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Full Length Research Paper

Aerobic mesophilic treatment of potato industry wastewater

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An evaluation of a laboratory-scale aerobic method for the treatment of potato-processing wastewater at 37°C was investigated. Composite samples were collected to establish batch variations. The wastewater was characterized for Chemical Oxygen Demand (COD), Permanganate Value (PV), Total Solids (TS), phosphates and pH over a period of 6 months. Wastewater with an average of 6.8 g COD/l, high concentration of total solids (up to 6725 mg/l), and low pH was subjected to active sludge treatment in a Continuously Stirred Tank Reactor (CSTR) with Organic Loading Rates (OLRs) gradually increased from 3.4 to 12.1 g COD/litre/day. Stepwise increase in OLR reduced average COD reduction from 86% at 3.4 g COD/litre/day to 76% at 12.1 g COD/litre/day. High rates of treatment efficiency (TE) were recorded at low OLRs (<6.8 g COD/litre day) with a notable pH of the effluent increasing from 4 to neutral values. TS reduction was achieved at 57% at HRT of 2 d. This study indicated that biological methods can be used for treatment of potato-processing wastewater in order to reduce the organic load and other pollutants acceptable levels for municipal discharge.

Key words: Potato wastewater, biotreatment, mesophilic, continuous stirred tank reactor (CSTR), activated sludge.

INTRODUCTION

The biotechnological treatment of organic waste is an integral part of a developed society. Food industries produce large quantities of effluent wastewater which is characterized by high concentration of organic pollutants and low concentrations of nutrients. The size of the wastewater output is seasonal, extensively varying in its quality (Zvauya et al., 1994; Suman et al., 2004). Generally, food industrial effluents are characterized by high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Orhon et al., 1993; Suman et al., 2004; Mishra et al., 2004). Noted major components in food industries wastewater effluents include; fats, oil/grease and a host of other recoverable nutrients from its organic material like starch, proteins, as well as mineral elements that include phosphorous and potassium (Mane and Qasim, 2013).

Disposal of the wastewater from industry not only threatens environmental quality but also underutilize the energy potential of the wastewater. Wastewater management is increasingly gaining momentum and it is

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the clearest paradigm of environmentally friendly technologies (Seghezzo et al., 1998).

Potato processing industries make use of large volumes of water during washing, peeling, slicing/shredding and blanching. The wastewater therefrom generated has high organic content and is acidic (Mishra et al., 2004). Being acidic nature causes phytotoxic to aquatic flora (Staneva, 1997; Byrne, 2001). Industrial discharge of wastewater with high organic pollution commonly results in eutrophication, destabilizing the aquatic ecosystem thereby reducing the aesthetic value of such water (Staneva, 1997; Chapman and Reiss, 1999; Aneja et al., 2000; Byrne, 2001). Aerobic treatment of potato wastewater effluent has been studied elsewhere resulting in considerable reduction of organic material and suspended solids (Hill, 1997). The organic component of the waste through bioremediation by the thermophilic and mesophilic microbes has been achieved through fermentation conditions of long retention times, low organic loadings, large amounts of suspended solids and high temperatures (Manahan, 2000; Mishra et al., 2004; Lasik et al., 2002, 2010; Mane et al., 2013). The simplest design for aerobic bioremediation systems is the Continuously Stirred Tank-Reactor (CSTR), that allow establishment of microbial aggregates (Scragg, 1999; Baylar and Bagatur, 2000). Microbial consortia of aerobic CSTR activated sludge include; *Pseudomonas*, *Chromobacteria*, *Enterobacteria*, *Micrococci*, *Zooglea*, *Corynebacteria*, *Sphaerotilus* and *Caulobacteria* sp. In the event that *Thiothrix* sp manifest itself, often sludge with poor settling characteristics, known as filamentous sludge bulking has been recorded (Nielsen et al., 2000).

This study intended to develop an efficient biotreatment using CSTR system in reducing organic solids and pH of the wastewater effluent from a potato processing company in Harare, Zimbabwe. However, the existing pre-treatment setup has been associated with low removal of dissolved organic and inorganic substances. On this basis, a study to establish an aerobic CSTR that could possibly enhance biotreatment was researched on by evaluating the digester's optimum operating conditions and its efficiency.

METHODOLOGY

A composite sample of wastewater was collected from the potato-processing factory effluent that included the equalization tank from which most of the particulate solids will have been removed and the municipal discharge point of the effluent from the washer, peeler, blanching and cleaning-in-place operations. Composite samples were collected regularly over a period of 6 months, stored at 4°C and used to establish variations. Physicochemical characterization of the effluent was performed within 24 h. The feed substrate for the studied CSTR aerobic reactor was collected at a point after the plant's hydrosieve which removes peels and raw pulp by a mesh screen.

Bioreactor design

Initially the Continuous Stirred Tank Reactor (CSTR) was set to a batch system using an Applikon AD1 1012 fermentor of capacity 1.5 L (Figure 1) used for aerobic treatment set at an agitation speed of 200 rpm and aeration was done using air compressor at a pressure of 40 mm Hg regulated by an air flow regulator (Brooks Instruments BV). The temperature was maintained and controlled at 37°C for mesophilic treatment. Urea was added (10 mg/l) to supplement the nitrogen content to the effluent wastewater. No pH adjustments were done to the wastewater. A 10% (v/v) of acclimatized and active seed sludge inoculum was obtained from an operational aerobic digester of Firle Sewage Treatment Works, Harare, Zimbabwe. The working volume in the bioreactor was 1.5 L of potato wastewater composite and inoculum. Samples of 50 ml were collected from the bioreactor daily and analyzed. Samples were analyzed in triplicates and average values used for statistical analysis.

Organic loading rates using continuous aerobic treatment

After batch mode aerobic system as described above for 72 h, the continuous mode carried out with the desired influent flow rates until steady-state was established as indicated by Permanganate Value (PV) and COD performance (Britz and Trnovec, 1998). The organic loading rates (OLR) of 3.4; 3.8; 6.8 and 12.1 g COD/litre/day, which translates to Hydraulic Retention Times (HRTs) of 2.0; 1.5; 1 and 0.5 days consecutively were applied through adjusting the flow rate of the wastewater into the reactor as shown in Table 1 using a peristaltic pump (MasterFlex 7521-35). The following parameters were analyzed on the effluent of the bioreactor to monitor the reactor performance at each HRT; PV (a measure of organic matter), COD, TS and pH.

Effluent characterisation

Samples were collected from the influent and effluents of the bioreactor during fermentation and analyzed using standard methods for COD, TS, Total Suspended Solids (TSS), Total Volatile Solids (TVS) and Phosphates (PO_4-P) (American Public Health Association (APHA), 1998). The residue from total solids determination (APHA, 2540. B) was ignited to constant weight at 550°C. The TS represent the fixed total dissolved and total suspended solids while the weight lost on ignition at 550°C is the volatile solids (APHA, 2540. E). The pH was determined on a Crison GLP21 pH meter. Crude protein was measured using the Kjeldahl Method. The differences from the initial value of the influent wastewater to that of the effluent were used to evaluate the biotreatment efficiency of the bioreactor. The analyses were done for three replicates and each one with three samples. Data obtained were expressed as mean ± standard deviation, and were subjected to one way analysis of variance (ANOVA). Means were separated by Bonferroni's multiple comparison test at $P < 0.05$.

Permanganate value determination

The permanganate value (PV) is a method of quantifying the organic matter noted as a measure of oxygen absorbed from acidified potassium permanganate during 4 h at 27°C. Samples of 10 ml volume were diluted to 100 ml using distilled water in a measuring cylinder then added to 250 ml conical flasks. To each flask, a volume of 50 ml of 0.0125 M potassium permanganate were transferred, followed by adding 10 ml of 25% (v/v) H_2SO_4. The flasks were tightly stoppered and incubated in a dark cupboard at 27°C for 4 h. After incubation 5.0 ml of potassium iodide was added and the resultant mixtures in each flask were then titrated against 0.025 M sodium thiosulphate. Starch indicator at 1.0% (w/v) was used to detect the end-point, noted by the disappearance of the

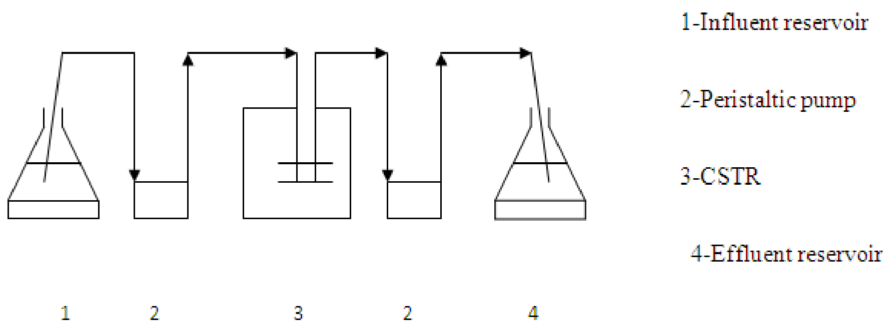

Figure 1. Schematic representation of the aerobic set-up

Table 1. Operational parameters levels for continuous aerobic treatment of potato wastewater using CSTR at 37°C.

Flow rate (cm^3/min)	Organic loading rate (g COD/litre/day)	Hydraulic retention time (days)
0.35	3.4	2.0
0.46	3.8	1.5
0.69	6.8	1.0
1.39	12.1	0.5

blue-black starch-iodine color. A blank titration was performed using 100 ml of distilled water instead of samples.

RESULTS AND DISCUSSION

Physicochemical status of the effluent

The physicochemical quality of the wastewater from the potato industry showed that there was high COD, phosphates and total solids (Table 2). The high phosphate value imparted a low pH value of around 4.9, hence resulting in acidic wastewater. However, it had very low protein content.

Organic content removal during batch treatment

Figure 2 shows the treatment efficiency of a CSTR under batch conditions as a function of the effluent's pH and COD reduction. The results indicated that the pH rose from 3.7 of the influent to 9.0 after 6 days of fermentation thereafter leveling off. Such an increase in pH is associated with production of alkaline products, such as alkaloids, amines and peptides as noted elsewhere (Boichenko et al., 2001).

Fermentation of starch, glucose, fatty acids, lactic acid, and other amino acids, nucleotides, urea added and water-soluble proteins by a number of microbes is also known to produce alkaline radicals (ammonia and et al., 2001; Nychas et al., 2008). However, in case of other alkaline fermentations, the produced ammonia controls the fermentation (Steinkraus, 1996; Prabir and Nout, 2014).

Generally, increase in pH under aerobic conditions is due to the extensive hydrolysis of proteins to peptides to amino acids and finally liberating ammonia dominated by *Bacillus* spp., principally *Bacillus subtilis* (Yokutsuka and Sasaki, 1998). Similar rise of from 7.0 to 9.6 during biodegradation of deproteined potato juice in the shake flask experiments involving a mixed population of bacteria of the genus *Bacillus* has been reported elsewhere (Lasik et al., 2002). It was quite interesting to correlate the observed rapid pH increase (3.9 to 9.0) associated with a rapid decrease of oxidisable organic matter from 6 769 to 816 mg/l COD value within 3 days. At such an uncontrolled pH, CSRT had a biotreatment efficiency of 88%, which is quite similar to a reduction of 84% as recorded by Cibis et al. (2004). However, these workers had nitrogen enrichment of potato slops using ammonium and phosphate salts. Biodegradability of any wastewater is conventionally evaluated by the assessment of the efficiency of treatment reduction on BOD and COD (Orhon et al., 1993).

There was a noticeable significant decrease ($P<0.05$) in the amount of total solids as shown in Figure 3, meanwhile the PV value (organic matter quantity) also showed a decline trend from 912 to 262 mg/l. Although, amines), contributing to increase in pH values (Bover-cid biodegradable organic matter can be used both in the production of energy and synthesis of biomass, the nature of the resultant product after fermentation was not

Table 2. Influent composite primary potato-processing wastewater physicochemical properties.

Parameter	Value
COD	6 769 ± 970 mg/l
PV	756 ± 101 mg/l
TS	6 725 ± 1 865 mg/l
TSS	2 187 ± 1 046 mg/l
TVS	4 797 ± 2 016 mg/l
PO_4-P	36 ± 28 mg/l
Crude protein	0.27 ± 0.04 % (w/v)
pH	4.9 ± 0.8
Temperature	35 ± 15.5°C

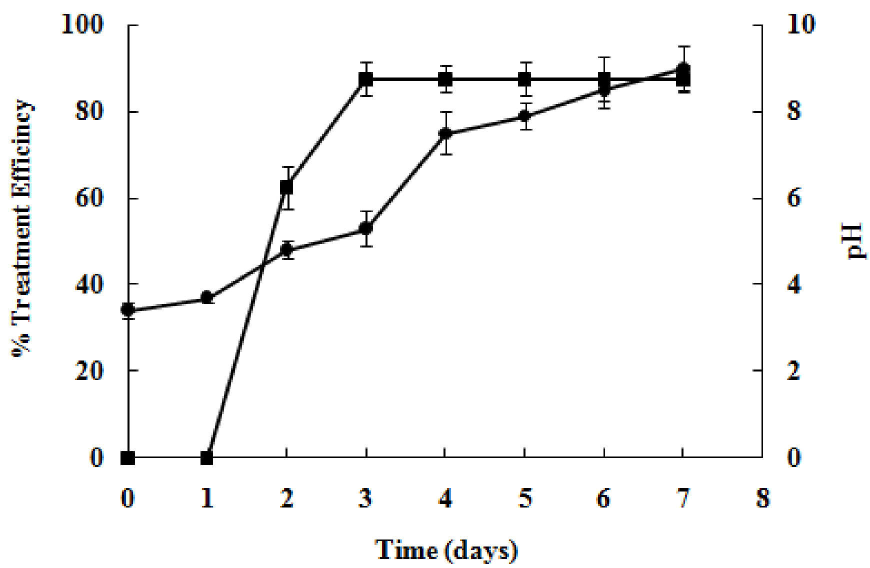

Figure 2. The COD treatment efficiency profile (■, COD %) and changes in pH (●) during aerobic treatment at 37 °C using a CSTR under batch conditions.

ascertained. However, much of the organic matter in the CSRT under aerobic fermentation was utilized and reduced by 71%. The recorded 68% reduction from 9 886 to 3185 mg/l of total solids, maybe this was due to the additional sludge generated during aerobic biotreatment. Leveling off of the PV and TS values occurred after 5 days.

CSRT aerobic biotreatment of the wastewater

After batch cultivation, the bioreactor was turned into a continuous mode and an increase in the biotreatment efficiency at each OLR rate from 3.8 to 12.1 g COD/liter/day until was noted reaching different quasi-steady states. The OLR of 3.4 had the highest biotreatment efficiency of 90% attaining a hydraulic retention time of 2 days (Figure 4).

A recorded increase in biomass in turn increased biodegradation of organic matter bringing about the efficiency rate of 90% at 3.4 to 58% at 12.1 g COD/liter/day. COD was measured until consecutive values differed by ±10 % to ensure a steady-state (Van der and Pakkies, 1992). However, unstable conditions were recorded at 3.8 g COD/liter/day. This was mainly due to persistent clogging of tubes which altered the reactor volume.

The decrease in oxidisable organic matter is attributed to the increase in biomass and stabilization of the aerobic process. Starch and organic acids which contribute to the high COD are oxidized to carbon dioxide and water. The removal of formic acid and sodium acetate has been recorded as an indicator for microbial biomass development in other activated sludge wastewater

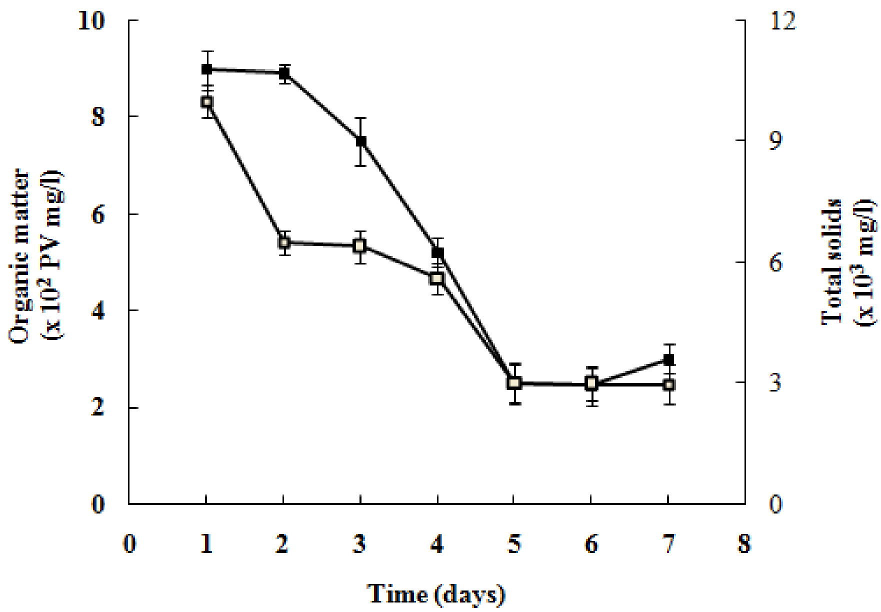

Figure 3. Total solids (■) and organic matter as permanganate value (□) profile during aerobic treatment at 37 °C using a CSTR under batch conditions.

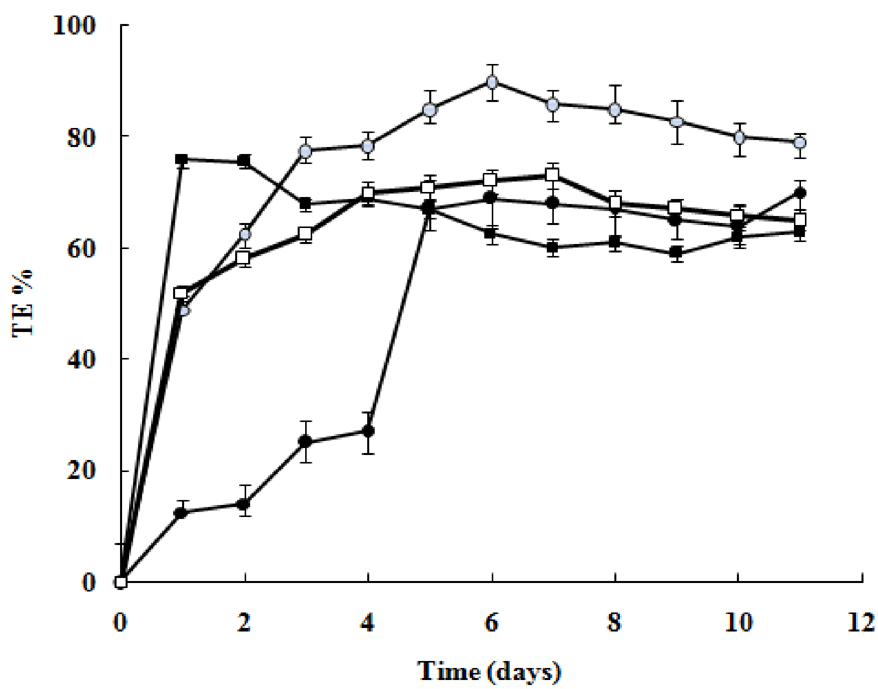

Figure 4. The organic matter recorded as permanganate value profile at OLR rates of 3.4 (○), 3.8 (●), 6.8 (■) and 12.1 (□) g COD/L/day on the biotreatment efficiency (TE %) during aerobic treatment of potato-processing wastewater at 37°C using a CSTR.

treatment plant elsewhere (Viggi et al., 2010; Bindhu and Madhu, 2013) and noted to show increase of microbial biomass. Similar levels of COD removal efficiency of more than 80% were recorded in both cases. Wastewater used for this study had quite high COD and TSS values of 6 769 ± 970 mg/l and 2 187 ± 1 046 mg/l.

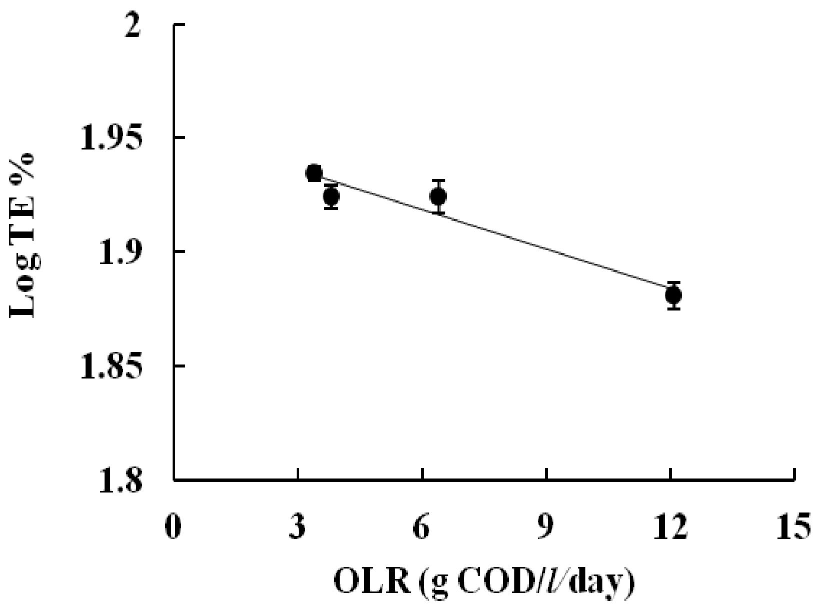

Figure 5. The COD treatment efficiency during aerobic treatment of potato-processing wastewater at 37 °C using a CSTR at various OLRs (n = 3).

The rapid period before attainment of steady-state levels within 4 days is an indication that for an efficient instrumentation for potato wastewater treatment then, oxygen and mesophilic temperatures are essential to be optimized for maximized BOD removal. Use of low loading rates also reduces sludge production by shearing flocs allowing increased surface area for oxygen transfer. Similar removal high efficiency rates with thermophilic aerobic (50°C) biodegradation on liquid fractions of potato slops had complete removal of acetic acid and malic acid achieved (Cibis et al., 2002).

In this study, mesophilic temperatures at 37°C were quite comparable to the thermophilic ones used in reduction of high COD following solids separation that varied between 77.57 and 89.14% after 125 h (Krzywonos et al., 2008). Comparison of organic and nitrogen removals by thermophilic and mesophilic aerobic processes has shown lower sludge production and higher COD reduction in Sequential Biological Reactors (SBRs)of thermophilic compared to mesophilic ones. SBR under 8.25 kg COD/m^3 d loading rate had varied treatment efficiencies of 59, 80 and 82% at 30, 47 and 60°C respectively (Abeynayaka and Visvanathan, 2011).

To evaluate the effect of OLR on the efficiencies of biotreatment process using the bioreactor, a log plot of the results in Figure 4 were used to determine minimum level of organic loading rate (Figure 5). There was a linear relationship of the organic loading rate to the log (treatment efficiency value). High biotreatment efficient values were noted when OLR were not more than 6.8 g COD/litre/day.

The maximum treatment efficiency recorded was 86% retention period of 2 days (Figure 4). Note that the other loading rates shown in Figure 4 gave about 76% as the maximum efficiencies over the same period. In a similar study, the extent of COD removal ranged from 80.4% (with COD of 11 g O_2/l) to 88% (with COD of 58 g O_2/l) in the aerobic biodegradation of potato slops (Cibis et al., 2006). Increase in COD reduction with increasing hydraulic retention time has been reported by other workers (Suman et al., 2004). However, even higher efficiencies of 99.2% for COD removal and 99.5% for BOD reduction were recorded in the treatment process of potato chips wastewater (Hadjivassilis et al., 1997). These observed trends described here were also obtained under comparative analysis of the treatment effects using batch, repeated-batch (with cell recycle and medium replacement) and continuous treatment operations (Lasik et al., 2010).

The amount of total solids in the potato wastewater generally decreased when the organic loading rates changed as shown in Figure 6. It was recorded that at 3.4 g COD/litre day, the TS decreased from 5 373 mg/l to 722 mg/l and that of 6.8 g COD/litre day had a down trend from 5 793 to 2 810 mg/l.

The soluble organic matter is easily degraded and converted to carbon dioxide and other products depending on fermentation conditions seed used. However particulate organic matter is first hydrolyzed to simple soluble products which are ultimately oxidized to provide energy. Rate of hydrolysis is depends on biomass activity which is in turn affected by the dilution rate. Consequently, the removal of solids decreased slightly as HRT decreased.

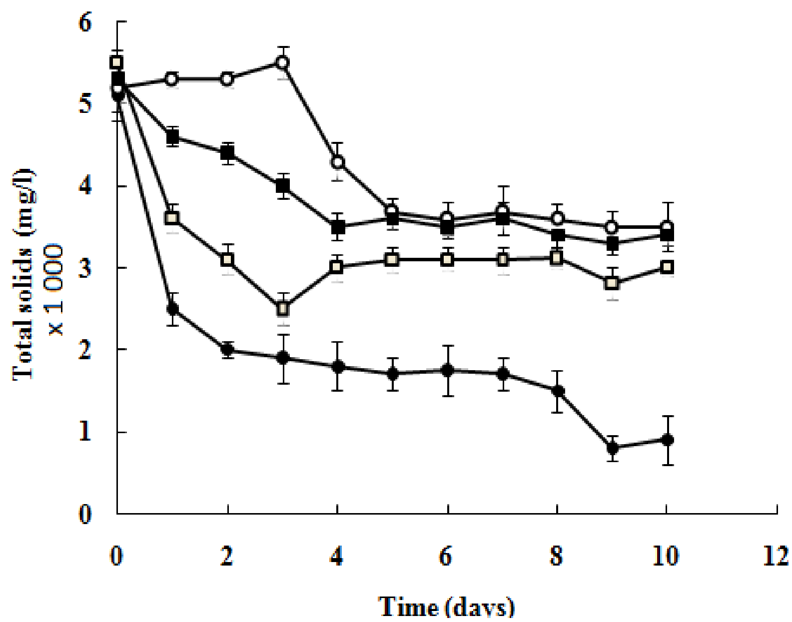

Figure 6. The total solids profile during aerobic treatment of potato-processing wastewater at 37 °C using a CSTR at various organic loading rates of 3.4 (●), 3.8 (○), 6.8 (□) and 12.1 (■)g COD/litre day.

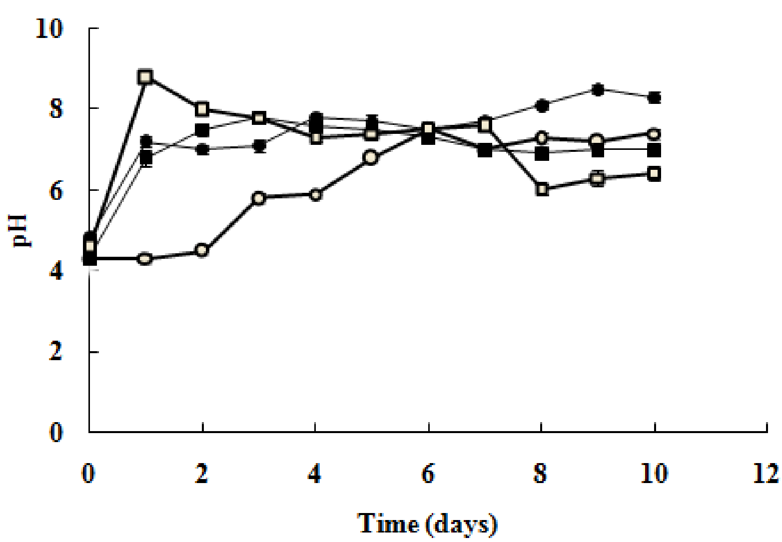

Figure 7. The pH changes during aerobic treatment of potato-processing wastewater at 37°C using a CSTR at various organic loading rates of 3.4 (●), 3.8 (○), 6.8 (■) and 12.1 (□) g COD/l.

Changes in pH during aerobic treatment

In this study, the pH increased at all HRTs investigated ranged from pH 6 to 8 (Figure 7). The organic acids are converted to carbon dioxide and water during aerobic treatment hence pH values around 7 were recorded. Tripathi and Allen (1999) believed that the increase in the pH may be induced by the formation of alkaline compounds, or by assimilation of organic acids (e.g. acetic acid) by the bacteria involved. The rise in the pH level can be explained in other terms as probably due to the changes in microbial population, which is paralleled by the release of alkaline by products (Malladi and Ingham, 1993; Cibis et al., 2004; Cibis et al., 2006). The pH value increases owing to the formation of a weak ammonium base from the ammonia produced in the course of the deamination process. However fluctuations may be a result of increase in dissolved CO_2 concentration or accumulation of organic acids in the influent leading to slight decrease in pH. In Zimbabwe, a similar study was done on opaque-beer wastewater using aerobic thermophilic treatment. The pH rose from 6·5 to 8·9 during treatment in 7 days (Zvauya et al., 1994)

Conclusion

This study indicated that aerobic biotreatment systems for wastewater can be implemented for efficient reduction of potato-processing wastewater at high COD and BOD levels by 80% without increasing the sludge levels. The aerobic treatment process gave good treatment efficiencies at mesophilic temperature (37°C). However, for aerobic treatment, an increase in OLR resulted in a decrease in to a certain level that reduces energy consumption through high operational conditions. The pH of the effluent increased to values around the neutral range which is amenable with WHO guidelines. Total solids removal was however poor due to sludge build-up with very low OLR rates. From the results obtained in this study, OLRs affect digester performance.

Conflict of Interest

The authors have not declared any conflict of interest.

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