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Full Length Research Paper

An evaluation of a mesophilic reactor for treating wastewater from a Zimbabwean potato-processing plant

Manhokwe S.[1], Parawira W.[2]* and Tekere, M.[3]

[1]University of Zimbabwe, Department of Biochemistry, P. Bag MP167 Mt. Pleasant, Harare, Zimbabwe.
[2]University of Zimbabwe, Institute of Food, Nutrition and Family Sciences, P. O. Box MP167 Mt Pleasant, Harare, Zimbabwe.
[3]University of South Africa, Department of Environmental Sciences, School of Agriculture and Environmental Sciences, P.O. Box X6, Florida, 1710, South Africa.

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An evaluation of anaerobic treatment of potato-processing wastewater using an up flow Anaerobic Sludge Bed (UASB) reactor at 37°C was conducted. Wastewater from a potato-processing plant in Harare, with an average of 6.8 g COD/l, (COD = chemical oxygen demand) a high concentration of total solids (up to 6725 mg/l) and low pH of 4 - 4.9 was subjected to anaerobic treatment in an UASB reactor. The start up period, which was indicated by gas production and stabilization of COD reduction was 21 days. The organic loading rates (OLRs) investigated varied between 1.3 g COD/l/d and 13.1 g COD/l/d, the maximum methane yield was 0.3 l/g $COD_{removed}$ at an organic loading rate of 6.6 g COD/l/d. An increase in OLRs to values above 13.1 g COD/ l/d resulted in digester failure. The maximum treatment efficiency (TE) in terms of COD reduction achieved was 90% at a hydraulic retention time (HRT) of 2.1 d and OLR of 3.3 g COD/l/d. The TE was reduced at higher reactor influent velocities, with a minimum TE (71%) recorded at HRT of 0.5 d. Total solids (TS) removal was inconsistent with an average reduction around 50% and phosphorus removal was poor and erratic. pH from the effluent oscillated around 7 with a notable decrease from 7.8 to 6.2 at HRT of 0.5 d. Based on these observations, the UASB process has potential to treat potato-processing wastewater as a pretreatment step before discharge into municipal sewerage system of Harare.

Key words: UASB reactor, potato wastewater, anaerobic digestion, methane yield, organic loading rate.

INTRODUCTION

Today's competitive market together with more stringent legislations requires companies to be more environment-tally friendly whilst remaining cost-effective and delivering products/services of a high quality standard (Walsdorff et al., 2004). Wastewater management is increasingly gain-ing momentum since industry not only has to adhere to environmental policies but also comply with the stringent legislative requirements.

The Zimbabwe National Water Authority (ZINWA) and the municipal authority in Harare are placing severe re-strictions on the quality of effluent that industries can discharge into the municipal system and rivers which makes on-site pretreatment necessary for certain types of effluent. Whilst the physical and chemical treatments methods for remediation of wastewater are also neces-sary to improve the quality of the effluent, incorporation of biological methods is important in that it reduces the organic load in an environmentally friendly way. The se-condary biological treatment methods can be cost-effec-tive and produce useful by-products such as me-thane if anaerobic digestion is incorporated.

The potato industry generates considerable quantities of waste, both solid and liquid. The potato processing Industry uses large volumes of water during process ope-rations such as washing, peeling and blanching during production of potato chips, potato slices and shredded

*Corresponding author. E-mail: aparawira@yahoo.co.uk. Tel.: +263 4 307762. Fax: +263 4 304071.

potatoes (Mishra et al., 2004). The effluent generated from in-plant processes is characterised by high organic loads, low pH and other foreign compounds to the potato such as preserving chemicals and other food ingredients (Pailthorp et al., 1975). Due to the organic nature of the pollutants in the potato-processing effluent, biological treatment methods are not only attractive but also an appropriate option.

Research on the application of anaerobic treatment technology, especially the UASB reactor, has received considerable attention in the past two decades (Parawira et al., 2005; Britz et al., 2002; Kalyuzhnyi et al., 1998; Lettinga, 1995; Defour et al., 1994). The UASB system has been successfully applied to treat wastewater from pulp-processing, dairy, brewing, meat-processing and textile industries.

The COD removal efficiencies as high as 95% have been achieved using different industrial effluents in the UASB (Kalyuzhnyi et al., 1998; Britz et al., 2002; Lindane et al., 1983; Christensen et al., 1984). The success of the UASB in industrial applications has been largely attributed to the high treatment efficiencies, low maintenance cost and the production of biogas. Its incorporation into any wastewater treatment system is, however, subject to thorough laboratory and pilot-scale investigations on the operational parameters such as temperature and pH as well as the industrial effluents involved.

This study therefore, sought to evaluate for the first time the performance of a laboratory scale anaerobic system in the pre-treatment of potato processing wastewater before the effluent is discharged into the municipal sewer at Cairns Foods chips processing plant in Harare, Zimbabwe.

MATERIALS AND METHODS

Bioreactor

A laboratory UASB reactor of capacity 0.54l was used for anaerobic treatment of potato wastewater. The jacketed reactor was operated continuously and temperature maintained at 37°C using a circulating water bath (Haake D38 Fisons, Germany). A peristaltic pump was used to continuously pump the industrial effluent from a feed reservoir into the rector. The organic loading rates applied to the UASB reactor ranged from 1.3 to 13 g COD/l/d and hydraulic retention time used ranged from 5.2 to 0.5 days.

The change to the next organic loading rate was effected after three hydraulic retention times when the system reached quasi-steady state with regard to COD removal, that is, the system performance was stable in terms of COD removal for one week.

Inoculum

The seed sludge used for inoculation was collected from an operational full-scale UASB reactor at a local opaque beer brewery effluent treatment plant in Harare, Zimbabwe (Parawira et al., 2005). It was sieved (< 2 mm) to remove any debris and large particles. The seed sludge had a total solid (TS) content of 9463 mg/l and a total volatile solids (TVS) content of 7940 mg/l. Sludge at 25% (v/v) was used to inoculate potato wastewater.

Wastewater

Wastewater was collected from the chips processing factory located in Harare, Zimbabwe. The company has a chip-processing plant that employs a continuous process generating 12 m^3 of wastewater per day. The feed substrate for the reactors was collected from an equalisation tank from which most of the particulate solids would have been removed by a hydro sieve. The wastewater was mainly from the washer, peeler, slicer and blanching operations. The characterisation of the wastewater was carried out monthly over a period of 6 months and the composition is shown in Table 1.

Gas measurement

Biogas from the reactor was collected using the gas displacement method (Khalil et al., 1998). The gas collected from the reactor was bubbled through 20% (w/v) NaOH solution to remove CO_2, leaving methane and residual gases to collect in another flask. The amount of residual gases was then measured using water displacement. The amount of water displaced was collected and measured to represent volumetric gas production.

Analyses

Samples were collected from the influent and effluent reservoir and analysed for COD, TS, TVS, Total Suspended Solids (TSS) and phosphate using Standard Methods (APHA, 1998). For COD analysis, samples were collected after every 3 days, diluted and analysed at every OLR investigated. The Permanganate Value (PV), a measure of oxidized organic matter) was used to monitor the reactor performance on a daily basis. The change in the PV was used to calculate the treatment efficiency.

Analyses of all the samples were done in triplicates to find the mean and the standard deviation. The pH was determined on a Crimson GLP21 pH meter. Total nitrogen determination was done using the Kjeldahl Method (AOAC, 1990). Statistical analysis was performed using Graphpad Prism 4.

RESULTS AND DISCUSSION

The reactor was started up in batch mode operation of the UASB process. Inoculum at 25% (v/v) was used to inoculate potato wastewater. The system was run on batch mode for three weeks while the content of the reactor was recycled for homogeneity. An acclimatization period of 21 days was necessary to allow the sludge to stabilize and to cultivate an active anaerobic microbial population. This was shown by biogas production with 75% methane content (results not shown). After these weeks the UASB was run continuously and observations were made for 40 days with an initial organic loading rate of 1.3 g COD/l/d.

Any assessment of anaerobic digestion must include quantification of the performance in terms of methane yield, maximum organic loading rate and COD removal, as these are important economic and technical factors when considering the feasibility of an anaerobic digestion process. The performance of the UASB reactor in terms of methane yield while treating potato wastewater is shown in Figure 1.

Generally, methane yield decreased with increasing

Table 1. Main characteristics of the potato-processing wastewater used.

Parameter	Mean	Standard deviation	Number of samples
COD $_{total}$ mg/l	6769	±970	18
PV mg/l	756	±101	21
TS mg/l	6725	±1865	21
TSS mg/l	2187	±1046	21
TVS mg/l	4797	±2016	21
Phosphates mg/l	36	±28	21
Nitrogen %	0.04	±0.01	3
Crude protein %	0.27	±0.04	3
pH	4.9	±0.8	15
Temperature °C	35	±15.5	15

*Factor used to calculate crude protein was 6.25.

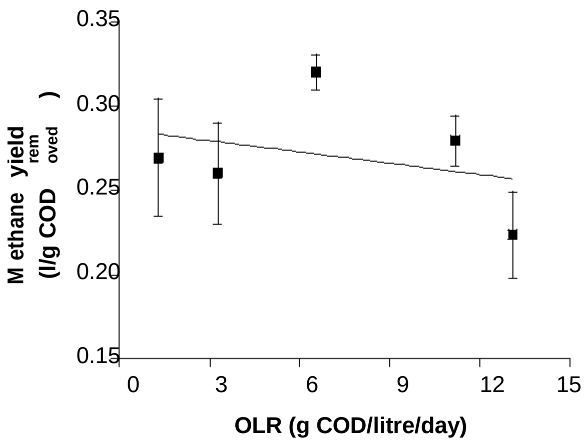

Figure 1. The methane yield during anaerobic treatment of potato-processing wastewater at 37°C using a UASB reactor at various OLRs.

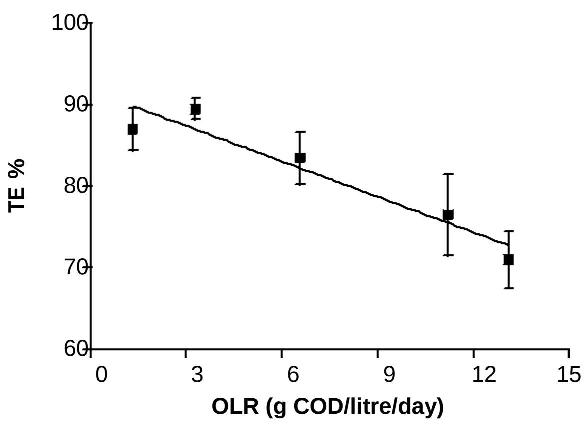

Figure 2. The COD treatment efficiency profile during anaerobic treatment of potato-processing wastewater at 37°C using an UASB reactor at various OLRs (n = 3).

g COD/l/d when methane yield decreased to below 0.1 l/g $COD_{removed}$. From results shown in figure 1, an average of 0.3 l/g $COD_{removed}$ was recorded when the maximum COD reduction of 90% was achieved in the UASB at OLR of 6.6 g COD/l/d. The observed maximum methane yield at the OLR investigated was lower than the theoretically expected value of 0.35 l/g COD $_{total}$/degraded under the same conditions (Kalyuzhnyi et al., 1998).

In this study the highest methane yield of 0.3 l CH_4/ g $COD_{degraded}$ is higher than methane yield of 0.23 l CH_4/ g $COD_{degraded}$ reported by Parawira et al. (2006) while investigating the performance of a UASB reactor and an anaerobic packed-bed reactor treating potato leachate. Considering that the theoretical value for methane yield is 0.35 l CH_4/g $COD_{degraded}$, a low yield of 0.3 l CH_4/ g $COD_{degraded}$ suggests that part of the influent organic matter passed through the reactor without being converted to biogas. Accumulation of organic acids and lowering of pH at high organic loading rates are also known to lead to suppression of methanogenic activity and process failure (Parawira et al., 2004). This was experienced at organic loading rate of 13.1 g COD/l/d in this study.

Steady state operation was noted by an average constant digester performance $\pm$10 % of the treatment efficiency in terms of COD removal. The UASB treatment process demonstrated average treatment efficiency of 71 to 90%. The maximum treatment efficiency of 90% was recorded at an OLR of 3.3 g COD/l/d as shown in Figure 2. Lower treatment efficiencies were obtained at higher OLRs with a minimal 71% being recorded at OLR of 13.3 g COD/l/d.

The decrease in COD was a result of good amenability of starch, protein and other organic molecules in the potato wastewater, followed by methanisation of the soluble COD to produce methane as well as CO_2. Carbohydrates (mainly starch) usually make up the bulk of the organic load in this type of feedstock. Several studies have been carried out on anaerobic treatment of potato wastewater with TE in terms of COD removal ranging from 75 - 95% (Landine et al., 1983; Nanninga and Gottschal, 1986; Mshandete et al., 2004; Parawira et al., 2006).

A fraction of the reactor effluent COD may be accoun-

Table 2. A summary of the results produced by other researchers using UASB reactors.

Author, Year	Wastewater	Reactor, Scale	OLR (kg/m^3d)	Retention time	TE %	Temperation °C
Parawira et al., 2006	Potato leachate	UA Lab SB	1.5 - 7.0	2.8 - 13.2d	90	37
Kalyuzhnyi et al., 1998	Potato-5.5 - 9 g/l maize	UASB, Lab	0.63-13.89	15.6-144 h	63.4-81.3	35
	Potato-maize	UASB, Lab	5.02-15	14.4- 43.2 h	71.1- 93.6	35
Defour et al., 1994	Potato 2.6 g/l	UASB, Full	8	7 d	90	-
	Potato 12.5 g/l	UASB, Full	12	18 d	78	-
This study	Potato- processing	UASB, Lab	1.3 - 13.1	0.52 - 5.21 d	71-90	37

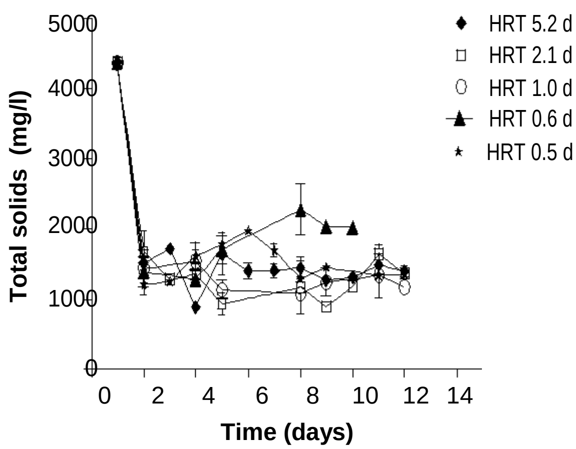

Figure 3. The total solids removal during anaerobic treatment of potato-processing wastewater at 37°C using a UASB reactor at various HRTs (n = 2).

ted for by biomass and undefined particulate organic matter other than soluble organic matter. The COD treatment efficiency recorded in this study decreased as OLR increased as indicated by results in Figure 2. A comparison of results achieved in this study with those reportted for potato wastewater treatment in UASB and other designs as shown in Table 2 illustrate that our results are satisfactory. However, it is must be stated that an actual comparison between various data sets can be based only on experiments where the same wastewater and reactors of comparable size with the same operation conditions are used.

Mackie and Bryant (1995) stated that in order to take advantage of anaerobic digestion, the reactors must be operated at high OLRs and short HRTs. The maximum OLR (11.5 g COD/l/d) for stable operation achieved in this study is quite comparable to 11 g COD/l/d obtained by Parawira et al. (2007) when they studied anaerobic treatment using of potato leachate in a mesophilic UASB reactor compared to a thermophilic UASB reactor.

The maximum OLR for the mesophilic UASB in the current study is comparable to the OLR of 10 g COD/l/d reported by Dinsdale et al. (1997) in a study of comparing mesophilic and thermophilic UASB reactors treating instant coffee production wastewater. The maximum OLR in this study was however, twice that obtained previously when the performance of a mesophilic UASB reactor was compared with an anaerobic packed bed reactor treating potato leachate (Parawira et al., 2006; Murto, 2003).

In these studies, it was found that at OLRs above 6 g COD/l/d stable mesophilic digestion was not possible. However, stable operation of UASB reactors at OLRs above 8 g COD/l/d was achieved with 20 ml/min continuous recirculation while OLRs of 12 g COD/l/d was achieved with 10 ml/min continuous recirculation as reported by Mshandete et al. (2004).

From the data presented in Figure 3, it is evident that the total solids content decreased at all HRTs investigated. The anaerobic degradation process resulted in an average total solids reduction of around 50%. At low HRTs the removal of solids was poor. Foaming was minimal but eruptions of gas bubbles from the sludge-bed were noted at low OLRs. The pH of the effluent oscillated around the neutral range of 7 as shown in Figure 4. Despite the acidic nature of the influent wastewater as indicated in Table 1, the reactor pH was self-maintained in the optimal range for anaerobic digestion of 6.6 - 7.4 (Moosbrugger et al., 1993).

The unusually high pH of 10.2 recorded at HRT of 5.2 d was mainly due to operational problems in which there was a back-flow of NaOH solution into the reactor from the gas collection system. This backflow was caused by a pressure imbalance. However, slightly low pH values were recorded at low HRTs. The pH in the UASB reactor varied between pH 7 and 8 at most of the hydraulic retention times used in this study except that it dropped to below 5 after 11 days at 0.5 d HRT. This indicated that anaerobic digestion can neutralise the acidic potato wastewater before it is discharged into public sewage systems. Similar pH profiles have been reported by other workers (Parawira et al., 2006; Ahring et al., 1995; Cobb and Hill, 1991).

It can be inferred that the concentration of volatile fatty acids (not measured) was consistently low when the reactor was operated at HRT of 5.2 to 1.0 d in this study as they were being converted into methane and carbon dioxide. The concentration of volatile fatty acids has been recognised for a long time as being an important parame-

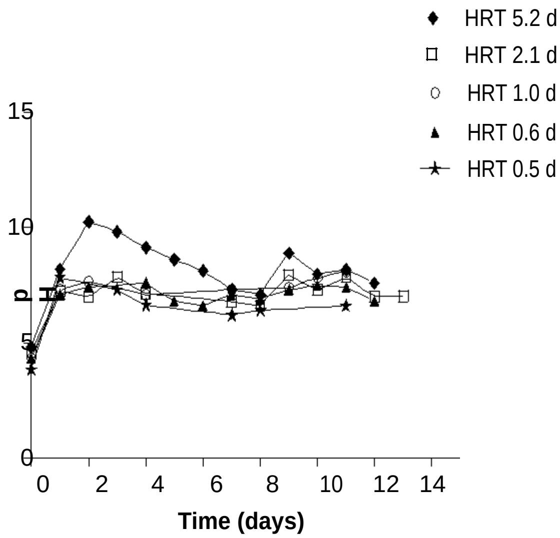

Figure 4. The pH changes during anaerobic treatment of potato-processing wastewater at 37°C using an UASB reactor at various HRTs.

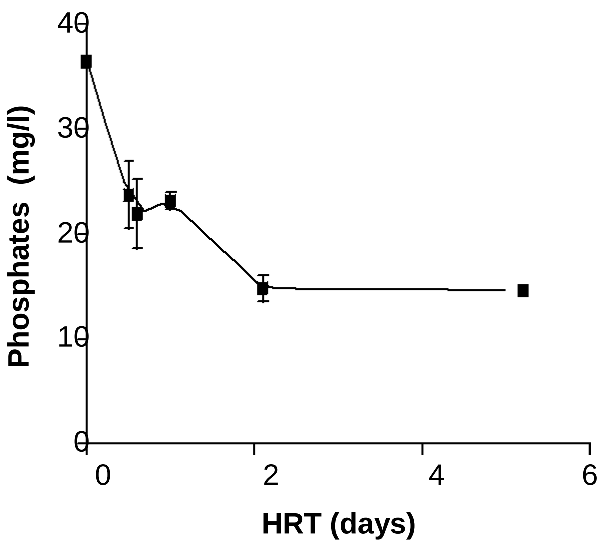

Figure 5. The phosphate concentration during anaerobic treatment of potato-processing wastewater at 37°C using an UASB reactor at various HRTs (n = 3).

ter in the control of the anaerobic digestion process. The pH has been reported to be comparable to partial alkalinity and volatile fatty acid concentrations in indicating process stability and process failure (Parawira et al., 2006).

The removal of phosphate from the wastewater using anaerobic treatment was poor. A reduction of 59% only, was recorded when the COD reduction was at its maximum, with a HRT of 2.1 d as indicated in Figure 5. However, the UASB reactor discharged effluent that contained total phosphates that fall within the permissible levels (30 mg/l) by the local authority, city of Harare. The anaerobic digestion process in UASB reactor has been reported to have low removal efficiency of nitrogen and phosphates because the system does not produce large quantities of sludge biomass (Fuchs et al., 2003; Parawira et al., 2003).

Conclusion

The results obtained from the study show that anaerobic digestion in UASB can be used for the treatment of potato-processing wastewater. The methane yield obtained in this study was satisfactory and comparable to results from other research using similar wastewater. The UASB reactor could be stably operated around 12 g COD/l/d. The performance of the digester is depended on the OLR, the HRT and operating conditions. High COD treatment efficiencies were recorded at low OLRs with a maximum of 90% being achieved at a laboratory scale. The wastewater released from the bioreactor had a low concentration of phosphates eliminating the need for post treatment of the effluent.

The UASB thus, can be used in the removal of organic load from potato wastewater and control of the pH of effluent discharged into municipal sewer. The results in this study indicated the feasibility of anaerobic treatment of potato processing wastewater at the plant in Harare, which if implemented at full-scale could result in significant reduction in organic load transmitted to the municipal treatment plant and subsequently to the environment. This also reduces legal battles between local authorities and polluting industries.

Further benefits from installing a full-scale UASB reactor could be realised by taping the energy generated by the anaerobic digestion process in the form of biogas. The biogas could be used to heat the steam boiler at the plant before other uses. The conclusion is that these laboratory studies indicated that the installation of an anaerobic treatment reactor by the industry would be an attractive economic and environmental investment considering that we are in an era of critical energy shortages, substantially higher prices and high demand for environmental protection. The Zimbabwe Environmental Management Act (Chapter 20:27 subsection 59) requires industries that discharge effluent into the environment to install appropriate plant for the pre-treatment of their effluents before discharge into municipal sewerage system.

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REFERENCES

Ahring BK, Sandberg M, Angelidaki I (1995) Volatile fatty acids as indi-

indicators of process imbalance in anaerobic digesters. Appl. Microbiol. Biotechnol. 43: 559-565.

American Public Health Association (1998) Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association, Washington, DC.

Association of Official and Analytical Chemists (1990) Official methods of analysis, AOAC, Washington DC: 829.

Britz TJ, Van Schalkwyk C, Roos P (2002) Development of a method to enhance granulation in a laboratory batch system. Water SA, 28: 49-54.

Christensen DR, Gerick JA, Eblen JE (1984) Design and operation of an upflow anaerobic sludge blanket reactor. J. Wat. Poll. Control Fed. 56: 1059-1062.

Cobb SA, Hill DT (1991) Volatile fatty acids relationships in attached growth anaerobic fermenters. ASAE, 34: 2564-2572.

Defour D, Decrycke D, Liessens J Pipyn P (1994) Field experience with different systems for biomass accumulation in anaerobic reactor technology. Wat. Sci. Technol. 30: 181-191.

Dinsdale RM, Hawkes FR, Hawkes DL (1997) Comparison of mesophilic and thermophilic Upflow Anaerobic Sludge Blanket reactors treating instant coffee production wastewater. Wat. Resear. 31: 163-169.

Kalyuzhnyi SV, Estrada De Los Santos L, Martinez JR (1998) Anaerobic treatment of raw and pre-clarified potato-maize wastewater in a UASB reactor. Bioresour. Technol. 66: 195-199.

Khalil EF, Whitmore TN, Gamal-Eldin H, El-Bassel A, Lloyd D (1998) The effects of detergents on anaerobic digestion. Appl. Microbiol. Biotechnol. 29: 517-522.

Lindane RC, Brown GJ, Cocci AA, VivaraghavanI T (1983) Anaerobic treatment of high strength, high solid potato wastes. Agric. Wast. 7: 111-123.

Lettinga G (1995) Anaerobic digestion and wastewater treatment systems. Antonie Van Leeuwenhoek, 67: 3-28.

Mackie RI, Bryant MP (1995) Anaerobic digestion of cattle waste at mesophilic and thermophilic temperatures. Appl. Microbiol. Biotechnol. 43: 346-350.

Mishra BK, Arora A, Lata P (2004) Optimization of a biological process for treating potato chips industry wastewater using a mixed culture of *Aspegillus niger* and *Aspegillus foetidus*. Bioresourc. Technol. 94: 9-12.

Moosbrugger RE, Wentzel MC, Ekoma GA, Marais GV (1993) Weak acid /bases and pH control in anaerobic systems-A review. Water SA, 19: 1-10.

Mshandete A, Murto M, Kivaisi AK, Rubindamayugi MST, Mattiasson B (2004a) Influence of recirculation flow rate on the performance of anaerobic packed-bed bioreactors treating potato-waste leachate. Environ. Technol. 25: 929-936.

Murto M (2003) Anaerobic digestion: Microbial ecology, improved operational design and process monitoring. Doctoral thesis. Department of Biotechnology, Lund University, Sweden ISBN: 91-89627-18-0.

Nanninga HJ, Gottschal JC (1986) Anaerobic purification of wastewater from a potato-starch producing factory. Wat. Res. 20: 97-103.

Pailthorp RE, Ritcher GA, Filbert JW (1975) Treatment and disposal of potato wastes. In: Talburt, W .F. and Smith, O. (Eds). Potato Processing, Wesport, AVI: 646-691.

Parawira W (2004) Anaerobic Treatment of agricultural residues and wastewater: Application of high-rate reactors, Doctoral thesis, Department of Biotechnology, Lund University, Sweden ISBN: 91-89627-28-8

Parawira W, Kudita I, Nyandoroh MG, Zvauya R (2005). A study of industrial anaerobic treatment of opaque beer brewery wastewater in a tropical climate using a full scale UASB reactor seeded with activated sludge. Proc. Biochem., 40: 593-599.

Parawira W, Murto M, Zvauya R, Mattiasson B (2006) Comparison of the performance of a UASB reactor and an anaerobic packed-bed reactor when treating potato waste leachate. Renew. Energ., 36: 893-903.

Parawira W, Murto M, Read JS, Mattiasson B (2007) A two-stage anaerobic digestion of solid potato waste using reactors under mesophilic and thermophilic conditions. Environ. Technol. 28: 1205-1216.

Walsdorff A, Van Kraayenburg M, Barnardt CA (2004) A multi-site approach towards integrating environmental management in the wine production industry. Water SA, 30: 630-635.

Wentezel MC, Laubscher ACJ, Le Raux JMW, Ekama GA (2001) Treatment of grain distillation wastewaters in an upflow anaerobic sludge bed (UASB) system. Water SA, 27: 433-444.