Providing Base Line Data for the Treatment of Mauritian Sugar Factory Wastewater by the Upflow Anaerobic Sludge Blanket (UASB) Process from Pilot-plant Study

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Abstract

Although the Mauritian sugar factories have to comply with the relevant norms applicable to discharge of effluents, they are not yet equipped with a conventional secondary biological wastewater treatment method. There is thus a need to find an appropriate and cost-effective treatment system for the factories. The upflow anaerobic sludge blanket (UASB) process was compared with other anaerobic treatment systems and has been found to be more advantageous and appropriate for the Mauritian sugar industry. In that context, a pilot study was carried out to determine the performance of the UASB process in treating sugar mill effluent and to provide base-line operational and design data for the reactor on a large scale. A sugar factory wastewater was characterised and the data were used to prepare the molasses-based synthetic influent involved in the pilot plant, thereby simulating real effluent. It was found that the real factory wastewater had an average chemical oxygen demand (COD) of 1065 mg/L and was deficient in nutrients and alkalinity. The investigations indicated that there was an influence of the hydraulic retention time (HRT), the only operational parameter, on the steady state COD removal efficiency of the reactor. At a HRT above 4 hours and an average organic loading rate of below 6.7 kg COD/m^3.day, the COD removal efficiency was found to be almost independent of the HRT and systematically remained above 76%. At shorter HRT, the COD removal efficiency decreased sharply. The optimum HRT of a UASB reactor was found to be between 4 and 6 hours. The inert soluble COD of the synthetic wastewater was found to be 16% of the total COD, which passed through the reactor unaffected. It was concluded that it is feasible to design and operate an UASB reactor to treat Mauritian sugar mill wastewater up to a COD removal efficiency of 90% at a HRT of 6 hours. However, the effluent should be pre-treated in terms of addition of alkalinity and nutrients. Also, in order to achieve compliance with the effluent discharge standards using a UASB reactor, a post-treatment should be applied.

Keywords: sugar factory effluents, anaerobic treatment, UASB process.

INTRODUCTION

The Mauritian authorities have introduced standards for effluent limitation applicable to the sugar factories. These norms have been in force since October 1999. However, the sugar mills in the island are not yet equipped with a conventional secondary or advanced treatment. Ragen & Wong Sak Hoi (1998) reported that most of the sugar factories are adopting wastewater management strategies for environmental protection. These include assessment of effluent quality to identify sources of pollution, implementation of pollution prevention measures, dilution of wastewater to meet the norms in case of discharge into rivers, and the use of sedimentation ponds, the output of which is used to irrigate the surrounding cane fields. However, some factories can neither practise dilution of the wastewater due to unavailability of raw water nor can adopt irrigation with their effluents because of practical reasons. For such factories, there is a need to find an appropriate treatment technique to treat their medium to high strength wastewater so that they can comply with the existing environmental law.

Since sugar cane factory effluent has been characterised as a non-toxic organic source of pollution (Wong Sak Hoi, 1994), a biological treatment system is desirable. The conventional aerobic wastewater treatment method would not be appropriate because of the large land space requirement, as well as, high capital costs (mechanical or diffused aeration systems) and operational costs (energy consumption during aeration and high nutrient requirement). Chengebroyen (1995) studied an existing waste stabilisation pond and found that the efficiency of treatment was poor at only 57% COD removal. Moreover, another investigation on the same method treating effluent from a sugar factory revealed that the cost of addition of lime to provide the system with the minimum buffering capacity was very excessive. As a result of the high operating cost, the factory did not implement this treatment system.

The potential advantages of applying anaerobic technologies for the treatment of industrial wastewater in Mauritius has been recognised (Ministry of Environment & Quality of Life, 1991), especially for sugar cane factory effluents. Moreover, the following facts indicate that sugar mill wastewater is amenable to an anaerobic treatment technique.

- High biodegradability and treatability of wastewater as reported by Dosooye (1998).
- Suitability of the anaerobic system for medium to high strength wastewater due to their capacity of operating at high organic loading rates of up to 20 kgCOD/m^3.day.
- Non-toxicity of the cane sugar mill effluents. Therefore, the anaerobic microbial populations responsible for the degradation of organic matter will not be affected.
- Low decay rate of anaerobic micro-organisms. This means that no problem is expected during the inter-crop season concerning the preservation of the sludge.

Van Haandel & Lettinga (1994) compared the different existing anaerobic treatment systems. Considering the major drawbacks of the other systems, the upflow anaerobic sludge blanket (UASB) reactor appears to be a potential candidate for the

Mauritian sugar mills. Moreover, pilot studies carried out in Mauritius have shown that the UASB process holds much promise as a treatment option for the sugar factory wastewaters (Ramjeawon, 1995; Ramdhony, 1998).

A literature review reveals that such a technology has not yet been employed on a large scale in a sugar cane plant, and there is thus a lack of operational experience in this field. Therefore, in order to develop and implement the UASB process in the country, there is a need to obtain base-line information for the design and operation thereof. Such information includes the characteristics of the wastewater, which are compared to the utilisation criteria of the UASB process, and the main operational variable, that is, the hydraulic retention time (HRT). In that context, a pilot study was conducted to assess the performance of the UASB in treating sugar mill wastewater and provide these base-line data. This paper presents the results of a work done on a 10 L pilot UASB reactor. Tests were carried out to determine the optimum HRT. The final effluent from a sugar factory was characterised, the results of which was used to simulate the synthetic molasses-based influent involved in this study.

MATERIALS AND METHODS

The study was carried out into two phases. Phase I consisted of the characterisation of a sugar factory wastewater during normal operating conditions, and phase II involved the determination of the optimum HRT of the reactor treating a synthetic influent.

Phase I

For two weeks during the normal running conditions, the final effluent at the factory was sampled. A composite sample was made from 12 hourly grab samples taken over a 12-hour period per day, preserved and analysed for filtered and unfiltered COD, TSS, alkalinity, TKN, total phosphorus and sulphate. Temperature and pH on each fresh sample were also recorded. COD was effected by a semi-micro digestion method followed by colorimetry (Wong Sak Hoi, 1992). The determination of TSS and alkalinity were carried out by the filtration method through Whatman GF/C filter (STASM, 1991) and the 5 pH titration method (Moosbrugger *et al.*, 1992), respectively. The method of Kjeldhal digestion followed by steam distillation (Rayment & Higginson, 1992) was used to determine TKN. Analysis of total P was carried out by the method of H_2SO_4/H_2O_2 decomposition followed by Murphy and Riley colorimetric finish (Murphy & Riley, 1962). Sulphate was analysed by the Sulfaver 4 method using a Hach DR/2000 Spectrophotometer.

Flow rates of the final effluent were also monitored using a Swoffer model 2100 series current velocity meter.

Phase II

The 10 L pilot UASB used in this study reactor is depicted in **Figure 1**. It was made up of glass and is of a cylindrical form. It was equipped with a gas-liquid-solids separator as an inverted funnel in the upper part and an outer wall jacket through which water can flow to maintain the reactor at the required temperature. The experimental set-up is illustrated in **Figure 2**. The flow of the influent was controlled using a Watson-Marlow peristaltic pump and the effluent coming out from the top was allowed to drain into a sink. The temperature of the reactor was maintained at 37^{o}C throughout the whole study by means of a water bath, which circulated warm water through the outer wall jacket. The gas generated passed through the gas collector towards the gas port, which led to a Mariot flask containing 15% NaOH solution to remove CO_2 from the biogas. Finally, the flow of the gas containing mainly methane was measured using a wet test gas flowmeter.

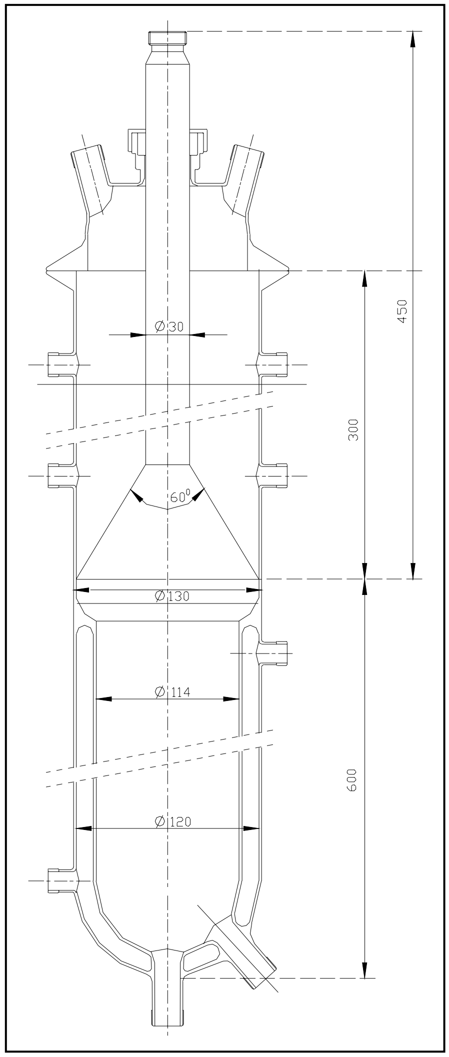

Figure 1: The 10 L UASB reactor (dimensions in mm)

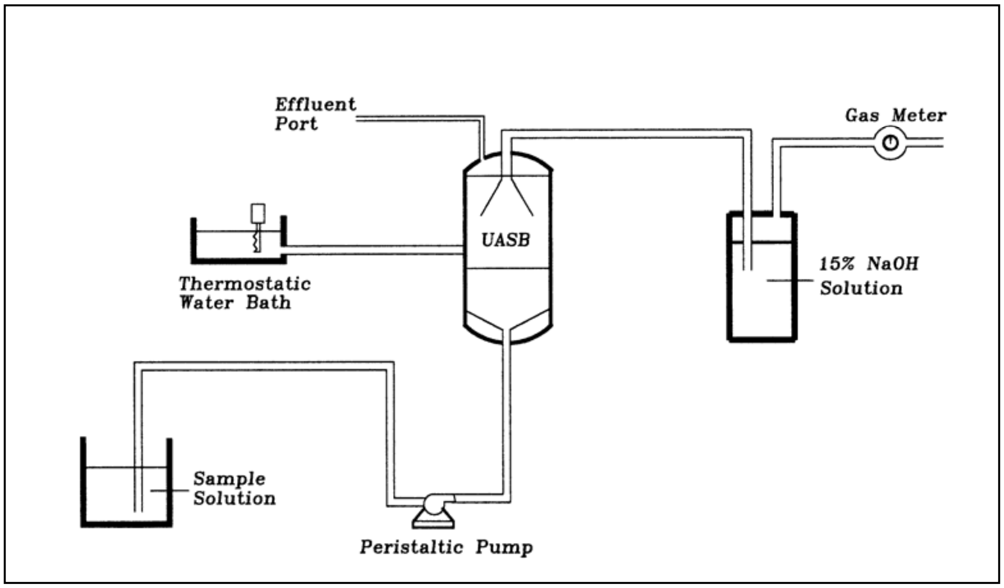

Figure 2: The experimental set-up

The synthetic influent, a molasses-based substrate prepared to simulate the real sugar factory wastewater, was buffered with sodium bicarbonate to prevent drop in pH. Nutrients and trace elements were also added into the solution to avoid inhibition of the microbial growth. Initially, the reactor was inoculated with 4 litres of sludge and was started-up with the influent for a period of 65 days to allow the microbial population to adapt and acclimate to the substrate. Phase II consisted essentially of reducing successively the HRT after the reactor had reached the steady-state condition, that is, when the COD removal efficiency did not vary for more than 5% of the mean value for the last four consecutive days. In other words, when steady-state is attained, no more COD will be degraded. Phase II was conducted over 72 days. **Table 1** shows the operation conditions during this phase.

Day Number	**HRT (hours)**	**Organic loading rate (kg COD/m^3.day)**
1 – 9	10.1	2.0 – 2.7
11 – 25	8.3	2.7 – 2.8
26 – 36	6.2	3.6 – 4.2
45 – 65	4.0	5.9 – 7.0
66 – 72	2.0	10.7 – 11.9

Table 1: Operating conditions of the reactor during Phase II

During Phase II, daily composite samples of the influent and effluent were made over a period of 8-hour from grab samples taken at one- hour intervals. The composite samples were preserved and analysed for pH, volatile fatty acids (VFA), alkalinity and COD. The influent samples were also analysed for total Kjeldhal nitrogen (TKN), ammonium nitrogen, nitrate-nitrogen, total phosphorus and sulphate. NH_4-N and NO_3-N were analysed by the steam distillation method (Black *et al*, 1965). The analysis was carried out on a daily basis. The influent was finally analysed for hard COD by the Germili *et al* (1991) method at the end of the experiment.

RESULTS AND DISCUSSIONS

Phase I

Table 2 shows the waste characteristics of the sugar factory effluent involved in this study.

Parameters	Range	Mean
pH	6.0 – 6.5	6.3
Temperature (^oC)	63 - 70	67
TSS (mg/l)	100 - 250	228
Unfiltered COD (mg/l)	700 - 1391	1065
Filtered COD (mg/l)	445 - 1122	780
Alkalinity (mg/l $CaCO_3$)	0 – 12	5
TKN (mg/l)	11.3 – 19.3	15.2
P (mg/l)	0.3 – 0.9	0.6
Sulphate (mg/l)	0 – 18	5
Flow (m3/h)	-	50

Table 2: Characteristics of final effluent

The criteria for the utilisation of the UASB process are given in **Table 3**.

pH	6.5 – 7.5
Alkalinity	> 0.49 g $CaCO_3$/gCOD digested
Temperature	Mesophilic range
Nutrients	COD:N:P > 100:2:0.5
Sulphate	COD/SO_4 > 10
Suspended	SS < 1000 mg/L or SS/COD < 0.5
COD load	Medium to high
Trace metals	Present in low concentrations

Table 3: Criteria for utilisation of UASB reactor
(Source: Souza, 1986)

It is to be noted that the pH range mentioned in **Table 3** is that of the solution inside an UASB reactor. The pH of the effluent would be the same since the reactor is normally operated under a continuous flow mode. Thus, when the pH of the effluent is within the range of 6.5 – 7.5, the buffering capacity of the system will be effective against sharp drop in pH. It is crucial to prevent the pH to drop below that range because the methanogenic bacteria, responsible for the production of methane from VFA, will be killed and the anaerobic process will be inhibited. This major operational failure of UASB processes can be avoided by maintaining the pH of the wastewater to be treated slightly above 7.5.

Comparing the results obtained in **Table 2** with the utilisation criteria (**Table 3**), the sugar factory effluent needs to be pre-treated as follows.

1. The pH was low, meaning that it should be increased slightly above 7.5.
2. The temperature was high, therefore it should be cooled to around 37 –40^{o}C.
3. The effluent was deficient in alkalinity. To maintain the required buffering capacity, the wastewater should be supplemented with alkalinity at a minimum of 0.49 g$CaCO_3$/gCOD.
4. The minimum COD: N:P was less than 100:2:0.5, meaning that N and P should be supplemented.

The ratio of COD/SO_4 was higher than 10, indicating that no odour and corrosion problems due to the release of H_2S are expected with the factory effluent.

Therefore, with the above-mentioned pre-treatment, the sugar factory effluent is amenable and suitable for treatment by the UASB process.

Phase II

The characteristics of the synthetic influent are given in **Table 4**.

Parameters	**Range**	**Mean**
pH	7.5 – 7.9	7.7
VFA (mg/l HAc)	0 – 84	31
Alkalinity (mg/l $CaCO_3$)	580 – 1095	742
TKN (mg/l)	21.6 – 34.6	31.4
NH_4-N (mg/l)	22.4– 24.5	23.6
NO_3-N (mg/l)	0 – 4.0	2.3
Organic N (mg/l)	8.7 – 10.1	9.1
Total N (mg/l)	31.1 – 38.5	34.9
Total P (mg/l)	4.0 – 12.7	9.8
Sulphate (mg/l)	20 – 32	26
COD (mg/l)	852 – 1150	1019

Table 4: Characteristics of influent during Phase II

Table 4 indicates that most of the criteria for utilisation for the UASB process had been satisfied. The average COD:N:P at 100:3.4:1.0 was higher than the minimum requirement. The optimal development and growth of the microbial populations had thus been ensured. The pH of the synthetic influent ranged from 7.5 to 7.9 with an average of 7.7. This range of pH was achieved by the addition of 1g sodium bicarbonate per g of influent COD to the prepared synthetic solution provide the necessary buffering capacity of the system. In fact, it was observed that the pH of the effluent varied between 6.6 and 7.4, which is indicative of a well-buffered system.

Phase II began at a HRT of 10.1 hours with a load of 1124 mg/L COD, representing an organic loading rate of 2.7 kg COD/m^3.day and after steady-state had been reached, the HRT was successively reduced to 8.3, 6.2, 4 and 2 hours. The whole phase took 72 days. During the same period the average organic loading rate increased from 2.3 to 11.5 kg COD/m^3.day.

It was observed that while decreasing the HRT, the interface initially present between the sludge and the clear effluent at low flow rates disappeared. The reactor content was completely mixed. This was due to the increasing upflow velocity accompanied by higher gas production (depending on organic loading rates) that caused further mixing of the sludge. However, at a HRT of 2 hours, the upflow velocity was too high for the settler to function properly. The hydraulic conditions were so drastic that sludge was carried out of the reactor and effluent was flowing though the biogas line. The air passage was blocked and no gas reading could be recorded at that HRT. There was also formation of scum, which had to be removed almost every day.

The steady-state performance of the reactor at different HRT is illustrated in **Figures 3**, **4** and **5** and given in **Table 5**.

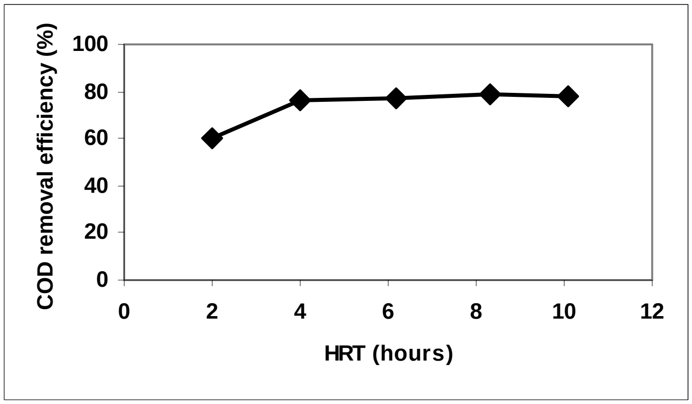

Figure 3: Changes in average COD removal efficiency at different HRT

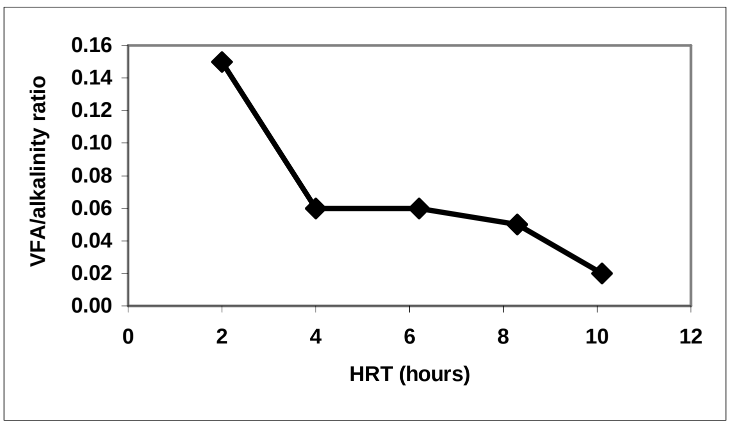

Figure 4: Changes in average VFA/alkalinity ratio at different HRT

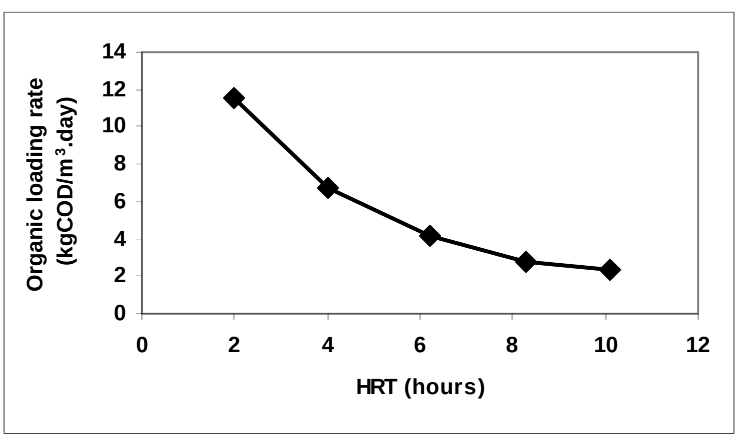

Figure 5: Changes in average organic loading rate at different HRT

	HRT (hours)				
	10.1	**8.3**	**6.2**	**4.0**	**2.0**
Number of operational days	9	15	11	21	6
Average organic loading rate (kg COD/m^3.day)	2.3	2.8	4.2	6.7	11.5
Upflow velocity (m/h)	0.10	0.12	0.16	0.25	0.49
Average influent VFA (mg/l HAc)	57	31	34	12	28
Average effluent VFA (mg/l HAc)	16	36	39	55	124
Average influent alkalinity (mg/l $CaCO_3$)	600	591	620	923	885
Average effluent alkalinity (mg/l $CaCO_3$)	647	647	849	927	815
Average effluent VFA/alkalinity ratio	0.02	0.05	0.06	0.06	0.15
Average influent COD (mg/l)	969	964	1086	1105	957
Average effluent COD (mg/l)	216	202	253	267	379
Average COD removal efficiency (%)	78	79	77	76	60
Maximum COD removal efficiency COD (%)	81	80	78	78	62

Table 5: Steady-state performance of the reactor under varying HRT

The results show that with a HRT of more than 4 hours and an organic loading rate below 6.7 kg COD/m^3.day, the efficiency of COD removal was almost independent of the HRT and systematically remained above 76%. However, with a HRT of 2 hours and an average organic loading rate above 11.5 $kgCOD/m^3$.day, a sharp drop in the efficiency of COD removal was observed (60% on average). This was concomitant with a similar increase in effluent VFA/alkalinity ratio (**Figure 4**). This indicates that the UASB reactor should not be operated at HRT of less than 4 hours.

It was observed that HRT had an influence on the COD removal efficiency of a UASB reactor. At long HRT, it was found that the efficiency of COD removal was independent of HRT but can be significantly lower at shorter HRT. In general, the COD removal efficiency decreased with declining HRT. The results also indicated that there was little benefit in operating the reactor, at a HRT exceeding 4 - 6 hours because no significant additional COD removal was achieved. The optimum HRT for a UASB was, therefore, found to be between 4 to 6 hours.

However, the optimum HRT to be applied depends on the desired results and whether post treatment is applied. If the UASB reactor is employed as the only or main treatment unit, the optimum HRT should be sufficiently high to guarantee high removal efficiency and consequently an average HRT of 6 hours is required. In case that a post-treatment is required after the UASB reactor then shorter HRT values can be applied and are advantageous under certain circumstances (Van Haandel and

Lettinga, 1994). The difference will be in the reactor volume, i.e. smaller in the latter case.

Although the efficiency decreased with shorter HRT, in no case was process failure observed, that is, collapse of the methanogenic activity due to an excessively short retention time. It can be stated that the UASB reactor was very stable under the loadings and other conditions applied in the system.

It was also observed that the effluent quality, specially in terms of COD, obtained showed that compliance with the effluent standard for discharge in rivers would not be met, indicating that a post-treatment will be required when treating sugar mill wastewater with the UASB reactor. This is in line with the observations of Ramjeawon (1995) and Ramdhony (1998).

Table 6 compares the results from this study with other similar works carried out by Yang et al (1991), Ramjeawon (1995) and Ramdhony (1998).

	Reactor capacity	**Optimum HRT (hours)**	**OLR (kgCOD/m^3.day)**	**COD removal efficiency (%)**
Yang *et al*[1]	10 L	4.3	6.7	85
Ramjeawon[2]	1 m^3	6	12.5	91
Ramdhony[3]	10 L	4	6.5	93
This study[4]	10 L	4 - 6	4.2 - 6.7	76 - 77

Table 6: Comparison of this study with other similar works

1: Real sugar mill wastewater under lab conditions
2: Real sugar mill wastewater under field conditions
3: Pure sucrose synthetic wastewater
4: Molasses substrate

Table 6 shows that the optimum HRT obtained by Yang et al. (1991), Ramjeawon (1995) and Ramdhony (1998) are comparable with the results obtained in this study, but their efficiencies of COD removal were higher. The difference in efficiency is attributed to the non-biodegradable fraction (inert soluble fraction) of the molasses solution that passed through the UASB reactor unaffected. In fact, this inert soluble COD fraction of the molasses solution was determined at the end of the experiments and was found to be 16% of the total COD. This figure is comparable to the hard COD of chemical and textile wastewater found to be 22 and 25 % of total COD, respectively (Dosooye, 1998). It is to be noted that the effluents from chemical and textile plants are among those which are the most difficult to treat biologically. Dosooye (1998) reported only 2.5% inert soluble COD in real sugar factory effluent, which was much more biodegradable. Had there not been such a high amount of inert soluble COD fraction in the molasses feed substrate utilised in this study, the COD removal efficiency could have been more than 90% at a HRT of 6 hours, as concluded by Ramjeawon (1995).

The COD removal efficiency of the UASB reactor at a temperature of 37^{o}C can be approximated by the following equation, found through regression analysis of the data obtained during phase II under steady state conditions.

$$E = 1 - 0.47\,(HRT)^{-0.37} \quad \text{(for average COD removal efficiency)}$$
$$E = 1 - 0.47\,(HRT)^{-0.41} \quad \text{(for maximum COD removal efficiency)}$$

where E is efficiency of COD removal and HRT is in hours (2 < HRT < 10.1).

Table 7 compares some empirical equations proposed after the study of the influence of HRT on steady state UASB reactor efficiency.

Workers	Wastewater	Expression
Aisse & Bollman	Domestic	$E = 1 – 1.53\,(HRT)^{-0.64}$
Kaskining	Domestic	$E = 1 – 0.68\,(HRT)^{-0.68}$
Ramjeawon(199	Real sugar	$E = 1 – 1.98\,(HRT)^{-1.32}$
Ramdhony	Pure-sucrose	$E = -0.03\,(HRT)^{2} + 0.53$
This study	Molasses	$E = 1 – 0.47\,(HRT)^{-0.37}$

Table 7: Comparison of Empirical relationships derived for various wastewaters
(Source: Van Haandel & Lettinga, 1994)

Table 7 shows that, except for Ramdhony, there is a general trend towards the following relationship:

$$E = 1 – C1\,(HRT)^{-C2}$$

where C1 and C2 are empirical constants, which are specific to each UASB reactor and the conditions employed. There is a considerable difference in the relationship between efficiency of COD removal and HRT, as evidenced by the variation in the values of the C1 and C2 constants. This may be attributed to the differences in HRT imposed, in the characteristics of the wastewater (domestic and sugar mill wastewater) and in operational conditions.

This general expression can be used to compare the HRT and hence the volume of UASB reactors. For illustration, the HRT were calculated for 80% COD removal efficiency and presented in **Table 8**.

Workers	**C1**	**C2**	**HRT for E=0.8**
Aisse & Bollman*	1.53	0.64	24
Haskoning*	0.68	0.68	6
Ramjeawon (1995)	1.98	1.32	6
This study (average E)	0.47	0.37	10
(maximum E)	0.47	0.41	8

Table 8: Empirical values of the characteristics constants and HRT for 80% COD removal efficiency for different UASB reactors
(Source: Van Haandel & Lettinga, 1994)

Table 8 shows that it is feasible to design an UASB reactor for a COD removal of 80% at or above a HRT of 6 hours. However, according to the equation obtained in this study, 80% COD removal efficiency was possible at a longer HRT, that is, between 8 and 10 hours. This is attributed to the presence of high inert soluble COD in the synthetic molasses substrate used in this study. The effects of such a proportion of hard COD in the substrate could be as follows.

1. Lengthening of the HRT for a specific COD removal efficiency, that is, the HRT for E = 0.8 should have been shorter than 8 –10 hours and thus in line with the conclusions of Ramjeawon (1995) shown in **Table 8**.

2. Reducing the efficiency of COD removal efficiency at a specific HRT. Thus it can be stated that it is feasible to treat sugar factory effluent up to more than 90%.

CONCLUSIONS

The followings are concluding remarks from the study:

1. The wastewater from the sugar cane mills was found to be amenable to the UASB treatment because of its high biodegradability and non-toxicity. However, it should be supplemented with alkalinity and nutrients.

2. The presence of inert soluble COD (hard COD) in the wastewater lowered the COD removal efficiency of the UASB process.

3. HRT, the main operational variable in a UASB reactor, influenced its COD removal efficiency. The latter decreased with declining HRT.

4. The optimum HRT that a UASB should be operated lay between 4 to 6 hours and the choice depends on the desired effluent quality and whether any post treatment is needed or not.

Finally, it can be concluded that it is feasible to design a UASB reactor to treat sugar factory wastewater at 90% COD removal efficiency at a HRT of 6 hours and the organic loading rate would depend on the influent COD.

REFERENCES

BLACK, C.A., EVANS, D.D., WHITE, J.L., ENSMINGER, L.E. & CLARK, F.E. (1965). Methods of soil analysis, Part 2, Agronomy 9. *American Society of Agronomists*, Inc., Madison, Wis.

CHENGEBROYEN, S. (1995). *Use of waste stabilisation ponds for the treatment of cane-sugar industry wastewater in Mauritius.* B.Tech. Dissertation, Faculty of Engineering, University of Mauritius.

DOSOOYE, K.L. (1998). *Assessment of the treatability of selected industrial Wastewaters.* B. Eng. Dissertation, Faculty of Engineering, University of Mauritius.

GERMIRLI, F., ORHON, D. & ARTAN, N. (1991). Assessment of the initial inert soluble COD in industrial wastewaters. Water Science Technology **23**, 1077–1086.

MINISTRY OF ENVIRONMENT AND QUALITY OF LIFE (1991). State of the environment in Mauritius. Ministry of the Environment and Quality of Life, Port-Louis, Mauritius.

MOOSBRUGGER, R.E., WENTZEL, M.C., EKAMA, G.A. & MARAIS, G.V.R. (1993). Alkalinity measurement: Part 3 – A 5 pH end point titration method to determine the carbonate and SCFA weak acid/base in aqueous solutions containing also known concentration of the other weak acid/bases. *Water SA*, 29–40.

MURPHY, J. & RILEY, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta.* **27**, 31–36.

RAMDHONY, R.R. (1998). Start-up and Operation of an Upflow Anaerobic Sludge Blanket (UASB) Reactor Using Synthetic Sucrose Feed Solution. B.Eng. Dissertation, Faculty of Engineering, University of Mauritius.

RAGEN, A.K. & WONG SAK HOI, L. (1998). Wastewater management strategy for compliance with the norms- a case study. P*roceedings of the international conference on "The Engineering Profession Beyond Year 2000*: 23 – 30.

RAMJEAWON, T. (1995). Integrated management of cane-sugar factory wastewaters in Mauritius using the upflow anaerobic sludge blanket (UASB) process. Ph.D. Thesis, Faculty of Engineering, University of Mauritius.

RAYMENT, G.E. & HIGGINSON, F.R. (1992). Nitrogen. In *Australia Laboratory Handbook – Soil and Water Chemical Methods*. Inkata Press, Melbourne, pp. 241–244.

SOUZA, M.E. (1986). Criteria for the utilisation, design and operation of UASB reactors. *Wat. Sci. Tech.*, **18** (12), 55–69.

STASM (1991). Laboratory manual for Mauritian sugar factories – Official Methods, p. 11.

VAN HAANDEL, A.C. & LETTINGA, G. (1994). In *Anaerobic Sewage Treatment – A Practical Guide for Regions with a Hot Climate*. J Wiley and Sons.

WONG SAK HOI, L. (1992). Application of a semi-micro method to routine monitoring of chemical oxygen demand (COD) of sugar factory effluent – Paper presented at the iXth STASM Congress Oct. 92. *Revue Agricole et Sucrière de l'Ile Maurice* **71** (2 & 3), 339–349.

WONG SAK HOI, L. (1994). Characterisation of sugarcane factory wastes and pollution control. *MSIRI Technical Reports ST 6 & ST 7*, **1** & **2**.

YANG, P.Y., CHANG, L.J. & WHALEN, S.A. (1991). Anaerobic/aerobic pre-treatment of sugarcane mill wastewater for application of drip irrigation. *Water Science Technology* **24** (9), 243–250.