terms of wastewater quality; the most frequently used of them in the plant

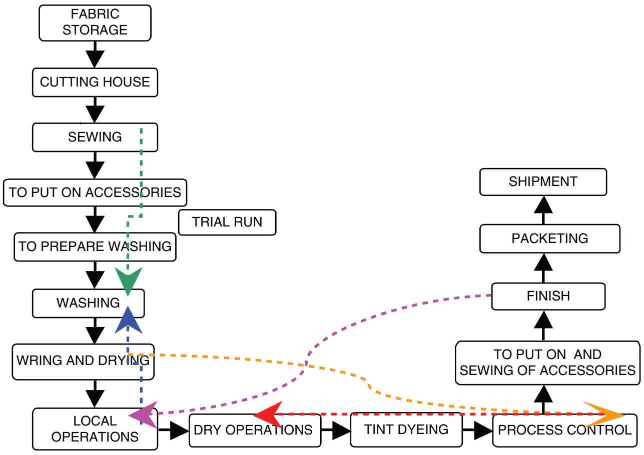

Fig. 1. General production scheme employed in the plant.

were identified by the help of the staff whose responsible for the washing line in the plant.

In the investigated plant, since the washing and dyeing step combinations can change according to customer demands, sometimes while some sub-processes are implemented almost routinely, some of them can be performed much less frequent. Thus, the daily plant production reflects the whole process range of the plant according to the distribution and related wastewater generation. So, in this study, the process profile of the plant, describing the correlation between the amount of pants processed and the flow rate of wastewater generated, was evaluated on the base of main sub-processes implemented in last three years in the plant.

### *2.2. Water usage*

The plant draws out water from 3 wells and then softens it through an ion exchange processes so that it can be used in all processes. Then discharges it in a receiving body called Sinanlı stream after treated in self physical and biological treatment systems composed of conventional activated sludge unit with the capacity of 1500 m$^3$.d$^{-1}$. The investigated plant production wet processes are defined as 5 different sub-processes which can be classified as rinse washing, local washing, bleaching washing, stone washing and tint dyeing similar to described in the literature [15].

According to customer request, denim garments are washed one or more type of washing combination of these sub-processes. So, the plant operations can involve about 16 different combination of these processes, all in consecutive batch system.

Furthermore, washing processes included rinse, stone, bleaching and local washing and tint dyeing are the most water consumption part of the investigated plant with the around 85% of the total water usage value. Besides, while the local part implemented mechanical and physical worn-out operations uses very low water with a 2.6% value, steam and domestic water usage values are determined as 8.2% and 4.6%, respectively.

### *2.3. Study design*

The characterization of the overall wastewater and the remaining wastewater, having high pollution load after sub-stream wastewaters which have low pollution potential were recovered, in terms of conventional parameters that are the relevant for both treatment and recovery were done in this part of the experimental studies. While the overall wastewater composed of 11 single segregated sub-stream wastewaters of investigated plant is designated as RUN 1, the remaining wastewater after recovery is named as RUN 2. On the other hand, after recovery, it was planed that 6 segregated single sub-stream wastewaters which have low pollution potential are being collected and passed through a treatment such as ozone application system or membrane filtration system includes Ultrafiltration (UF)/Nanofiltration (NF) which have a brine to be rejected to hazardous waste site as usual. The short schematic illustration of study design is given in Fig. 2.

Characterization studies carried out at wet processes of investigated plant including washing and tint dyeing parts which were shown in Fig. 1. All sub-stream wastewaters of washing and tint dyeing processes contributing to the plant overall wastewater, were determined with details in-plant survey. In this framework, sub-stream wastewaters originating from the all wet operations, as mentioned in Fig. 2, were collected separately from the discharge channel of industrial washing machines used in the wet processes along the period of batch discharge. The plant survey carried on more than six months and involved three different representative samples from each process step corresponding the similar bathing formulations.

### *2.4. Biological treatability on the base of COD fractionations and biological kinetics*

The analysis of biodegradation characteristics of the RUN 1 and the RUN 2 is the next step of this study. The particulate and soluble inert COD components, $X_{I1}$ and $S_{I1}$ of these wastewaters were determined according to a proposed experimental procedure [16]. Readily biodegradable COD, $S_{S1}$ [17], heterotrofic yield coefficient, $Y_H$ together with the maximum heterotrofic growth rate, $(\mu_H)_{max}$ [18] and endogenous decay coefficient $b_H$ [17] assessment were done according to respirometric procedures. OUR measurements were implemented with Applitek Ra-Combo® Continuous Respirometer.

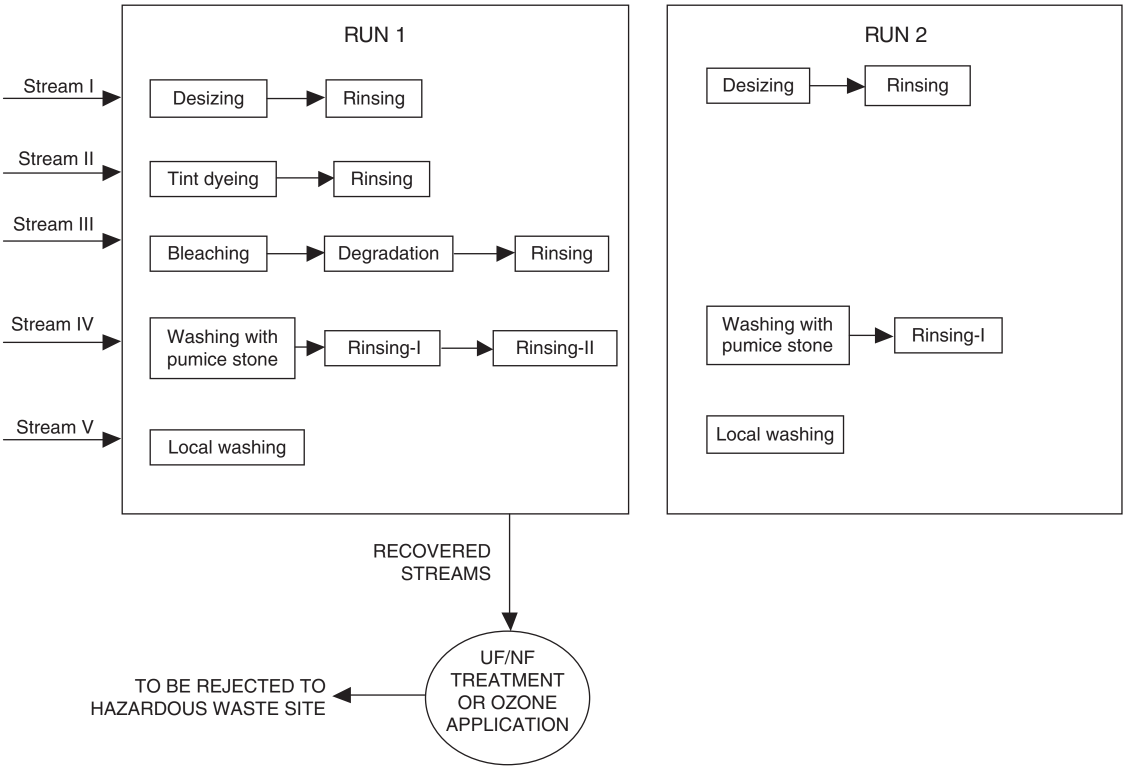

Fig. 2. Short schematic illustration of study design.

A nitrification inhibitor (Formula 2533®, Hach Company) was used at all OUR runs to prevent possible interference of nitrification. The model was calibrated with the experimental OUR data to yield meaningful values for (i) the kinetic and stoichiometric model parameters associated with different processes incorporated into the model, and (ii) relevant COD fractions in the RUN 1 and the RUN 2 of the plant. Model simulations and parameter estimation were done using AQUASIM [19]. In the model, constants ($\mu_{Hmax}$, $K_s$, $b_H$, $Y_H$, $k_h$, $K_x$, $f_{ES}$ and $f_{EX}$) must have an appropriate values for evaluation and modeling of activated sludge behavior of organic carbon removal. While $Y_H$ and $b_H$ coefficients were identified by OUR measurements, $K_s$, $k_h$ and $K_x$ constants could be calculated only by curve fitting the model to experimental OUR profiles. Although the growth process ($\mu_{Hmax}$, $K_s$) is described as directly related with biodegradable COD, according to recently accepted models for determining of activated sludge behavior, it was understood that this process is not very important for systems operated only organic carbon removal in terms of COD removal efficiency which depends mostly on the hydrolysis of the slowly biodegradable COD. The matrix representation of the model structure is given in Table 1. The model parameters and initial state variables were estimated in accordance with the method proposed [20] and [21].

### *2.5. Analysis*

All analyses were performed according to the Standard Methods [22] except COD. The COD was measured according to ISO 6060 Method [23]. For soluble COD determination, samples were subjected to vacuum filtration by means of Millipore membrane filters with a pore size of 0.45 μm.

The Millipore AP40 glass fiber filters were used for total suspended solids (TSS) and volatile suspended solids (VSS) measurements. pH was measured using WTW 330® pHmeter during sampling period.

## 3. Results and discussion

Pollution and process profile table was organized according to 5 segregated sub-streams composed of 11 segregated single streams contribute overall wastewater of the plant. As outlined in Table 2, the average production capacity of the plant was calculated as 52,434 pants per day from the evaluation of the last three years production on the base of sub-procesess mentioned in Fig. 2, with a wastewater flowrate of around 445 $m^3$ per day, corresponding to an average unit wastewater generation 8.5 l per pants processed. This value quite compatible with the range reported in the literature [24].

Table 1
Matrix representation of the selected model

| Component → | 1 | 2 | 3 | 4 | Process rate |
|---|---|---|---|---|---|
| Process ↓ | $S_S$ | $X_S$ | $X_H$ | $S_0$ | $M.l^{-3}.T^{-1}$ |
| Growth | $-\frac{1}{Y_H}$ | | 1 | $-\frac{1-Y_H}{Y_H}$ | $\hat{\mu}_H \frac{S_S}{K_S + S_S} X_H$ |
| Hydrolysis | 1 | –1 | | | $k_h \frac{X_S / X_H}{K_X + X_S / X_H} X_H$ |
| Decay | | | –1 | $-(1-f_E)$ | $b_H \cdot X_H$ |
| Parameter, $M.l^{-3}$ | COD | COD | Cell COD | $O_2$ | |

Table 2
Process profile of segregated sub-stream wastewaters of investigated plant based on COD load before recovery

| | Unit wastewater generation [l.(pants)$^{-1}$] | Production [pants. d$^{-1}$] | Water usage (»Wastewater amount) | | COD | | |
|---|---|---|---|---|---|---|---|
| Process | | | [m$^3$.d$^{-1}$] | (%) | (mg.l$^{-1}$) | (kg.d$^{-1}$) | % |
| Desizing | 3.1 | 7138 | 22 | 5 | 5090 | 112 | 23.1 |
| Rinsing | 3.8 | 7138 | 27 | 6 | 1252 | 34 | 7.0 |
| **Stream I–Rinse Washing** | **6.9** | **7138** | **49** | **11** | **2975** | **146** | **30.1** |
| Tint dyeing | 3.8 | 6964 | 26.5 | 6 | 117 | 3 | 0.6 |
| Rinsing | 3.8 | 6964 | 26.5 | 6 | 145 | 4 | 0.8 |
| **Stream II–Tint dyeing** | **7.6** | **6964** | **53.1** | **12** | **131** | **7** | **1.4** |
| Local washing | 5.7 | 16556 | 94.6 | 21 | 652 | 62 | 12.7 |
| **Stream III-Local Washing** | **5.7** | **16556** | **94.6** | **21** | **652** | **62** | **12.7** |
| Bleaching | 3.8 | 7574 | 29 | 6.5 | 310 | 9 | 1.9 |
| İndirgeme | 3.8 | 7574 | 29 | 6.5 | 356 | 10 | 2.1 |
| Rinsing | 3.8 | 7574 | 29 | 6.5 | 177 | 5 | 1.1 |
| **Stream IV-Bleaching Washing** | **11.4** | **7574** | **87** | **19.6** | **281** | **24** | **5.0** |
| Washing with pumice stone | 3.8 | 14202 | 54 | 12.1 | 3029 | 164 | 33.7 |
| Rinsing-I | 3.8 | 14202 | 54 | 12.1 | 1129 | 61 | 12.6 |
| Rinsing-II | 3.8 | 14202 | 54 | 12.1 | 400 | 22 | 4.5 |
| **Stream V–Stone Washing** | **11.4** | **14202** | **162** | **36.4** | **1519** | **246** | **50.8** |
| **Overall Composite (calculated)** | **8.5** | **52434** | **445** | **100** | **1090** | **485** | **100** |
| **Overall Composite** | | | **445** | **100** | **1210*** | **540** | |

*measured.

In addition, Table 2 also shows that while the maximum water usage (»Wastewater amount) was observed at Stone washing process [36.4%], the minimum water usage occurred in Rinse washing process [11%], respectively as comply with the literature [24]. On the other hand, when an assessment was done in terms of COD loading, maximum COD loading was found at Stone washing process with the ratio of 50.8% similar to water usage (Wastewater amount). But minimum COD loading was calculated for bleaching process with the ratio of 5% unlike water usage (»Wastewater amount).

As expected, significant quality fluctuations and differences were obtained, best illustrated by an observed range of 117–5090 mg.l$^{-1}$ for COD, 300–4230 mg.l$^{-1}$ for TDS, 61-40844 Pt-Co unit for color and 14–1218 for NTU for segregated single wastewater streams. Sampling procedure carried on every batch discharge also enables 6 different recoverable segregated single streams, basically related with low COD and color contents. So, the conventional characterization of RUN 1 and RUN 2 were measured as shown in Table 3. The values measured both wastewater exhibit strong character with respect to domestic sewage except nutrients [16].

Furthermore, the amount of the recoverable stream was calculated as 193 m$^3$.d$^{-1}$, corresponding to around 43% of the total wastewater volume. The RUN 1 and the RUN 2 were represented by preparing and analysing flow proportional composite samples. The results are summarized in Table 4. According to this table, the plant overall wastewater (RUN 1) reflects the typical character of denim processing effluents, with a high COD level of 1210 mg.l$^{-1}$ and TDS level of 1536 mg.l$^{-1}$ with respect to domestic sewage [16 ]. The table also shows that the segregation of the recoverable fraction with a COD concentration of only 275 mg.l$^{-1}$ which is likely to leave behind a wastewater of different quality in terms of the COD parameters.

There is no decisive quality requirement determined for reuse of textile effluents in the process. Generally, color is designated as the major concern together with chemical oxygen demand (COD) and total hardness.

As shown in Table 5, the COD and color magnitude of the RUN 1 are around 1210 mg.l$^{-1}$ and 5485 Pt-Co unit, respectively. 6 segregated single recoverable streams were selected according to the magnitude of these pollutants so that to minimize the effects of them on RUN 1 characteristics. But in any case, both with a COD of 275 mg.l$^{-1}$ and a color level of 483 Pt-Co unit, will require polishing before recovery such as UF/NF treatment or ozone application to achieve recovery criteria for textile wastewater segregated streams as described in the literature [12,25].

Since the stringent effluent limitations, the overall wastewater of the plant requires effective treatment to comply with the standards, similar to other textile wastewaters. Because more than 80% of the COD is soluble in

Table 3
Conventional characterization of wastewaters before and after recovery

| Parameters | RUN 1 | RUN 1 used in OUR experiment | RUN 2 | RUN 2 used in OUR experiment |
|---|---|---|---|---|
| pH | 5.8–6.5 | 5.82 | 5.3–6.45 | 5.34 |
| Conductivity, (mS.cm$^{-1}$) | 2.5–3.3 | 3.27 | 2.2–2.4 | 2.21 |
| TDS (mg.l$^{-1}$) | 1600–2110 | 2095 | 1410–1535 | 1415 |
| COD$_{tot}$ (mg.l$^{-1}$) | 1200–1577 | 1580 | 1750–2295 | 2295 |
| COD$_{sol}$ (mg.l$^{-1}$) | 700–1210 | 1200 | 1080–1692 | 1695 |
| TSS (mg.l$^{-1}$) | 2840–6800 | 2845 | 3330–9735 | 3330 |
| TVSS (mg.l$^{-1}$) | 280–625 | n.m. | 795 | n.m. |
| Alkalinity (mg.l$^{-1}$) | 2.5 | n.m. | 2.5 | n.m. |
| TKN (mg.l$^{-1}$) | 0.28 | n.m. | 0.28 | n.m. |
| T-P (mg.l$^{-1}$) | 4.3 | n.m. | 6.2 | n.m. |
| Turbidity (NTU) | 60 | n.m. | 100 | n.m. |
| Color (340 nm) | n.m | 1.059 | n.m | 0.983 |

*n.m.:not measured.*

Table 4
Pollution profile of the plant before and after recovery

| Wastewater | Flowrate | | COD | | TDS | |
|---|---|---|---|---|---|---|
| | [m$^3$.d$^{-1}$] | % | [mg.l$^{-1}$] | [kg.d$^{-1}$] | [mg.l$^{-1}$] | [kg.d$^{-1}$] |
| Overall wastewater | 445 | 100 | 1210 | 540 | 1536 | 684 |
| Reusable wastewater | 193 | 43 | 275 | 53 | 1600 | 309 |
| Effluent after recovery | 252 | 57 | 1750 | 441 | 1140 | 287 |

Table 5
Evaluation of wastewater quality for recovery

| Parameters | Recovery criteria | | | | Water quality | |
|---|---|---|---|---|---|---|
| | Hoehn (1998) [26] | Li and Zaho (1999) [27] | Goodman ve Porter, 1980 (Şahinkaya, 2007) [28] | Process water | RUN 1 | RUN 2 |
| pH | 6.5–7.5 | – | – | 7.65 | 6.6 | 6.7 |
| COD (mg.l$^{-1}$) | < 50 | 0–160 | 178–218 | 0 | 1210 | 275 |
| TDS (mg.l$^{-1}$) | – | 512–1408 | 1056–1408 | 250 | 1536 | 1600 |
| Color (Pt-Co unit) | 0 | – | 20–30 | – | 5485 | 483 |

textile wastewater and also wastewater generated from investigated plant in this study, mostly an activated sludge system is built as a treatment plant to achieve national standards. So, investigation and evaluation for this sector must be focused on biological treatability and with in the framework of the current understanding and interpretation of activated sludge behavior. Besides, COD fractionation and the experimental assessment of relevant kinetic and stoichiometric coefficients become a necessity to provide high biological treatment efficiency. The concept of differentiating COD fractionations based on biodegradability was developed and tested primarily for domestic sewage [29,30]. It was only recently that reliable information for industries, and especially for textile effluents were derived and reported in the literature [16]. Table 6 summarizes similar experimental data obtained from this study.

The results given in the Table 6 designates that while the biodegradable and readily biodegradable COD ratios of RUN 1 are around 95 % and 65 % respectively, it is observed that there is no any markedly alternation for these ratios which was calculated as 94% and 62% respectively in the RUN 2 comply with denim processing and cotton finishing values determined in the literature [31,32]. But when an assement was done in terms residual COD, while soluble inert fraction of the initial total COD ($S_I/C_T$) was not change with the ratio 3% before and after recovery, particulate inert fraction ratio of the initial total COD was ($X_I/C_T$) increase from the 1.6% ratio to 3.4% ratio. This may be considered as a specific COD fingerprint for the investigated plant. On the other hand, when these values compared to the other results determined in the literature, it is observed that both inert ratio values were found in the ranges determined for textile industry, while they much lower than associated with domestic sewage [28,32,33].

On the other hand, the kinetics coefficients were estimated according to Table 1, as illustrated in materials and methods. So, Table 7 shows experimentally computed values of these coefficients for both the RUN 1 and the RUN 2. As shown in this table, a $Y_H$ value of 0.68 g cellCOD.(g COD)$^{-1}$ and a $b_H$ value of 0.14 d$^{-1}$ were assumed to characterize both type wastewaters, as typical value equally related with most other textile industrial effluents.

The total COD concentration, although a useful index for biological treatment, in both RUN 1 and RUN 2 does not provide the necessary clues for the biodegradation characteristics of different organic matter fractions and therefore gives no indication on the treatability of the wastewater before and after recovery by means of biological processes. So, respirometric studies representing a major part of the investigation were carried out on wastewater occurred from before and after recovery implementation.

In this study, this information is obtained from the interpretation of OUR profiles derived for each wastewater streams. As displayed in Fig. 3 and Fig. 4, the OUR profiles associated with the RUN 1 and the RUN 2 represents nearly similar character, although they contain COD fractions with different biodegradation characteristics. Ss fraction of initial total COD is about 4% level for before and after recovery. However $S_{H1}$ fraction of initial total COD is decreased from 61% level to the 55% level while Xs fraction increase from 31% to 35% level.

COD fractionations derived from respirometric studies also indicates a soluble COD fraction of 68% for RUN 1 and 62% for the RUN 2, respectively, almost all indicates very small readily biodegradable portion with 4%. These values were found lower than determined in the literature determined for both textile industry and domestic sewage [31–33]. This situation can be explained as the different structure of the chemicals used in processes. On the other hand, it can be said that recovery does not have negative effect on the soluble and biodegradable fraction. Moreover, slowly biodegradable fraction of total COD was found 31% level for RUN 1 and 35% level for RUN 2. This fraction were found on the same level determined in the literature for the textile organized industry wastewater [33].

On the other hand, in terms of inert particular fractions, while it has been found that 3% of total COD has a soluble inert structure on the base of composite sample for both wastewater, 3.4% of total COD has been found in particular inert form in the RUN 2 to be about two times higher than the RUN 1. These values were found comply with the slowly biodegradable fraction of total COD for both RUN 1 and RUN 2.

Respirometric evaluations of RUN 1 and RUN 2 also showed that endogenous decay model best describes both the biodegradation of soluble fraction and kinetic coefficients. As a result of modeling studies, the yield coefficient, endogenous decay rate coefficient and half saturation rate coefficient values have been assumed for both wastewaters as 0.68 gcellCOD.(g COD)$^{-1}$, 0.14 d$^{-1}$ and 15 mg.l$^{-1}$ respectively, as similar to literature values determined for denim processing [31]. Maximum specific growth rate, hydrolysis half saturation rate coefficient, first and second level maximum specific hydrolysis rate coefficients for RUN 1 have been determined as 5.9 d$^{-1}$, 0.026 gCOD.(g cellCOD)$^{-1}$, 2.6 d$^{-1}$ and 0.05 d$^{-1}$, respectively. Similarly for the RUN 2, these values have been determined as 6 d$^{-1}$, 0.11 gCOD.(g cellCOD)$^{-1}$, 3.41 d$^{-1}$ and 0.05 d$^{-1}$, respectively. At the same time, parallel to biodegradation fraction results, khs/Kxs ratio also decrease from 100% level to the 31% level after recovery which are the highest than the literature determined for both textile industry and domestic wastewater [28,31,32,33].

Table 6
COD fractionations before and after recovery

| | Initial COD | | | COD Fractions | | | | | | | | | | Refrence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{T1}$ (mg.l$^{-1}$) | $S_{T1}$ (mg.l$^{-1}$) | $X_{T1}$ (mg.l$^{-1}$) | $S_{S1}$ (mg.l$^{-1}$) | $S_{S1}/C_{T1}$ (%) | $S_{H1}$ (mg.l$^{-1}$) | $S_{H1}/C_{T1}$ (%) | $S_{I1}$ (mg.l$^{-1}$) | $S_{I1}/C_{T1}$ (%) | $X_{S1}$ (mg.l$^{-1}$) | $X_{S1}$/CT1 (%) | $X_{I1}$ (mg.l$^{-1}$) | $X_{I1}/C_{T1}$ (%) | |
| **Denim processing** | | | | | | | | | | | | | | |
| *RUN 1* | 1580 | 1075 | 508 | 65 | 4 | 960 | 61 | 50 | 3 | 485 | 30 | 25 | 1.6 | This study |
| *RUN 2* | 2295 | 1432 | 878 | 92 | 4 | 1265 | 55 | 75 | 3 | 800 | 35 | 78 | 3.4 | |
| Denim processing | 1910 | 1570 | 340 | 325 | 17 | 1005 | 53 | 240 | 13 | 340 | 18 | – | – | [31] |
| Cotton Finishing | 2310 | 1900 | 400 | 420 | 18 | 1310 | 57 | 170 | 7 | 365 | 16 | 35 | 2 | [32] |
| Polyester Finishing | 1985 | 1485 | 500 | 300 | 15 | 770 | 39 | 415 | 21 | 390 | 19 | 110 | 6 | [32] |
| Textile Organised Industry District | 935 | 580 | 355 | 140 | 15 | 420 | 44 | 20 | 2 | 335 | 35 | 40 | 4 | [33] |
| Municipal wastewater | 450 | 155 | 295 | 40 | 9 | 97 | 21 | 18 | 4 | 250 | 56 | 45 | 10 | [28] |

Table 7
Estimated model parameters and state variables by means of model calibration

| | $Y_H$ (gcell COD. (gCOD)$^{-1}$) | [$\mu H_{max}$] (d$^{-1}$) | $K_S$ ( mg COD. l$^{-1}$) | $b_H$ (d$^{-1}$) | $k_{hs}$ (d$^{-1}$) | $K_{Xs}$ (gCOD.(gcell COD)$^{-1}$) | Reference |
|---|---|---|---|---|---|---|---|
| **Denim processing** | | | | | | | |
| *Overall wastewater* | 0.68 | 5.9 | 15 | 0.14 | 2.6 | 0.026 | This study |
| *Remaining wastewater after recovery* | 0.68 | 6 | 15 | 0.14 | 3.41 | 0.11 | |
| Denim processing | 0.68 | 3.2 | 20 | 0.14 | 1 | 0.16 | [31] |
| Cotton Finishing | 0.62 | 3.2 | 13 | 0.19 | 0.8 | 0.7 | [32] |
| Polyester Finishing | 0.69 | 5.3 | 25 | 0.12 | 3.8 | 0.65 | [32] |
| Textile Organised Industry District | 0.62 | 3.9 | 10 | 0.18 | 2 | 0.4 | [33] |
| Municipal wastewater | 0.67 | 4.9 | 6 | 0.24 | 2.5 | 0.45 | [28] |

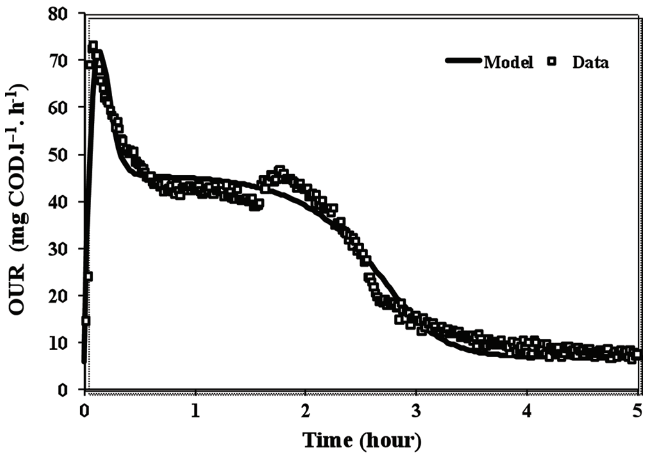

Fig. 3. Model calibration of the OUR profile obtained for the RUN 1.

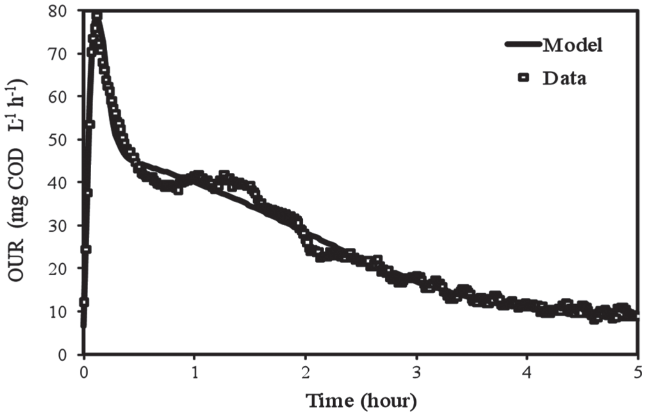

Fig. 4. Model calibration of the OUR profile obtained for the RUN 2.

## 4. Conclusions

Recently, although recovery operations seems very trendy approach in industrial systems, detailed treatability assessment for remaining wastewater after recovery is not investigated usually. The main objective of this study was to evaluate water recovery in terms of biological treatability assessment. The evaluation of this study can be summarized as follows:

- It is observed that there is no any difficulty as expected for biological treatability of remaining wastewater after recovery as a private for this plant. So, recovery application does not come into any restrict in terms of both biological treatability of remaining wastewater and discharge limits for the investigated plant.
- Consequently, because of water sources supply problem in all over the world, water recovery which considers on the changing in treatability characteristics of wastewater should be researched and assessed especially in industrial facilities in advanced level. Hence, water recovery researches carried out according to the character of pollution source can be implemented in similar to this plant in the next studies.

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