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A pilot scale trickling filter with pebble gravel as media and its performance to remove chemical oxygen demand from synthetic brewery wastewater*

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Abstract: Evaluating the performance of a biotrickling filter for the treatment of wastewaters produced by a company manufacturing beer was the aim of this study. A pilot scale trickling filter filled with gravel was used as the experimental biofilter. Pilot scale plant experiments were made to evaluate the performance of the trickling filter aerobic and anaerobic biofilm systems for removal of chemical oxygen demand (COD) and nutrients from synthetic brewery wastewater. Performance evaluation data of the trickling filter were generated under different experimental conditions. The trickling filter had an average efficiency of (86.81±6.95)% as the hydraulic loading rate increased from 4.0 to 6.4 $m^3/(m^2\cdot d)$. Various COD concentrations were used to adjust organic loading rates from 1.5 to 4.5 kg $COD/(m^3\cdot d)$. An average COD removal efficiency of (85.10±6.40)% was achieved in all wastewater concentrations at a hydraulic loading of 6.4 $m^3/(m^2\cdot d)$. The results lead to a design organic load of 1.5 kg $COD/(m^3\cdot d)$ to reach an effluent COD in the range of 50–120 mg/L. As can be concluded from the results of this study, organic substances in brewery wastewater can be handled in a cost-effective and environmentally friendly manner using the gravel-filled trickling filter.

Key words: Biodegradation, Pilot scale trickling filter, Aerobic treatment, Brewery wastewater, Chemical oxygen demand (COD), Trickling filter performance
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1 Introduction

Industrial discharge into rivers is one cause of irreversible degradation occurring in surface water systems (Rajaram and Ashutosh, 2008). Due to their role in carrying off industrial wastewater, rivers are among the most vulnerable water bodies to pollution. There have been significant impairments to rivers from pollutants, rendering the water unsuitable for beneficial purposes, such as domestic use, irrigating agricultural lands, recreation, drinking, wildlife propagation, and food processing purposes in industries; all of these uses are on the rise, particularly in developing urban areas. With increasing scarcity of a treated public water supply, fresh river water has become an alternative source for these purposes (van der Bruggen and Braeken, 2006).

"Untreated brewing effluent poses a significant treat to surface and ground water qualities." The main brewery effluent sources include losses during bottle filling, cleaning (of returned bottles, fermentation and conditioning tank, vat and floors) and draining tank bottoms (Yu and Gu, 1996; Driessen and Vereijken, 2003). Untreated brewery effluent typically contains total suspended solids (TSS) (200–1000 mg/L), biochemical oxygen demand (BOD) (1200–3600 mg/L), chemical oxygen demand (COD) (2000–6000 mg/L), nitrogen (N) (25–80 mg/L), and phosphorus (P) (10–50 mg/L), with temperature in the range of 18–40 °C and a pH between 3–12 (Driessen and Vereijken,

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2003; IFC, 2007). The high organic content of brewery effluent classifies it as a very high-strength waste, meaning that the brewery effluent cannot simply be discharged into sewers or water courses (Huei, 2005). Direct discharge can bring about a rapid deterioration of the physical, chemical, and biological qualities of the receiving water bodies (The Breweries of Europe, 2002; Parawira *et al.*, 2005; Al-Rekabi *et al.*, 2007).

The decomposition of organic matter depletes the amount of dissolved oxygen in the water that is vital for aquatic life. Release of nitrogen and phosphorous compounds in the wastewater also stimulates aquatic plant growth contributing to eutrophication of water bodies. Furthermore, turbidity and color reduce the penetration of light, which, in turn, affects photosynthesis, thereby affecting the primary link in the food chain. The removal of organic compounds from the wastewater is important to avoid anaerobic conditions in the receiving waters. Nutrients like N and P should also be removed to avoid algal blooms that disturb the ecosystem of the receiving waters (Driessen and Vereijken, 2003).

Sequence batch reactor (SBR), upflow anaerobic sludge blanket (UASB) or conventional methane-oriented anaerobic digestion, activated sludge process, membrane process, and stabilization ponds have been extensively used for the treatment of different wastewaters. However, it has been found that these processes are affected by the presence of ammonium nitrogen (NH_4^+-N). NH_4^+-N in the wastewater can be removed by raising the pH value and then air-stripping the wastewater; however, this method is sometimes quite ineffective, depending on the operational parameters used and water quality, and the cost is usually prohibitively high, especially in developing countries (Zhao, 1999; 2001; Henry and Prasad, 2000; Zhao *et al.*, 2000; Youcai *et al.*, 2002). It is also well reported in the literature that in a complex wastewater treatment system, activated sludge normally exhibits poor settleability; as such, fixed film systems that would involve trickling filters, rotating biological contactors, et cetera, are recommended (Zurchin *et al.*, 1986).

In this study, a detailed investigation aimed at analyzing the performance of gravel-filled, naturally aerated trickling filter on brewing industry wastewater. Additionally, we aimed to demonstrate the use of a trickling filter filled with gravel as an alternative biological process over conventional activated sludge process, especially for low income countries. The present study is the first report on COD biological reduction in a pilot scale trickling filter using a mixed culture of microorganisms, originating from industrial wastewater sludge.

2 Materials and methods

2.1 Wastewater characterization

The wastewater was first subjected to pH adjustment using NaOH and HNO_3, roughing screens, and defoaming by the brewing company. The wastewater samples were then analyzed for COD, 5-d BOD (BOD_5), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4^+-N), total nitrogen (TN), phosphate (PO_4^{3-}), and total phosphorus (TP) calorimetrically. Prior to analysis, the soluble fraction of the wastewater samples was obtained by filtering with a syringe filter of 25 mm diameter (W/0.45 μm cellulose) for analyses of NO_3-N, NO_2-N, NH_4^+-N, and PO_4^{3-}. An unfiltered wastewater sample was used for analyses of COD, TN, and TP.

2.2 Pilot scale trickling filter

The schematic diagram of the pilot scale trickling filter is shown in Fig. 1. The pilot scale trickling filter consisted of a Plexiglas tube with an inner diameter of 40 cm and a total height of 180 cm. Sampling ports are located at fixed intervals of 260 mm along the height of the biofilter. At the top of the filter, a fixed flow distributor was installed to facilitate a uniform distribution of the wastewater fed to the filter's free surface. The wastewater was fed to the reactor after being stirred in a wastewater reservoir. Moreover, a secondary clarifier was installed to collect and settle the effluent from the filter's draining system. The supernatant from the secondary clarifier was collected in a 10-L container for recirculation via a recirculation pump.

The supporting material for bacterial growth was pebble gravel purchased from a gravel producer. The diameter of the filter stones, as obtained from the sieve analysis, was in the range of 4–6 cm. At the surface of the biofilter, a smaller sized stone (about

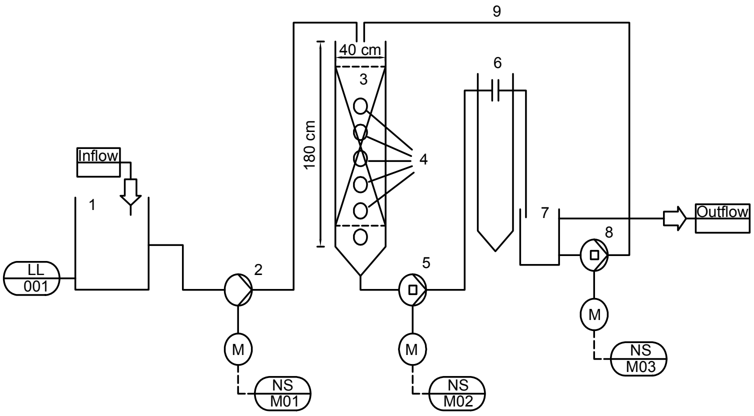

Fig. 1 Flow scheme of the experimental setup—pilot scale trickling filter

1: wastewater reservoir; 2: fed pump; 3: trickling filter; 4: sampling ports; 5: draining pump; 6: secondary clarifier; 7: clarified water; 8: recirculation pump; 9: recirculation

1.6–3.2 cm) that amounts to 5% of the total filter media was placed to get a larger surface area for bacterial attachment. The filter had a specific surface area and void ratio of 71.83 m^2/m^3 and 45%, respectively. The total depth of the filter media was 160 cm including the support stones at the base of the reactor.

Since the placement of the filter media is of paramount importance to the efficiency of the percolating filter, it was carried out with particular care and under proper control. Filter media were placed without prolonged intermediate storage. After the trickling filter was filled with the filter media, the packed filter media were washed with a sufficiently large volume of tap water and checked for flooding, flow rates, and hydraulic loading rates of the operation (flow rates up to 556 ml/min or hydraulic loadings up to 637 $ml/(cm^2 \cdot d)$). The other purpose of washing was to remove sands.

2.3 Ventilation of the trickling filter

The trickling filter was aerated naturally. Passive devices for ventilation of the trickling filter were presented in the form of vent stacks on the trickling filter periphery, extensions of underdrains through trickling filter sidewalls (the underdrain is angled to admit air). The other techniques of aeration in the trickling filter were ventilating manholes, louvers on the sidewall of the tower near the underdrain, and discharge of trickling effluent to outside in an open channel or partially filled pipes. Also the underdrain was kept always half filled.

2.4 Sludge control mechanism

As backwashing was not suitable for this type of bioreactor to control the sludge, the trickling filter was washed by pumping 10 L of 0.1 mol/L NaOH solution repeatedly for the first time after the trickling filter operated for 22 d, and then it was washed every two weeks. To bring the microbial environment near neutral, the reactor was subsequently washed with tap water. The other operation done on the trickling filter to reduce excess biomass was trickling filter starvation for a few days by turning off both the influent flow and recirculation flow for 3 to 4 d.

2.5 Instrumentation and analytical methods

Biomass concentrations were determined by weighing dried (24 h, 105 °C) 100 ml samples of the liquid phase. A spectrophotometer (Hach Lange Xion 500 LPG385) was employed for the measurement of COD and nutrients. Thermostatically controlled incubators with standard/glass door were employed for the measurement of BOD_5. Microprocessor-controlled standard-pH-ion-meter pMX 3000/pH was used to measure the pH values and temperatures of the influent and effluent. The influent and effluent samples collected and kept in a refrigerator were analyzed for the selected parameters using the Dr. Lange cuvette test system. During all experiments, measurements of pH, concentrations of COD, NH_4^+-N, PO_4^{3-}-P, and TN, and temperature were made three times per week unless otherwise indicated. COD removal efficiencies of the trickling filter can be calculated based on the reduction of COD concentration between the influent and effluent streams as shown in Eq. (1):

$$\text{COD removal}=(c_{\text{in}}-c_{\text{out}})/c_{\text{in}}\times 100\%, \quad (1)$$

where c_{in} is the influent COD concentration (mg/L) and c_{out} is the effluent COD concentration (mg/L).

2.6 Trickling filter operation

The synthetic wastewater simulated a medium-loaded, physically pretreated brewery wastewater. A concentrated substrate was used and later diluted with tap water to prepare the synthetic wastewater. Continuous operation of the trickling filter was conducted during all trickling filter operations. The first operation was the seeding of the trickling filter with real wastewater. The trickling filter was then acclimated firstly with real wastewater, then a mixture of both real and synthetic wastewater, and finally only with synthetic water until the system reached its steady state. COD reduction was monitored to evaluate the growth of the microbial population. Confirmation of the acclimation period was realized when the COD measurements for three consecutive days on the final effluent were approximately the same.

The next operation was the investigation of the effects of hydraulic and organic loading rates on the performance of the system. During this operation of the trickling filter, the performance was evaluated at five different hydraulic and organic loading rates. At each hydraulic and organic loading rate, the trickling filter was operated for about five consecutive days to ensure repetitiveness of the result. Investigation of the effect of different daily influent flow and inflow concentrations was also carried out. Initial influent sample analysis was done at the beginning of each run in all cases and final effluent sample analysis was done three times a week to investigate the effects of hydraulic and organic loading rates unless otherwise indicated and on a daily basis to investigate the effect of daily influent variation. The performance of the trickling filter for the temperature range of 20–40 °C and pH range of 3–12 was also investigated. Analyses of effluent COD taken from different heights of the trickling filter bed were also made.

3 Results and discussion

3.1 Real wastewater characteristics and preparation of synthetic water

The detailed characterization that was carried out on the Rostock brewery wastewater is shown in Table 1. The analysis characterized the brewery wastewater from the Rostock brewery as having BOD_5, COD, NH_4^+-N, NO_2-N, TN, PO_4^{3-}-P, and TP concentration ranges of 1.412–3.980, 1.651–9.306, 0.003–0.011, 0.229–0.440, 0.010–0.101, 0.008–0.010, and 0.017–0.050 g/L, respectively. All PO_4^{3-}-P, NO_3-N, NO_2-N, and NH_4^+-N concentrations stated throughout are soluble values only and were determined from microfiltered samples (0.45 μm).

Table 1 Physicochemical characteristics of the brewery wastewater

Constituent	Mean	Standard deviation	Maximum	Minimum
COD (mg/L)	5351	3228.2	9303	1651
BOD_5 (mg/L)	2101.2	1015.10	3980	1342
NH_4^+-N (mg/L)	4.96	2.94	10.50	2.47
NO_3-N (mg/L)	15.0	14.3	25.1	4.9
NO_2-N (mg/L)	0.25	0.14	0.44	0.09
TN (mg/L)	47.4	40.10	102.0	7.2
PO_4^{3-}-P (mg/L)	6.34	4.20	10.12	0.36
TP (mg/L)	25.42	13.69	43.40	13.00
Temp. (°C)	25	6.4	34	17
pH	9.42	1.60	12.40	8.00

As the brewery and laboratory were far apart, it was difficult to bring real brewery wastewater; therefore, as influent to the trickling filter plant, a synthetic sewage (Boeije, 1996) was used with a COD:N:P ratio of 102:2.1:1 (w/w/w). The type and concentration of each ingredient are based on typical concentrations of BOD_5, COD, pH, and nutrients found in brewery wastewater (Driessen and Vereijken, 2003) as well as on the analysis of samples obtained from Rostock brewery, Germany. Synthetic brewery wastewater was composed of 1 g/L malt extract, 0.5 g/L yeast extract, 0.15 g/L peptone, 0.86 g/L maltose, 0.10–2.20 g/L $(NH_4)_2SO_4$, and 2.80 ml/L ethanol. Buffering salts of 0.08 g/L NaH_2PO_4 and 0.14 g/L of Na_2HPO_4 are added to maintain the pH at 6.7. The final concentrations of COD, N, and P of the synthetic wastewater were also determined. The theoretical COD of the ingredients was calculated from their oxidation equation. For yeast extract, malt extract, maltose, and peptone, it is assumed that 1 mg/L of product equals 1 mg/L of COD. This was verified by comparing the calculated and the measured total COD of the influent (Boeije, 1996). According to one chemical supplier (Jeevan Chemicals and Pharmaceuticals, India), the measured value of N in peptone and yeast extract is 10.0% and 10.5%, respectively. And as per another supplier (Murphy & Son Limited, UK), typical malt has an analysis for TN within 1.45%–1.75%. The calculated COD:N:P ratio of the synthetic influent was 102:2.1:1 (w/w/w). The theoretical BOD_5, assuming a COD to BOD_5 conversion factor of 0.65, was 3451 mg/L. The composition of the synthetic influent based on this fact is presented in Table 2.

3.2 Trickling filter operation and performance

The pilot scale trickling filter was first seeded with real brewery wastewater. Near neutral brewery wastewater sludge (pH 6.7) was collected from the equalizing chamber of Rostock brewery. The wastewater was collected from the bottom of the chamber and taken with a cleaned plastic Jeri Can having a volume of 10 L. The reason to seed the trickling filter with this effluent is due to the fact that there is a high probability of getting microbial populations that are native to the wastewater (Rittman and Whiteman, 1994; Leta, 2004).

After the trickling filter seeding with the real wastewater and before developing performance data, the acclimation of the trickling filter was carried out. Firstly the trickling filter was operated in batch mode for seven consecutive days with a mixture of real and synthetic water by feeding new synthetic water on the 1st, 3rd, 5th, and 7th days. In all cases, the total COD concentration of the solution was 2000 mg/L. COD concentration was monitored during these operations. COD removal efficiencies of 81.7%, 71.5%, 79.8%, and 86.8% were achieved as monitored on the 1st, 3rd, 5th, and 7th days, respectively. Then the acclimation of the trickling filter continued only with synthetic wastewater from the 7th day onwards. This time the influent COD was varied from about 1000 to 4800 mg/L. A COD removal efficiency ranging from 74.0% to 95.4% was achieved during this last acclimation phase of the trickling filter. At this point, we considered the start up period completed and the filter ready for full operation. The trend of COD degradation during acclimation is presented in Fig. 2.

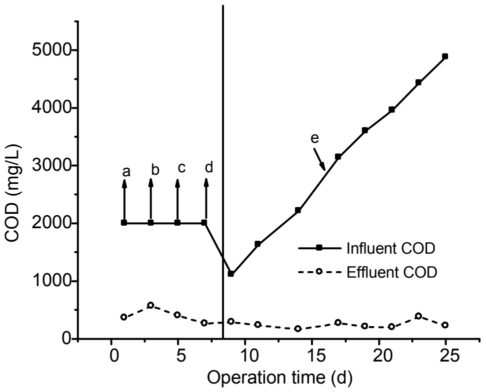

Fig. 2 Acclimation behavior of the trickling filter for COD degradation
a: 75% real and 25% synthetic; b: 75% real and 25% synthetic; c: 50% synthetic and 50% real; d: 25% real and 75% synthetic; e: 100% synthetic

Table 2 Composition of the synthetic influent used in this study

Name	Formula	Concentration	Solution
Ammonium sulphate	$(NH_4)_2SO_4$	100–2200 mg/L	Nitrogen source
Disodium hydrogen phosphate	Na_2HPO_4	140 mg/L	Phosphorus source & buffer
Ethanol	CH_3CH_2OH	2.8 ml/L	C-source
Malt extract		1000 mg/L	C-source
Maltose		860 mg/L	C-source
Peptone		150 mg/L	C-source
Sodium hydrogen phosphate	NaH_2PO_4	80 mg/L	Phosphorus source & buffer
Yeast extract		500 mg/L	C-source

3.3 Effect of hydraulic loading rate

The performance of the trickling filter at different hydraulic loading rates was also investigated. Four different flow rates were used in the feed, namely 800, 700, 600, and 500 L/d including recirculation flow at constant influent COD concentrations. The system efficiency ranged up to 77.70%–93.10%, 79.40%–96.70%, 88.30%–91.20%, and 84.10%–88.30% COD removal for the hydraulic loading of 6.3, 5.6, 4.8, and 4.0 $m^3/(m^2 \cdot d)$, respectively. An important conclusion that can be drawn here is that there is no significant decrease in the efficiency with increase of the hydraulic loading rate in the given range.

According to the relationship between mass removal loading rate and mass loading rate shown in Fig. 3, there is a direct relationship between the two parameters with 91% confidence limit. The slope of 0.83 means that when the mass loading rate increased by 1 $g/(m^2 \cdot d)$, the mass removal rate increased accordingly by 0.83 $g/(m^2 \cdot d)$.

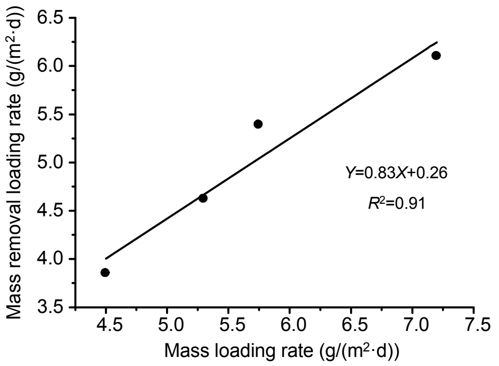

Fig. 3 Mass removal loading rate as a function of mass loading rate

3.4 Effect of organic loading rate

The response of the trickling filter for different organic loading rates was studied by varying the initial influent COD concentration (COD in the feed was increased to 1000, 1500, 2000, and 3000 mg/L), for a constant hydraulic loading of 6.3 $m^3/(m^2 \cdot d)$ and organic volumetric loading of 1.5, 2.5, 3.0, and 4.5 kg $COD/(m^3 \cdot d)$, respectively. The experiment was run for five consecutive days at each organic loading rate. The range of efficiencies at each organic loading rate was 84.20%–92.40%, 76.10%–87.10%, 70.58%–93.50%, and 76.50%–83.10%, respectively.

Since real situation wastewater that comes to the reactor varies in flow and concentration from day to day, the performance of the trickling filter at four different flows each with different initial COD concentration was also investigated. Four different flow rates were chosen: 300, 250, 200, and 150 L/d. The trend of the trickling filter effluent during each run was monitored. As can be seen from Fig. 4, the trickling filter efficiency was above 80% for all influent properties. This confirms that there is no significant decrease in trickling filter efficiency with increase in flow rate and COD concentration.

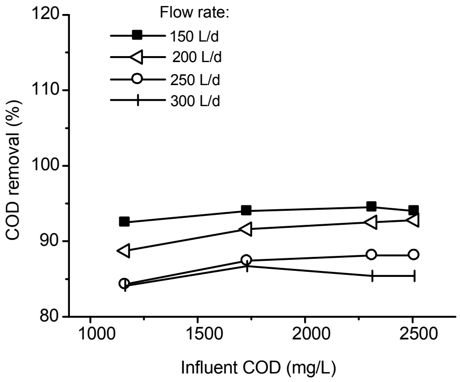

Fig. 4 Effects of wastewater COD concentration and flow rate on the efficiency of trickling filter

3.5 Effect of fed water pH

The effect of pH on COD degradation capacity of the trickling filter was examined over a pH range of 5.00–9.00. The pH was adjusted manually every 30 min to the desired value by the addition of 0.1 mol/L NaOH or 0.1 mol/L HCl as necessary. The trickling liquid at each specific pH was only kept for two consecutive days unless otherwise indicated. As can be observed in Fig. 5, the removal efficiency was maintained at a high value, (86.67±9.90)% between pH 6.00 and 8.00, and around 94.6% at pH 6.30. The COD removal capacity increased from 66.13 to 81.53 g $COD/(m^3 \cdot h)$ when decreasing the pH from 8.00 to 6.30, and dropped to the values of 46.63, 54.90, and 55.92 g $COD/(m^3 \cdot h)$ for pH values of 5.10, 8.30, and 9.00, respectively. The optimal degradation capability was obtained when the pH was regulated at a value of 6.3. This may be due to two reasons: on the one hand, it has been shown that different autotrophic and heterotrophic microbial groups and activities dominate at different pH values; on the other hand, the degree of availability of the different substrates is different at different pH values in the wet biofilm where the biodegradation takes place. To conclude, although it performs best in the pH range of 6.30–7.00, there was no significant decrease in the efficiency in the other typical pH values of brewery wastewater, indicating that the trickling filter system was able to effectively cope with the imposed change in pH.

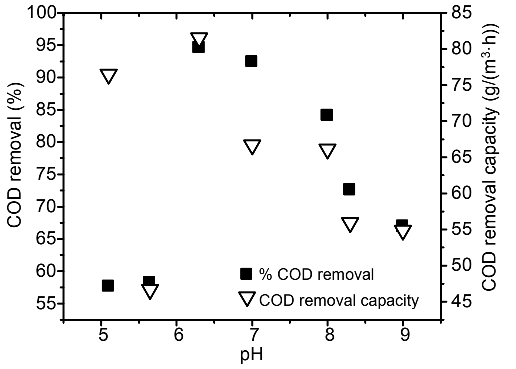

Fig. 5 COD removal capacity and removal efficiency of the trickling filter as a function of initial wastewater pH
Inflow: 300 L/d; Feed COD: (1102.59±68.93) mg/L

3.6 Effect of fed water temperature

Temperature is a very important parameter during the assessment of the overall efficiency of a biological treatment process. Temperature influences the metabolic activities of the microbial population and has also a profound effect on such factors as gas-transfer rates and the settling characteristics of the biological solids (Metcalf & Eddy, 1991a; Crites and Tchobanoglous, 1998). Temperatures below the optimum typically have a more significant effect on growth rates than that above the optimum. It has been observed that growth rates double with approximately every 10 °C increase in temperature until the optimum temperature is reached (Metcalf & Eddy, 1991b).

To investigate the effect of temperature on the trickling filter performance, the system was operated at five different temperatures: 20, 25, 30, 35, and 40 °C (Fig. 6). This temperature range was chosen to test the performance of the trickling filter, because it is the typical range for the wastewater of most brewing companies (Driessen and Vereijken, 2003). The result of this investigation showed that the trickling filter performs above 80% in all cases and the values are close to each other, indicating that temperature only exhibits a minor effect on the performance of the trickling filter for the given temperature range.

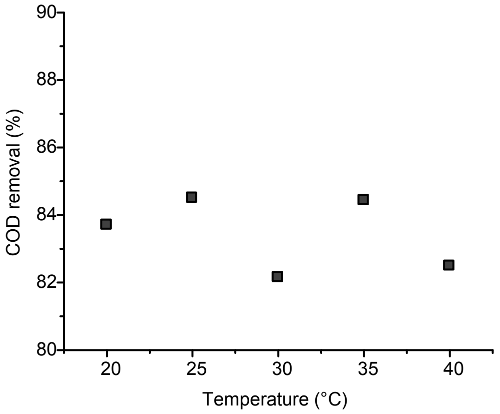

Fig. 6 Effect of wastewater temperature on COD removal efficiency
Influent COD: 1182 mg/L; Inflow: 300 L/d; Fed water pH: 6.30−6.81, nearly constant

3.7 COD removal profiles of the trickling filter

Fig. 7 depicts COD removal profiles of the trickling filter. A normal trend of effluent COD along the trickling filter height (downward decrease in effluent COD) was obtained during analysis of samples taken from the top, middle, and bottom sections of the trickling filter. However, the change in COD was not significant, which implies there was a homogeneous mixture in the reactor.

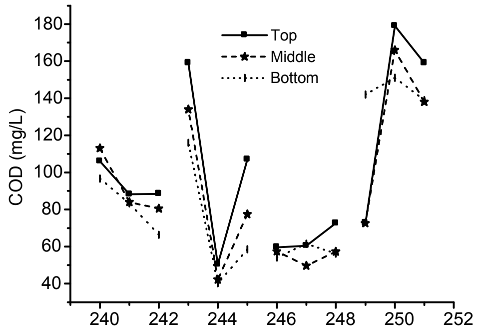

Fig. 7 Property of effluent COD along the trickling filter height
Inflow: 300 L/d; Feed COD: (1102.59±68.93) mg/L

3.8 Sludge reduction

3.8.1 Sodium hydroxide washing

The operation of the trickling filter with an average COD removal efficiency of (92±2.7)% was maintained until Day 17 (Fig. 8). However, after Day 18, due to excessive biomass accumulation, the removal efficiency was decreased. The higher rate of biomass accumulation was due to the operation of the trickling filter at high hydraulic and organic loading rates. The removal efficiency was below 62% on Days 18–21, and 50% at Day 19. The major cause for the decrease in trickling filter efficiency is believed to be the reduction of the biofilm-specific surface area with increases of biomass contents (Alonso *et al.*, 1997). To remove the excess sludge, the trickling filter was washed by repeatedly pumping 10 L of 0.1 mol/L NaOH solution (Weber and Hartmans, 1995). There was no significant decrease in the efficiency of trickling filter due to change in pH as a result of NaOH washing. The higher COD removal efficiency of the trickling filter was regained after washing of the trickling filter, because of the higher specific surface area of the trickling filter for the attachment of new biofilm growth and increase in porosity after the excess sludge is reduced.

3.8.2 Starvation

Decreased efficiency as a result of excess biomass accumulation was also managed by starving the trickling filter for a few days. The trickling filter was starved for a total of 4 d as described in Table 3. After starvation, there was a significant decrease in the biomass which may be the result of microorganism death, endogenous respiration, or secondary processes such as the predation of higher organisms (Zhang *et al.*, 2009). The recovery processes commenced after a 4-d starvation period, at which time normal operation of the biotrickling filter resumed. The biotrickling filter obtained high removal efficiency within 2 d of normal operation. Fig. 9 shows the efficiency of the trickling filter before and after starvation. The fast recovery of the biotrickling filter for COD removal suggests that there is no need for the buildup of significant amounts of new degrading biomass to resume the normal operation of the trickling filter.

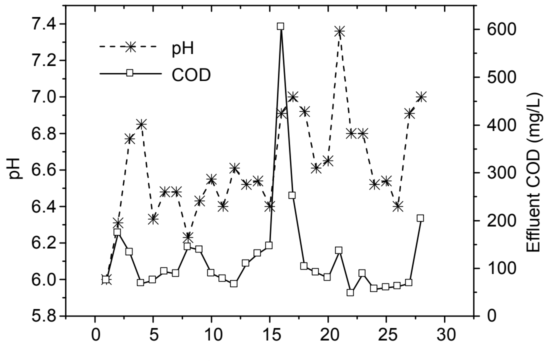

Fig. 8 Drop in trickling filter COD removal efficiency due to biofilm thickness and its recovery after NaOH washing

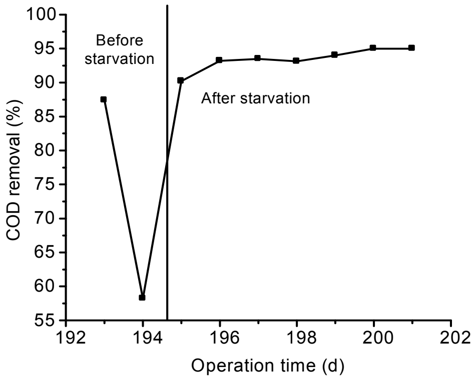

Fig. 9 A few days' starvation of trickling filter as sludge control mechanism and its effect on its COD removal efficiency

Table 3 Operating conditions for a few days' starvation of trickling filter

Operation day	Influent supply	Recirculation flow supply	Atmospheric air supply	Possible condition
1st & 2nd	On	Off	On	Defect of recirculation pump, equipment malfunction, discontinuity of electricity
3rd & 4th	Off	Off	On	Time of no beer manufacturing (week end or holiday)

4 Conclusions

The seeding of the trickling filter can be achieved just by pumping the brewery wastewater itself repeatedly to the trickling filter, which means there is no need to use special inoculation to seed the trickling filter. The trickling filter seeded in such a way has a short acclimation phase before being ready for full operation. Increasing the hydraulic or organic loading rate has no significant effect on the efficiency. An average value of (84.42±6.5)% COD removal efficiency was achieved when the loading rate increased from 1.5 to 4.5 kg COD/(m^3·d). The trickling filter can have sufficient air circulation naturally and the only energy demand is for pumping of the fed water. Handling of the excess sludge is not a problem because the amount of sludge produced is small and the dense nature of the sludge makes it easily settleable inside the secondary clarifier. Therefore, the proposed biological treatment process appears to be a promising wastewater treatment method for coping with beer manufacturing wastewaters with respect to the removal of COD.

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Compliance with ethics guidelines

Haimanot HABTE LEMJI and Hartmut ECKSTÄDT declare that they have no conflict of interest.

This article does not contain any studies with human or animal subjects performed by any of the authors.

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Recommended paper related to this topic

Water quality improvement of a lagoon containing mixed chemical industrial wastewater by micro-electrolysis-contact oxidization

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Abstract: A lagoon in the New Binhai District, a high-speed developing area, Tianjin, China, has long been receiving the mixed chemical industrial wastewater from a chemical industrial park. This lagoon contained complex hazardous substances such as heavy metals and accumulative pollutants which stayed over time with a poor biodegradability. According to the characteristics of wastewater in the lagoon, the micro-electrolysis process was applied to improve the biodegradability before the bioprocess treatment. By the orthogonal experimental study of main factors influencing the efficiency of the treatment method, the best control parameters were obtained, including pH=2.0, a volume ratio of Fe and reaction wastewater of 0.03750, a volume ratio of Fe and the granular activated carbon (GAC) of 2.0, a mixing speed of 200 r/min, and a hydraulic retention time (HRT) of 1.5 h. In the meantime, the removal rate of chemical oxygen demand (COD) was up to 64.6%, and NH_4^+–N and Pb in the influent were partly removed. After the micro-electrolysis process, the ratio of biochemical oxygen demand (BOD) to COD (B/C ratio) was greater than 0.6, thus providing a favorable basis for bioprocess treatment.