# TREATABILITY EVALUATION OF MUNICIPAL WASTEWATER AND ANAEROBICALLY-TREATED INDUSTRIAL EFFLUENT IN A ROTATING BIOLOGICAL CONTACTOR

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**Abstract** Performance of a rotating biological contactor (RBC) in treating municipal wastewater from primary sedimentation basin and anaerobically treated industrial effluent from an upflow anaerobic sludge blanket (UASB) reactor was investigated. The 280-L six-stage RBC pilot was operated at different organic loading rates and biodisc speeds. The overall removal efficiencies of soluble BOD decreased with increasing organic loading rates. Disk rotational speed did not have significant effect on performance in the range studied. The results showed that satisfactory treatment of UASB effluent to meet regulatory requirement for agricultural purposes (effluent BOD of 100 mg $L^{-1}$) can be achieved with sufficient margin of safety at organic loading rate of up to 4.9±0.4 g SBOD $m^{-2}$ $d^{-1}$ with SBOD removal efficiency of 59±9%. For municipal wastewater, it was possible to achieve SBOD effluent values of below 20 mg $L^{-1}$ all the time. Most of the organics were removed in the first three stages with minimal contribution from the remaining stages of the RBC reactor. There was a decrease in SBOD removal efficiency to 74 ± 3% at OLR value of 17.8 ± 2.1 g SBOD $m^{-2}$ $d^{-1}$ and 66 ± 6% at OLR value of 4.7 ± 1.9 g SBOD $m^{-2}$ $d^{-1}$ for UASB effluent and municipal wastewater, respectively. The results for elimination capacity (EC) values indicated a linear relationship with first-stage organic loading rates without any signs of limitation in the range of OLR values investigated in this study. However, average first-stage elimination capacity rates of 3.2 and 2 at OLR values of 17.8 and 11 gSBOD $m^{-2}$ $d^{-1}$ for UASB effluent and 1.3 and 2 at OLR values of 4.7 and 5.3 gSBOD $m^{-2}$ $d^{-1}$ for municipal wastewater were relatively lower than previous studies of RBC performance using domestic or industrial wastewater without anaerobic pretreatment. It was suggested that the lower EC values were due to the fact that a smaller fraction of UASB effluent was biodegradable as reflected in SBOD/SCOD ratios of 0.47± 0.04. For municipal wastewater, even though SBOD/SCOD ratios were 0.49± 0.03, the low EC values were suggested to be contributed to lower influent concentration potential considering first-order kinetics governing biochemical reactions.

**Keywords** RBC, Biofilm, Fixed-Film Treatment, UASB, Slaughterhouse, Industrial Wastewater

**چکیده** عملکرد یک سیستم دیسکهای گردان RBC در تصفیه فاضلاب شهری خروجی از حوضچه ته نشینی اولیه و فاضلاب صنعتی تصفیه شده توسط سیستم بیهوازی بررسی شد. سیستم پایلوت شش مرحله ای با حجم ۲۸۰ لیتر، بارگذاری آلی و سرعت مختلف چرخش دیسک راهبری گردید. بازدهی کلی تصفیه SBOD با افزایش بارگذاری آلی کاهش یافت ولی سرعت چرخش دیسک‌ها تأثیر قابل ملاحظه‌ای بر عملکرد ایجاد ننمود. نتایج بدست آمده نشان داد که میزان تصفیه قابل قبول برای تأمین الزامات استفاده فاضلاب برای اهداف کشاورزی (BOD خروجی ۱۰۰ mg/L) در بارگذاری ۴/۹±۰/۴ با ضریب ایمنی مناسب با بازدهی تصفیه SBOD ۹±۹۵٪ قابل دستیابی است. برای فاضلاب شهری، مقدار خروجی در کلیه شرایط کمتر از ۲۰ بود. اکثر مواد آلی در اولین سه مرحله حذف گردید و نقش دیگر مراحل ناچیز بود. راندمان تصفیه در بارگذاری آلی OLR برابر g SBOD $m^{-2}$ $d^{-1}$ ۱۷/۸±۲/۱ به ۳± ۷۴٪ و در OLR برابر g SBOD $m^{-2}$ $d^{-1}$ ۴/۷±۱/۹ به ۶±۶۶٪ بترتیب، برای فاضلاب صنعتی خروجی از UASB و فاضلاب شهری کاهش یافت. نتایج ظرفیت حذف EC از وجود رابطه خطی با بارگذاری آلی به مرحله اول حکایت می‌کرد و نشانی از محدودیت میکروارگانیسمها در حذف BOD در دامنه مورد بررسی بروز ننمود. در عین حال، میانگین نرخ ظرفیت حذف معادل ۳/۲ و ۲ در بارگذاری آلی ۱۷/۸ و gSBOD $m^{-2}$ $d^{-1}$ ۱۱ برای خروجی UASB و ۱/۳ و ۲ در بارگذاری آلی ۴/۷ و gSBOD $m^{-2}$ $d^{-1}$ ۵/۳ ، بطور نسبی کمتر از ارقام گزارش شده در مطالعات قبلی بود. پیشنهاد شد که ارقام کمتر می‌تواند ناشی از این امر باشد که با توجه به نسبت موجود در خروجی، درصد مواد آلی تجزیه پذیر کمتر بوده است. برای فاضلاب شهری، اگر چه نسبت برابر بود، اما مقدار کمتر بدست آمده می‌تواند بعلت کمتر بودن پتانسیل غلظت بعنوان نیروی محرکه در سینتیک درجه اول واکنشهای بیوشیمیایی باشد.

## 1. INTRODUCTION

A rotating biological contactor (RBC) is an efficient and reliable aerobic treatment system for both municipal and anaerobically pre-treated industrial wastewater. Anaerobic effluent has to be complemented by aerobic post-treatment in order to meet applicable discharge standards for surface water or irrigation purposes. RBC is a fixed-growth aerobic treatment system consisting of a series of biomass covered hard plastic disks partially submerged in wastewater and in alternate contact with wastewater and exposure to air. Needed nutrients for microbial community are derived from the wastewater film flowing over the discs' surface and oxygen is supplied from air. Different configurations can be employed but multistage concept has proven more efficient. Since its first application in Europe in late 50s and early 60s, a growing market has been reported for both domestic and industrial effluents ranging from small units serving residential dwellings to very large ones treating large flows of up to several million liter per day ( Strom and Chung [1]; Borghi et al. [2]; Saggy and Kott [3]; Banerjee [4] ). The principal reasons are easy construction, simplicity of operation and maintenance, stability under shock loads, and low energy consumption. Modifications made to augment performance characteristics of rotating biological contactors have made this treatment system more popular in the past two decades. Different operational parameters influencing reactor performance have been studied including rotational speed of disks (Friedman et. al.[5]), dissolved oxygen concentration of wastewater ( Paolini [6] ), organic and hydraulic loading rates ( Lin et. al., 1986 ) and number of stages ( Evans [7]; Andreadakis [8] ) to elucidate the behavior and thus the performance of RBC process. Fixed-film biomass accounts for almost all of the activity observed and the role of suspended growth is minimal and significant only for enhancing biofilm development on the disc media ( Ware [9] ). Tyagi et al. [10] reported up to 88% removal efficiency of TCOD from petroleum refinery effluent at disk speed of 10 rpm and various hydraulic loading rates (0.01-0.04 $m^3$ $m^{-2}$ $d^{-1}$). At an organic loading rate of 7.8 g SBOD $m^{-2}$ $d^{-1}$, Poon et al. [11] did not observe a significant effect from disk speed variations in the 3-7 rpm range. Results from RBC treatment of slaughterhouse effluent ( Blanc et al. [12] ) showed a maximum of 74% COD removal at OLR of 5 g SBOD $m^{-2}$ $d^{-1}$.

In this study, performance of a rotating biological contactor is compared for post treatment of effluent from UASB effluent and treatment of municipal wastewater after going through the primary sedimentation basin. Particular attention was paid to system stability under different organic loading rates and disk speed. The results for performance of different stages are also presented.

## 2. MATERIALS AND METHODS

**2.1. Experimental Set Up** A six-stage rotating biological contactor system was setup downstream of an upflow anaerobic sludge blanket reactor and downstream of primary sedimentation tank of a municipal wastewater treatment plant. The 280-L pilot used in this study (Figure 1) contained 16 hard polyethylene disks with an effective surface area of 0.375 $m^2$. The disk diameter was 0.5 m with a thickness of 0.03 m and they were spaced at 0.03 m intervals. The disks were 37% submerged into wastewater. The system was covered to retard photosynthetic growth.

**2.2. Feed** The wastewater stream from a traditional slaughterhouse used as influent to UASB reactor consisted of effluent from a combination of several stages. It included blood from killing operations, wash waters from stomach and intestines, and wastewater from the refrigerated chambers and toilets. There was no differentiation of effluent form these operations and because of the inherent nature of the process, characteristics varied at different times. Addition of nutrients was not deemed necessary since wastewater characteristics including lack of blood recovery indicated adequate concentration of essential proteins and trace elements. For the municipal wastewater, a side stream from the outlet of primary sedimentation basin of a municipal wastewater treatment plant serving a population of around 1.5 million was used as influent to the RBC reactor.

Characteristics of RBC influent were dependent on UASB reactor performance, which was in turn a function of slaughterhouse operations. A sedimentation tank was used to capture high solids content of influent at times of UASB malfunction and sludge washout. For the municipal wastewater, there was

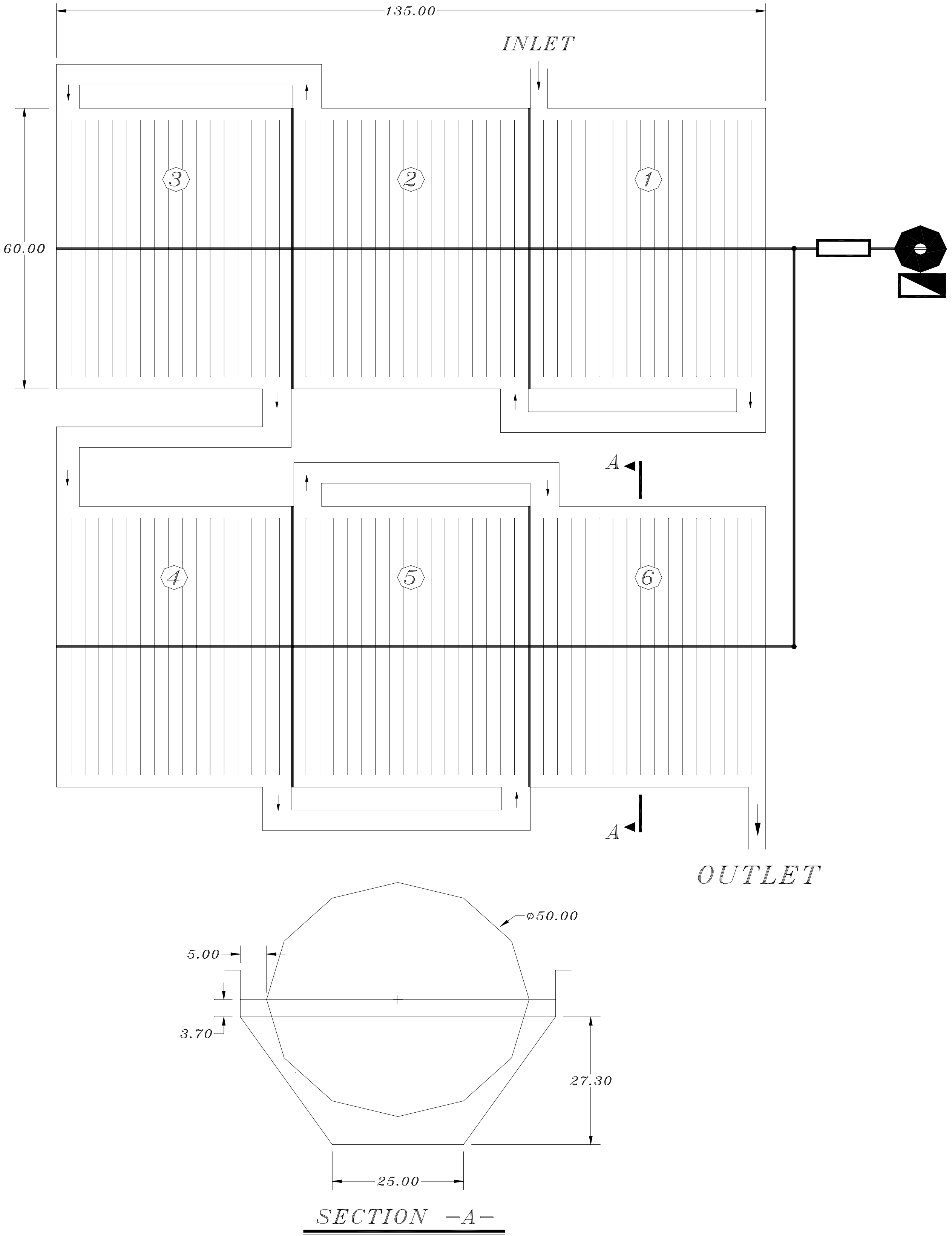


**Figure 1.** Schematic diagram of rotating biological contactor.

**TABLE 1. Wastewater Characteristics of RBC Influent at Different Periods of Study.**

| Parameter | UASB Effluent | | Municipal Wastewater | |
|---|---|---|---|---|
| | Range | Average±SD | Range | Average±SD |
| SBOD, mg/L | 331-1160 | 624 ± 264 | 31-92 | 61±17 |
| TBOD, mg/L | 658-1460 | 961 ± 257 | 99-113 | 106±6 |
| SCOD, mg/L | 721-2273 | 1122 ± 433 | 114-134 | 125±7 |
| TCOD, mg/L | 1415-3426 | 2061 ± 637 | | |
| SBOD/SCOD | 0.43-0.85 | 0.55 ± 0.09 | 0.47-0.54 | 0.49±0.03 |
| TSS, mg/L | 400-1498 | 729 ± 305 | 81-95 | 89±5 |
| VSS, mg/L | 243-1099 | 645 ± 216 | 57-74 | 64±7 |
| $NH_4$-N, mg/L | 26 - 46 | 36 ± 15 | 18-22 | 20±1.4 |
| TKN, mg/L | 36 - 64 | 52 ± 15 | | |
| Soluble P, mg/L | 3.2 – 5.6 | 3.9 ± 1.6 | | |
| pH | 7.1-7.8 | 7.5 ± 0.2 | 7.2-7.4 | 7.3±0.1 |

**TABLE 2. Summary of Operational Conditions for the RBC Reactor (Value ± Standard Deviation).**

| Municipal Wastewater | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Phase | Period, days | HLR, $m^3 m^{-2} d^{-1}$ | HRT, h | T, ºC | Disk speed rpm | SBOD, mg/L | OLR, $gSBODm^{-2} d^{-1}$ | Effluent SBOD, mg/L |
| 1 | 40-64 | 0.03 | 6.2 | 15.1±2.8 | 7 | 62.3±17.1 | 1.87±0.54 | 8.5±1.1 |
| 2 | 70-87 | 0.05 | 3.4 | | | 59.7±18.4 | 3.28±1.1 | 16.5±5.3 |
| 3 | 94-113 | 0.08 | 2.3 | | | 58.7±16.2 | 4.69±1.4 | 19.8±6.1 |
| 4 | 123-143 | 0.08 | 2.3 | 21.0±1.7 | 10 | 65.8±15.7 | 5.27±1.3 | 16.5±5.2 |
| 5 | 148-166 | 0.05 | 3.4 | | | 58.4±17.2 | 3.21±0.99 | 11.1±3.3 |
| 6 | 173-196 | 0.03 | 6.2 | | | 62±16.6 | 1.86±0.52 | 6.5±2.1 |

| UASB Effluent | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Phase | Period, days | HLR, $m^3 m^{-2} d^{-1}$ | HRT, h | T, ºC | Disk speed rpm | SBOD, mg/L | OLR, $gSBODm^{-2} d^{-1}$ | Effluent SBOD, mg/L |
| 1 | 1-22 | 0.018 | 10.4 | 17.1±3.7 | 8 | 987±115 | 17.8±2.1 | 252±26 |
| 2 | 23-60 | 0.01 | 18.8 | | | 887±201 | 8.9±2 | 149±10 |
| 3 | 61-85 | 0.01 | 18.8 | | | 525±286 | 5.3±2.9 | 76±36 |
| 4 | 85-114 | 0.025 | 8.4 | 30.0±1.7 | 11 | 432±31 | 11±2.9 | 120±33 |
| 5 | 114-128 | 0.015 | 12.5 | | | 483±25 | 7.3±0.4 | 99±17 |
| 6 | 128-143 | 0.01 | 18.8 | | | 488±36 | 4.9±0.4 | 59±9 |

much less variation in the characteristics of influent to the RBC reactor. The range and average values of different parameters for both cases are shown in Table 1. Dissolved oxygen concentration for the UASB case was below 0.5 mg $L^{-1}$ most of the time because no auxiliary aeration was provided prior to RBC entry. Characteristic rotten egg smell of hydrogen sulfide was noticeable resulting in the growth of sulfur bacteria on the first few disks of the first stage. Furthermore, the fraction of biodegradable organics was different form the raw wastewater in that the UASB reactor treated the majority of these constituents.

**2.3. Operation** It was possible to direct flow into the different stages of the RBC reactor in parallel, series, or a combination of both but in this study only series option was used. Samples were collected two to three times a week from influent, stages one, three, and six.

Two schemes of operation were selected. In the first three phases of the study, disk speed was set at 7-8 rpm and organic load was varied and in the next three phases disk speed was 10-11 rpm. Variation of organic load was achieved by a combination of the use of different influent concentrations and hydraulic load variation into the RBC reactor. Temperature of the wastewater was different for different disk speeds mainly because the reactor temperature was governed by temporal variations and no temperature compensation mechanism was in place. Other operational conditions are presented in Table 2.

**2.4. Analytical Methods** Grab samples of influent, and stages 1 and 3 and 6 (effluent) of the reactor were collected in containers and stored in fridge at 4 ºC and analyzed within 24 hours after collection. Routine analyses including soluble (filtered sample with a 0.45 μm pore size glass microfiber filter) and total $BOD_5$ and COD, nitrogen, and phosphorus were performed using procedures outlined in the Standard Methods (APHA[13]).

**2.5. Operational and Performance Parameters** Operational and performance parameters include organic and hydraulic loading rate, removal efficiency, elimination capacity, and hydraulic detention time. Loading rates can be looked at from the pollution indicator, empty reactor bed volume, disk surface area, and microbial mass. Organic loading rate (OLR) used here takes into account the liquid flow rate and contaminant concentration and is defined as the mass of pollutant applied onto a unit area of RBC reactor disk area per unit time (e.g. g COD $m^{-2}$ disk. day). As such, this parameter integrates reactor characteristics, operational characteristics, and biofilm mass and activity into the surface area of biodiscs. Elimination capacity (EC) can be used as a performance indicator. Elimination capacity is related to organic loading rate in that it is defined as the fraction of the organic load biodegraded. It differs from removal efficiency (η), an operational parameter, which is a measure of the effectiveness of the reactor in degrading a contaminant. Elimination capacity is a useful parameter for design purposes and removal efficiency helps the operator determine if his system is complying with regulatory effluent requirements.

Mass loading rate (g $m^{-2}$ $d^{-1}$) and elimination capacity (g $m^{-2}$ $d^{-1}$) were determined using the relationships between influent and effluent contaminant concentration, effluent flow rate, the effective volume of the RBC reactor, and applying appropriate conversion factors as follows:

$$OLR = \left( \frac{Q}{A_d} \right) C_{in} \tag{1}$$

$$EC = \left( \frac{Q}{A_d} \right) \left( C_{in} - C_{out} \right) \tag{2}$$

where Q is the effluent flow rate ($m^3$ $h^{-1}$), $A_d$ is the surface area of biodiscs($m^2$), and $C_{in}$ and $C_{out}$ are the contaminant concentrations (mg $L^{-1}$) in the influent and effluent stream of the whole or each stage of the reactor, respectively.

## 3. RESULTS AND DISCUSSION

Performance of the RBC reactor during the study can be subdivided into six different phases according to organic loading rates applied and disk rotational speed. The results of operational conditions and performance of the RBC reactor are presented in table 2.

**3.1. Start-Up** During start-up, the RBC reactor for UASB effluent treatment was filled with raw wastewater from slaughterhouse and was inoculated with a seed culture from an activated sludge unit of a domestic wastewater treatment plant. For the municipal wastewater RBC, initial filling was with raw domestic wastewater. Feeding was started at a hydraulic residence time of 3 days. After a week, a thin biofilm was observed on the disks for both

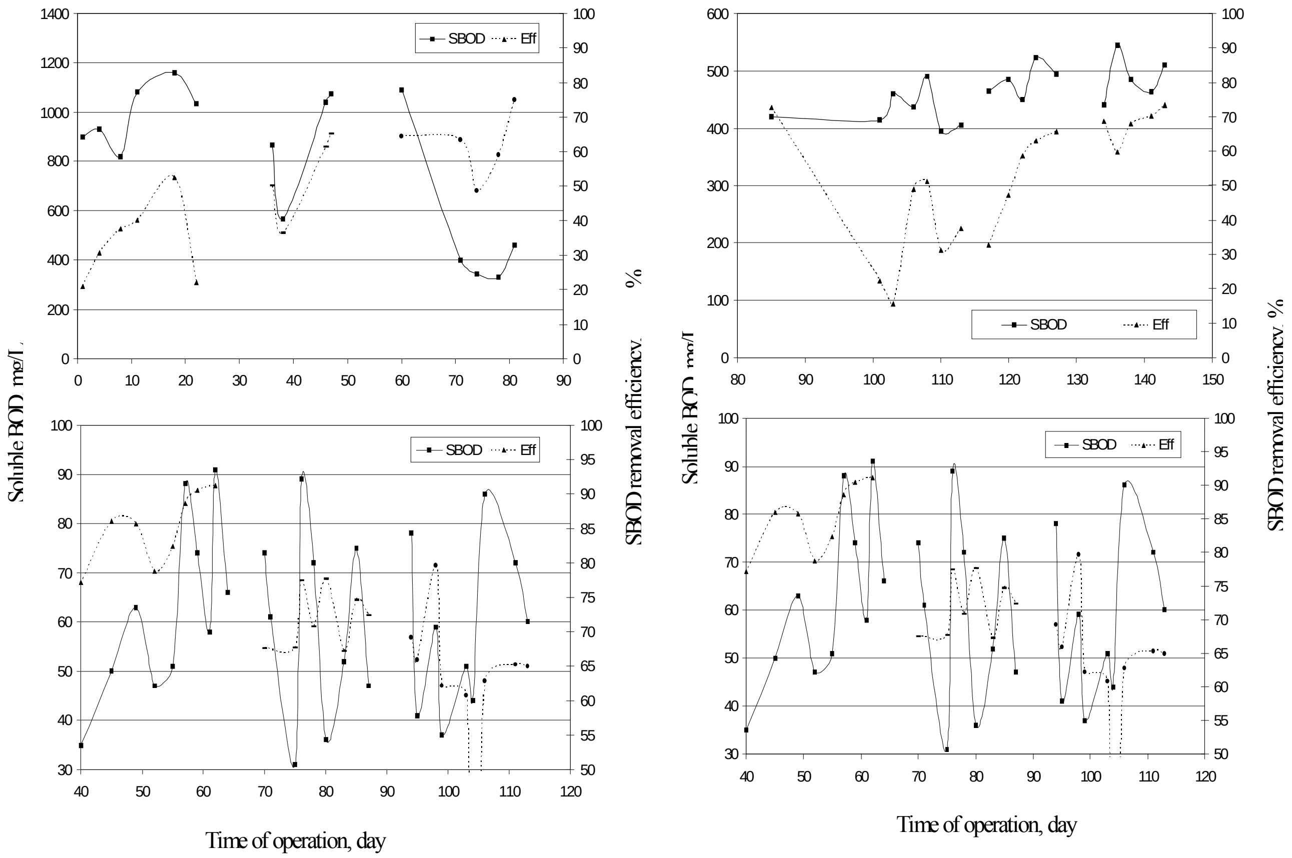


**Figure 2**. Overall removal efficiencies at different organic loading rates(top: industrial, bottom: municipal).

cases. At this time, feed was switched to the UASB effluent or municipal wastewater from primary sedimentation basin.

## 3.2. Organic Loading Rate

**Removal Efficiency** The influence of organic loading rate on process efficiency was studied by applying OLR values of between 5 and 18 gSBOD $m^{-2}$ $d^{-1}$ for the UASB effluent and 2 and 5.3 gSBOD $m^{-2}$ $d^{-1}$ for the municipal wastewater. The results presented in Figure 2 show decreased removal efficiencies with increasing organic loading rate. The overall removal efficiencies at different OLR values for 10-11 rpm (7-8 rpm) were as follows:

- SBOD from 88 ± 2 to 72 ± 8% (85 ± 4 to 74 ± 3%) - UASB effluent
- SBOD from 90 ± 4 to 73 ± 4% (85 ± 5 to 66 ± 6%) - Municipal wastewater

Low SBOD removal efficiencies in the beginning phases of UASB effluent experiments for different rotational speeds of days 1-22 and 85-114 at OLR values of 17.8 ± 2.1 and 11 ± 2.9 gSBOD $m^{-2}$ $d^{-1}$, resulted in unacceptable effluent quality (BOD of 220-290 mg $L^{-1}$). However, for the municipal wastewater, effluent quality of RBC reactor remained below 20 mgSBOD $L^{-1}$ all the time. There was a gradual increase in SBOD removal efficiency at high organic loading rates (Table 3) with time but it did not go above 50% and 30% for UASB effluent and municipal wastewater, respectively. For the UASB case, biofilm color in these phases was light gray and $H_2S$ smell was quite noticeable but for municipal wastewater first-stage dissolved oxygen concentration remained

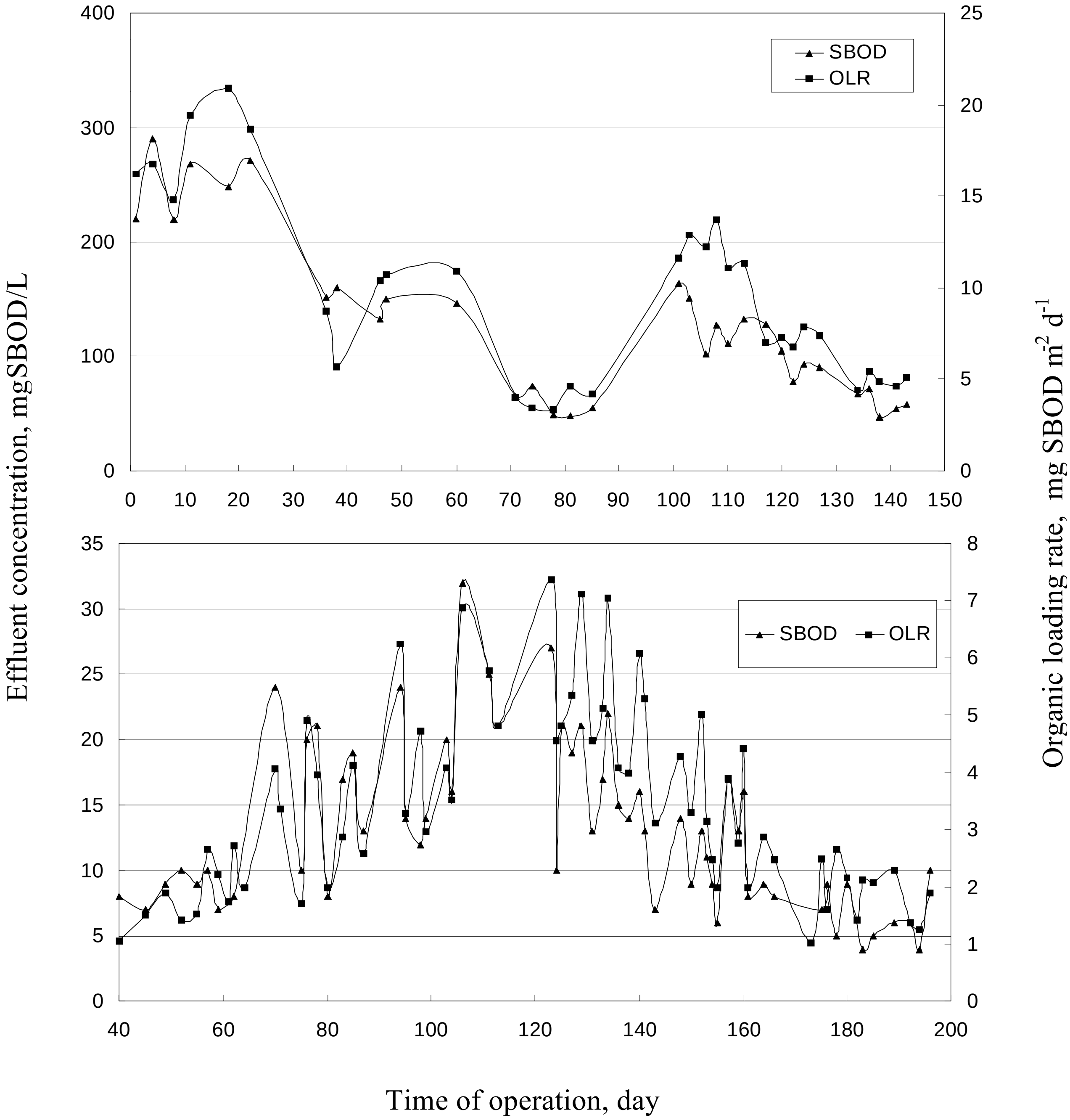


**Figure 3**. Effluent concentration of the RBC reactor at different organic loading rates(top: industrial, bottom: municipal).

above 1 mg $L^{-1}$ most of the time and never fell below 0.6 mg $L^{-1}$.

Decreased removal efficiencies could have been due to a combination of heavy biomass growth and oxygen limitations in the liquid phase of anaerobically treated wastewater. This in turn would have resulted in decreased mass diffusion of substrate and oxygen into the inner layers of active biomass. Available data in literature confirms the occurrence of these conditions. However, development

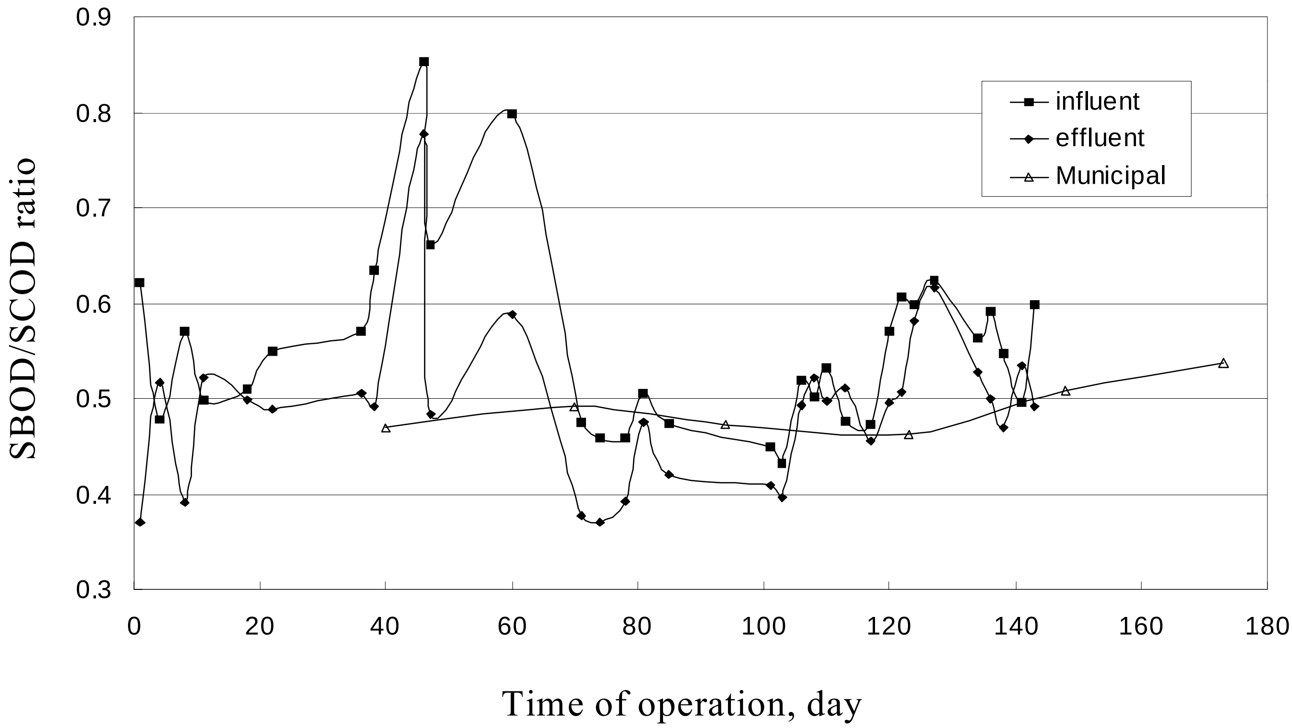


**Figure 4**. Total BOD/COD ratios for influent and effluent from RBC.

of anaerobic conditions and foul odor in this study occurred at lower OLR values than the reported in the literature. Previous investigations showed no indication of first-stage overloading problems at loading rates of up to 17.6 gSBOD $m^{-2}$ $d^{-1}$ (Evans[7]; Surampalli[14]). The main reason for this may be the fact that those studies were conducted on raw industrial and/or domestic wastewater without any pretreatment.

Post-treatment of anaerobically treated wastewater has the ultimate objective of obtaining effluent meeting regulatory requirements for intended uses. The results for effluent concentration at different organic loading rates and two disk speeds of 8 (days 1-85) and 11 rpm (day 85 onward) are shown in Figure 3. As illustrated in the figure, effluent concentrations meeting local regulatory requirements for agricultural purposes (effluent BOD of 100 mg $L^{-1}$) were achieved at organic loading rate of 4.9±0.4 g SBOD $m^{-2}$ $d^{-1}$ with SBOD removal efficiency of 59±9%. Effluent COD values were higher than normal ranges due to inherent nature of industrial wastewater of slaughterhouse industry containing less biodegradable chemicals used for cleaning facilities and equipment. There was no indication of any improvement due to the changes in rotational speed of biodiscs. Most of the organics were removed in the first three stages with minimal contribution from the remaining stages of the RBC reactor.

Comparison of removal efficiencies in this study with previous investigations indicates lower overall removals efficiencies. The reason could have been the fact that in those studies raw wastewaters were treated whereas in this study, RBC reactor was located downstream of a UASB system. This was indicated in the BOD/COD ratio calculations (see Figure 4). Influent and effluent BOD/COD ratio for RBC used to treat UASB effluent was 0.4-0.6 and 0.15-0.25, respectively, whereas for raw wastewater is 0.7-0.8 (Metcalf & Eddy[15]). For the municipal wastewater from primary sedimentation basin, this ratio was 0.49 as well. Results from relatively similar operating conditions are comparable to the findings of this study. For example, for treatment of anaerobically treated

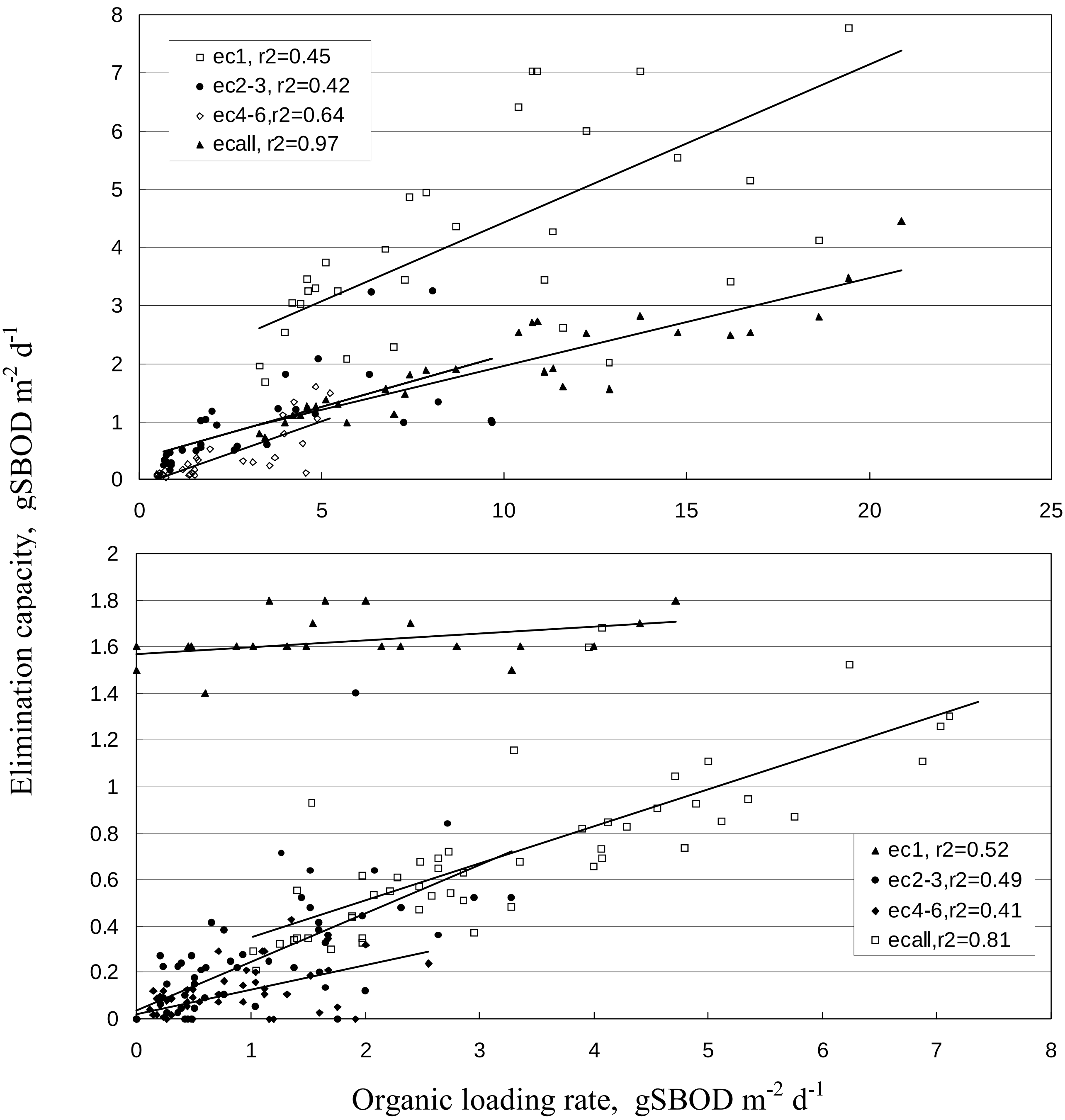


**Figure 5**. Elimination capacity of the RBC reactor at different organic loading rates(top: industrial, bottom: municipal).

domestic sewage at an OLR range of 6-21 g COD $m^{-2}$ $d^{-1}$ SCOD and TCOD removal efficiencies of 56-73 and 73-83% has been reported (Tawfik et al., 2002).

**Elimination Capacity** The results presented above indicate an adverse effect of increasing organic loading rate on operational indicators such as efficiency. Elimination capacity was used to

**TABLE 3. Elimination Capacities (gSBODm$^{-2}$ d$^{-1}$) and SBOD Removal Efficiencies (%) at Different Stage of the RBC Reactor.**

| Municipal Wastewater | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Phase | stage 1 | | stage 2-3 | | stage 4-6 | | overall | |
| | EC | η | EC | η | EC | η | EC | η |
| 1 | 1.1±0.44 | 60±8 | 0.15±0.09 | 37±17 | 0.07±0.04 | 41±19 | 0.53±0.22 | 85±5 |
| 2 | 1.4±0.59 | 41±10 | 0.27±0.15 | 28±14 | 0.13±0.08 | 31±9 | 0.72±0.39 | 72±4 |
| 3 | 1.7±0.73 | 34±12 | 0.39±0.17 | 26±10 | 0.20±0.10 | 26±13 | 0.85±0.37 | 66±6 |
| 4 | 1.9±0.48 | 36±5 | 0.7±0.35 | 39±12 | 0.22±0.13 | 30±12 | 1.04±0.34 | 73±4 |
| 5 | 1.5±0.60 | 45±9 | 0.33±0.17 | 39±9 | 0.14±0.07 | 38±10 | 0.72±0.28 | 81±4 |
| 6 | 1.2±0.45 | 66±8 | 0.13±0.10 | 39±24 | 0.05±0.04 | 43±20 | 0.50±0.15 | 90±4 |

| UASB Effluent | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Phase | stage 1 | | stage 2-3 | | stage 4-6 | | Overall | |
| | EC | η | EC | η | EC | η | EC | η |
| 1 | 6.2±2.5 | 34±11 | 1.9±1 | 31±13 | 1.7±0.5 | 41±7 | 3.2±0.7 | 74±3 |
| 2 | 5±1.9 | 53±11 | 0.9±0.2 | 46±11 | 0.2±0.2 | 28±11 | 2.1±0.7 | 82±6 |
| 3 | 3.3±1.9 | 62±8 | 0.5±0.3 | 46±5 | 0.1±0.05 | 24±7 | 1.3±0.7 | 85±4 |
| 4 | 4.1±1.7 | 40±18 | 1.3±0.6 | 36±8 | 0.6±0.6 | 26±12 | 2±0.5 | 72±8 |
| 5 | 3.9±1 | 53±12 | 0.6±0.05 | 35±6 | 0.4±0.25 | 30±12 | 1.6±0.2 | 79±4 |
| 6 | 3.3±0.2 | 68±4 | 0.4±0.1 | 44±6 | 0.15±0.05 | 31±7 | 1.3±0.1 | 88±2 |

determine the influence of increasing OLR on reactor performance. The results shown in Figure 5 for two different disk speeds indicate a linear relationship between OLR and elimination capacity for both industrial and municipal experiments. This linearity is more pronounced when considering the overall behavior ($r^2$=0.81 and 0.97) observed in all stages rather than considering performance of the RBC reactor at individual stages ($r^2$=0.41-0.52 and 0.42-0.64). The linearity of data even at high OLR values indicates that the reactor did not experience limitations regardless of disk rotational speed. However, there seems to be more scatter of the data at higher organic loading rates.

A summary of the applied organic loading rates and the associated elimination capacities for different stages of the RBC reactor are shown in Table 3. Average first-stage elimination capacity rates were 3.2 and 2 at OLR values of 17.8 and 11 gSBOD m$^{-2}$ d$^{-1}$ for the UASB effluent and 1.3 and 2 at OLR values of 4.7 and 5.3 for the municipal wastewater. These values are relatively lower than the almost 50% removal rate of 17 gSBOD m$^{-2}$ d$^{-1}$ at OLR value of 38.8 gSBOD m$^{-2}$ d$^{-1}$ observed by Surampalli [14] for a combination of municipal and dairy wastewater. As suggested before, the main reason can be low BOD/COD ratios and the presence of a higher fraction of less easily biodegradable organic matter for the UASB case. Other parameters potentially having influence on the observed elimination capacities include hydraulic residence time and wastewater temperature. Hydraulic residence times of 13-16 h for the UASB case were higher than the normal contact time for biodegradation in the fixed-growth systems but the range of 2.3 to 6 hours for the municipal wastewater were typical of the actual full-scale treatment plant conditions. Temperature could also have influenced the low EC values. However, comparison of the EC values for the first three phase of the study with the last three phases negates this possibility since there was no significant differences observed for up to 13 °C and 6 °C for the UASB and municipal case.

Analysis of the correlation coefficients confirmed the statement of linear relationship between OLR

**TABLE 4. Correlation Matrix for Different Parameters. Only Significant Values at p>0.05 are Shown.**

| Municipal Wastewater | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SBOD | | | Dissolved Oxygen | | | OLR | | | | EC | | |
| | HLR | RPM | 1 | 3 | 6 | 1 | 3 | 6 | 1 | 2 | 3-4 | 4-6 | 1 | 2-3 | 4-6 |
| SBOD1 | .62 | | 1.0 | | | | | | | | | | | | |
| SBOD3 | .65 | | .84 | 1.0 | | | | | | | | | | | |
| SBOD6 | .74 | | .82 | .89 | 1.0 | | | | | | | | | | |
| DO1 | -.87 | | -.58 | -.57 | -.63 | 1.0 | | | | | | | | | |
| DO3 | -.84 | | -.44 | -.46 | -.59 | .80 | 1.0 | | | | | | | | |
| DO6 | -.83 | .45 | -.44 | -.57 | -.68 | .77 | .84 | 1.0 | | | | | | | |
| OLR1 | .77 | | .91 | .85 | .84 | -.69 | -.57 | -.56 | 1.0 | | | | | | |
| OLR2 | .86 | | .92 | .83 | .87 | -.77 | -.66 | -.65 | .95 | 1.0 | | | | | |
| OLR3-4 | .86 | | .82 | .93 | .91 | -.73 | -.67 | -.71 | .91 | .93 | 1.0 | | | | |
| OLR4-6 | .87 | | .80 | .85 | .96 | -.75 | -.71 | -.75 | .88 | .93 | .96 | 1.0 | | | |
| EC1 | .37 | | .63 | .64 | .53 | -.34 | | | .79 | .56 | .57 | .51 | 1.0 | | |
| EC2-3 | .62 | | .81 | .44 | .57 | -.61 | -.46 | -.38 | .76 | .83 | .57 | .64 | .38 | 1.0 | |
| EC4-6 | .60 | | .64 | .83 | .56 | -.49 | -.42 | -.44 | .70 | .67 | .81 | .60 | .53 | .27 | 1.0 |
| ECALL | .55 | | .81 | .73 | .65 | -.51 | -.36 | -.34 | .93 | .77 | .71 | .66 | .95 | .65 | .61 |

| UASB Effluent | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SBOD | | | RPM | HLR | OLR | | | | EC | | |
| | 1 | 3 | 6 | | | 1 | 2-3 | 4-6 | overall | 1 | 2-3 | 4-6 |
| SBOD1 | 1.0 | | | | | | | | | | | |
| SBOD3 | .93 | 1.0 | | | | | | | | | | |
| SBOD6 | .96 | .96 | 1.0 | | | | | | | | | |
| RPM | -.49 | -.42 | -.43 | 1.0 | | | | | | | | |
| HLR | | | .36 | .40 | 1.0 | | | | | | | |
| OLR1 | .88 | .87 | .90 | | .65 | 1.0 | | | | | | |
| OLR2-3 | .83 | .92 | .89 | | .62 | .96 | 1.0 | | | | | |
| OLR4-6 | .79 | .83 | .87 | | .75 | .96 | .96 | 1.0 | | | | |
| OLRAVG | .87 | .89 | .92 | | .65 | .98 | .97 | .98 | 1.0 | | | |
| EC1 | .41 | .40 | .50 | | | | | .39 | .48 | 1.0 | | |
| EC2-3 | .77 | .56 | .69 | | .54 | .84 | .65 | .75 | .78 | | 1.0 | |
| EC4-6 | .79 | .93 | .82 | | .40 | .84 | .94 | .80 | .85 | | .45 | 1.0 |
| ECALL | .70 | .65 | .75 | | .36 | .67 | .63 | .68 | .77 | .92 | .57 | .51 |

and EC. As shown in Table 4, there was a significant correlation at $p>0.05$ level between OLR and EC for individual stages as well as overall value for the RBC reactor. The highest correlation coefficients were 0.93 between overall EC and OLR at stage 1 for the municipal case and 0.77 between overall EC and overall OLR for the industrial case. There was a consistent decreasing correlation from the beginning to the end stage for the municipal case whereas there was no discernible difference between stages for the industrial case. This may have been a reflection of the fact that at lower substrate concentrations, biofilm shows more sensitivity to incremental decrease in OLR whereas at high loadings, biofilm seems to be utilizing the easily accessible and sufficient substrate.

**3.3. Disk Speed** To determine the effect of rotational speed on the performance, the system was operated at 7 and 10 (municipal) and 8 and 11 rpm (industrial). Comparison of results for different speeds shows little change in performance due to disk speed. Correlation coefficients shown in Table 4 further illustrates the lack of any significant relation at $p>0.05$ level. There is a possibility that the peripheral velocity range studied (0.2-0.28) has been above the optimum and so no effect has been observed. However, the upper limit where increased speed results in no improvement is reported to be above 0.27 m/s ( Lehman [16] ).

## 4. CONCLUSIONS

Data presented in this study indicates the feasibility of using rotating biological contactors for treatment of municipal wastewater from primary sedimentation basin and post treatment of UASB effluent. There was a general trend of decreased removal efficiencies at higher organic loading rates but there was no indication of limitations in reactor elimination capacity even at high OLR values. The results showed that a major portion of the removals was realized in the first three stages of the RBC reactor. Acceptable effluent quality meeting secondary discharge requirement for agricultural purposes was obtained at organic loading rate of 4.9±0.4 g SBOD $m^{-2}$ $d^{-1}$ with SBOD removal efficiency of 85±3%. Effluent quality for the municipal experiments remained below 20 mg $L^{-1}$ all the time regardless of the disk rotational speed and organic loading rates applied.

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