MAURITIUS RESEARCH COUNCIL

START-UP AND OPERATION OF THE UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) PROCESS

Final Report

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UNIVERSITY OF MAURITIUS

Faculty of Engineering

START-UP AND OPERATION OF THE UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) PROCESS

(A Mauritius Research Council Funded Project)

MRC/RUN-9806

Final Report

Dr T RAMJEAWON

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Preface

This report presents the results of the project funded by the Mauritius Research Council (Project No: MRC/RUN/9806): Start-up and operation of the UASB process. This was a collaborative project between the University of Mauritius and Rose Belle Sugar Estate. The Principal Investigator of the project was Dr T Ramjeawon, Associate Professor at the Faculty of Engineering of the University of Mauritius.

I would like to express my thanks to the following persons/institution for their valuable help and assistance during the project:

- Associate Professors Dr B K Baguant and Dr A Chan Chim Yuk, previous Deans of the Faculty of Engineering, University of Mauritius.

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- The Technical Staff of the Public Health Engineering Laboratory of the Faculty of Engineering, University of Mauritius.

Dr T RAMJEAWON

Principal Investigator

EXECUTIVE SUMMARY

Pilot Plant Investigations have shown the feasibility of the Upflow Anaerobic Sludge Blanket (UASB) process in effectively removing about 90 percent of the COD contained in sugar industry effluents at an organic loading rate of 12.5 Kg COD/m^3.day and a hydraulic retention time of 6 hours. Within the context of promoting the use of biotechnology for environmental protection, the Mauritius Research Council (MRC) funded the construction of a 50m^3 demonstration plant at Rose Belle sugar factory, which was completed in September 1998. The main objective of this project was to determine the optimum criteria during the start-up phase of the treatment plant using a suitable inoculum and to operate it during two milling seasons.

A proper equalization pond is a pre-requisite for the successful operation of any high-rate anaerobic system. Alkalinity has to be added to this pond to achieve a minimum concentration of 1500 mg/l $CaCO_3$. The start-up of the plant has proved to be difficult and good quality sludge needs to be available. The presence of good quantity of seed sludge is the key for success of the UASB plant. It is proposed that in the Mauritian context the reactor be seeded either with septic tank sludge, anaerobic pond sediments or with imported granular sludge. Following the addition of a proper quantity of sludge in the reactor, the COD removal efficiency reached 70 percent during the 2001 milling season. The organic loading rate was 3.5 KgCOD/m^3.day for a HRT of 24 hours. The organic loading rate can be further increased provided there is a good quantity of acclimatized sludge in the reactor.

A pre-design cost estimation arrived at a capital investment of about Rs 12,000 per m^3 of reactor. A 150 TCH factory will have to invest about 5 million rupees for a UASB treatment plant. The net annual operating cost is estimated at about Rs 3.00 per Kg of influent COD.

Increased recycling of process water in industries will lead to lower amounts but higher concentrated effluents and an increased demand for anaerobic processed can be expected in the future. The effluent charges set by the Wastewater Management Authority (WMA) for discharge into sewers will increasingly lead to pre-treatment of industrial effluents using anaerobic technologies. The full potential of high-rate anaerobic technologies has so far not been exploited in the Mauritian context. There is a need for specialized training courses on anaerobic treatment for industry personnel and responsible authorities and financial organizations must be informed on the potential of these technologies.

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Chapter 1

Background, Project Objectives and Work Plan of Project

The University of Mauritius initiated in 1990 a research programme on environmental issues related to cane-sugar industry wastewater treatment and disposal.

Among the treatment processes reviewed, the Upflow Anaerobic Sludge Blanket (UASB) process has more advantages over other processes. Moreover there have been many successful experiences around the world dealing with different scales of the UASB process. Thus the UASB process was proposed to receive application for the treatment of cane-sugar industry wastewaters. A pilot plant investigation at one of the sugar factories during the period 1993 to 1995 has shown the feasibility of the UASB process in effectively removing about 90% of the COD contained in the wastewater at an organic loading rate of 12.5 kg COD/m^3 day and a hydraulic retention time of 6 hours.

Following the recommendation of Engineers from the sugar industry and external visitors and examiners, an industrial scale investigation has been formulated with the collaboration of Rose Belle Sugar Factory and proposed to the Mauritius Research Council for funding. Within the context of promoting use of biotechnology for environmental protection, funding was secured from the council for a period of three years, i.e. 1995-1998. A 50 m^3 UASB reactor was designed and the construction was completed in September 1998.

The main objectives of this project were:

(1) Determination of the optimum criteria during the start-up phase of the treatment plant using a suitable inoculum

(2) To operate it during two milling seasons to determine optimum operation criteria

(3) Determination of the technical and economic feasibility of the treatment system for the Mauritian Cane-Sugar Industry.

The work plan for the project was as follows:

June 1998	• Allocation of research contract
June 1998 – December 1998	• Commissioning of plant and elimination of all snags identified. Preliminary operation of reactor.
January 1999 – June 1999	• Construction of a big equalisation pond at Rose Belle Sugar Factory and seeding of reactor
July 1999 – December 2001	• Operation of reactor during the milling season

Chapter 2

Wastewater Characteristics at Rose Belle Sugar Factory

For effective wastewater management, it is necessary to separate the wastewater generated in a typical 100 TCH factory into 3 main streams as tabulated in Table 1.

Table 1: Combined Wastewater Flows, Strengths and Pollution Loads

WASTEWATER	FLOW	BOD_5		TSS	
	m^3/d	mg/L	kg/d	mg/L	kg/d
1. Overflow spray-pond + Overflow fly-ash treatment plant	4320	62.3	269	134	579
2. Excess condensates + Boiler blow down	780	361.5	282	10.3	8
3. Floor wash + Miscellaneous Cooling waters + Mill House Wastewater	720	1819	1310	244	205

The medium and high effluents of Rose Belle Sugar Factory (stream 3) were monitored during the 1998 milling season and the results are presented in Table 2. As observed, during daily factory operation, the effluents of the factory is slightly acidic, contains about 80% of soluble organic matter, has very low alkalinity and is deficient in nitrogen and phosphorus for biological treatment. This effluent stream needs to undergo some form of biological treatment so as to meet the standards promulgated for the sugar industry (see Appendix 1).

The overall pollutant load of Rose Belle Sugar Factory during a milling season, including the high strength effluents discharged during the end-of-crop, is about 600 tonnes of COD. Of this pollution load, 68% is generated during daily factory operation, 21% during the weekend shutdown washings and 11% during the end-of-crop shutdown washings. The pollution rate of the factory for the milling season is about 2.3 kg COD per tonne of cane.

Table 2: Typical Characteristics of Effluent to be treated in a Cane Sugar Factory

Flow	0.4 m^3/tonne of cane or about 800 m^3/day for a 100 TCH factory
BOD_5	1800 mg/L
COD	4300 mg/L
TSS	250 mg/L
pH	6.2
Temperature (ºC)	28
Alkalinity	50mg/L

Chapter 3

UASB as an Appropriate Technology for the Mauritian Cane-Sugar Industry

Failure of wastewater management strategies is often attributed to the objectives not being clearly defined and inappropriate selection of treatment process. Three major factors which need to be properly addressed, for sustainable wastewater management, are listed below:

- **Technical ignorance**: This is widespread in developing countries and it includes such questions as why wastewater management is necessary, what it can and cannot achieve, and what are the requirements for optimization.
- **Failure to consider all relevant factors**: Failure to take into account all aspects of a country's ability to cope with imposed technologies and an under appreciation or lack of realistic understanding of the constraints of any proposed strategy.
- **The setting of standards**: Standards are the link between what one desires socially and environmentally and what one can afford economically, technically and institutionally. The use of inappropriate discharge standards has many negative repercussions, for example, standards, which are too stringent, may lead to selection of a high level of technology which is complex to operate and can lead to total failure.

Bhamidimarri (1991) defined appropriate technology as:

"The technology which is adaptable to given social, cultural and environmental conditions and which is based on low investment, organisational and operational simplicity, and on the principles of environmental and resource conservation".

Appropriate technologies are developed taking into account the socio economic and environmental conditions of a country. Economies are very often fragile in industrialising small countries, presenting the need for sustainable technologies.

The requirements of any appropriate wastewater treatment technology are summarised in Table 3.

Table 3: Requirements for an Appropriate Industrial Wastewater Treatment System

(i) Produce good effluent quality (low COD, low TSS, etc)
(ii) Remove pollutants at high rate (short retention time)
(iii) Consume minimum materials (oxygen, nutrients, alkalinity)
(iv) Produce useful sub products (Methane, effluent for irrigation)
(v) Have a stable performance (No operational failures, resistance to shock loadings)
(vi) Be "imperceptible" (no noise, no odours, "invisible")
(vii) Have low construction and operational costs and ability of industry to pay
(viii) Ability of the industry to take responsibility for treatment and disposal.

Based on the characteristics of the UASB process, it can safely be concluded that the UASB does provide many of the requirements for an appropriate wastewater treatment system for the cane-sugar industry. Furthermore, it does possess resource recovery potential which is essential in a well adapted appropriate technology. Other factors which tend to favour such a process are:

- The high cost of traditional aerobic technologies for the treatment of industrial wastewaters in rural areas represent a constraint for the sugar factories.
- Treatment of sugar mill wastewaters by trickling filter and activated sludge processes has been studied by many researchers with varying degree of success. Sugar mill wastewaters are deficient in nutrients and the carbohydrate concentration leads to sludge bulking problems. As a result, the efficiency of BOD removal in either of the two systems was observed to be poor (Miller, 1973) and the methods considered uneconomical for adoption in practice. Since anaerobic digestion would need considerably

less amount of nutrients than aerobic treatment processes and no bulking problems will arise, it seems to be more appropriate for this type of wastewater. Sugar campaign is also seasonal in nature. Since a biological wastewater treatment plant normally requires at least a month for stabilising, a fully mechanised type of plant for treatment of sugar mill wastewaters is in most cases considered uneconomical. The treatment of sugar factory wastewaters by lagooning or in oxidation ponds has, therefore, been found feasible and economical where the availability and cost of land is not a constraint.

- A special problem of campaign agro-industries is the start-up of biological treatment systems at the beginning of each campaign. Accordingly, the start-up of high-rate anaerobic systems is less problematic than aerobic treatment systems.
- The anaerobic process can be preserved unfed for a long period without any deterioration. Borghans *et al* (1987) report that UASB reactors utilised for the treatment of sugar beet wastewater remain viable after nine months of shutdown.
- There have been many successful experiences of the UASB with beet sugar industry wastewaters. In 1971, the first laboratory UASB reactors were operated at the Agricultural University of Wageningen in the Netherlands (Lettinga *et al*, 1984). These were operated with well settling flocculent sludge treating sugar beet juice solutions at volumetric loading rates of 10 Kg COD/(m^3.day). The enhanced settling characteristics of the sludge granules allowed much higher sludge concentrations, consequently, enabling higher loading rates of up to 30 Kg COD/(m3.day). From 1977 onward anaerobic wastewater treatment in the beet sugar industry using the UASB process has been successfully implemented (Hulshoff Pol and Lettinga, 1986). There have been many successful experiences dealing with different scales of the UASB process for beet sugar industry wastewaters (Pette and Versprille, 1981). Table 4 summarises the basic design and performance features of a 800 m^3 UASB plant treating beet sugar industry wastewaters.

- There is no literature on the installation of a full-scale UASB process in cane-sugar factories. Yang *et al* (1991) reports that a 10 litres pilot plant UASB reactor effectively removed 85% of the COD contained in the sugar cane mill wastewater in Hawaii at an organic loading rate of 7 kg COD/m^3.day and a HRT of 4.3 hours. The organic loading rate achieved was low, due to the low influent COD concentration (1500 mg/L). Manjunath *et al* (1990) found that in a 11.4 L pilot UASB reactor, COD removal above 90% can be achieved at sludge loading rates of up to 1.25 kg COD kg VSS^{-1} d^{-1} while treating synthetic cane sugar mill effluents.

Table 4: Design Features of a 800 m^3 UASB Plant Treating Beet Sugar Industry Wastewaters

Tank configuration	Rectangular
Building Material	Concrete
Height (m)	4.5 m
Bottom surface (m^2)	178
Depth of digesting zone (m)	3.3
Depth of settling zone (m)	1.2
Organic loading	
- (Kg COD/d)	13000
- (Kg COD/m^3.day)	16.3
Influent concentration (mg COD/L)	3000
Purification efficiency (%)	88
Average hydraulic flow (m^3/h)	180
Gas Production (m^3/m^2.h)	1.2

(adapted from Pette K.C. Full scale Anaerobic Treatment of Beet Sugar Wastewater. Proc. 35th International Waste Conference, Purdue Univ. (1981), Ann Arbor, Michigan)

- Anaerobic treatment is feasible at low ambient temperatures. The application of the anaerobic process is more attractive in a tropical country like Mauritius and for the sugar industry where high temperature wastewaters can be obtained.

- The process can be applied at very small scale and at very large scale as well.
- Chengebroyen (1995) showed that the organic loading rates in anaerobic ponds were about 3 times the recommended loading rate of 300 g/m^3.day during factory operation and more than 4 times the value during shutdown periods. The open pond anaerobic process was not very effective, removing at best about 60% of the COD. However, most of this COD removal was achieved by suspended solids removal (80-90% TSS removal efficiency). Inadequate buffering capacity and overloading of the systems led to a significant drop in the effluent pH to less than 5 and to high VFA values (> 200 mg/L). Chengebroyen (1995) also calculated the land requirement for an adequately designed WSP system for a model 150 TCH factory at about 3 hectares. The conversion of land under cane cultivation to a WSP system would represent a reduction in sugar production of about 23 tonnes annually.
- Compared to anaerobic lagoons, UASB reactors have the following additional advantages:
    - Biogas is recovered
    - Far less space is required and compact installations can be applied
    - No seepage and groundwater pollution problems
    - Better removal efficiency
    - No odour nuisance
    - Better control.
- The applicability of UASB depends on the formation of a well settling sludge. Although a wide variety of factors are essential for the rapid growth of granular sludge, it has in recent years become clearer that high energy carbohydrates in particular contribute to this phenomenon. The COD-concentration of the influent is optimally 2000 to 10 000 mg/L mainly consisting of readily biodegradable carbohydrates (De Smedt and Grusenmeyer, 1991). The sugar industry is an ideal industry where UASB reactors could be used to treat the medium to high-strength wastewaters generated that specifically needs biological treatment.

- The installations are fairly simple in construction, i.e. generally they do not have any sophisticated mechanical devices and can be built with locally available construction materials. Most importantly, it is felt that with the expertise available in Mauritian sugar factories, the latter can themselves do the construction work.

For the above reasons, the UASB process can be considered as an appropriate treatment technology for cane-sugar factory wastewater. Though the design of the UASB is relatively simple, it is not necessarily easy to start up and operate. Apart from some general guidelines that should be followed to obtain and preserve the proper sludge quality and quantity (de Zeeuw, 1984), each type of wastewater provides its own typical problems and requires a set of specific operation skills. Such skills can be acquired by operating pilot scale plants. Consequently, the operational process performance, including start-up period, sludge flocculation and wash out and influent quality control such as alkalinity addition has been investigated in a $50m^3$ demonstration plant.

Chapter 4

Materials and Methods

4.1 Typical Treatment Scheme for a Cane-Sugar Factory

- Establishing good water management with as much recycling of process water as possible is essential. Separating waste streams with low BOD load from streams with a high BOD load is vital in this context. Few sugar factories in Mauritius segregate waste streams in a systematic way. Three classes of floor drains must be used in a sugar factory. These are:

  (a) an effluent drain for the high strength effluents (floor washings, mill-house wastewaters and shutdown washings)

  (b) a barometric condenser cooling water/overflow spray pond drain which may also carry any storm water runoff

  (c) a drain to cope with excess condensate, boiler blow-down and cooling waters. With proper entrainment control, the pollution load of this stream is expected to be low and can be discharged together with the overflow from the spray pond.

- The treatment system would consists of the following unit operations:

  - coarse and fine screening
  - separation of oil and grease
  - flocculation with anionic polyelectrolyte and lime
  - clarification
  - anaerobic digestion for BOD reduction
  - aerobic treatment for further polishing of effluent.

4.2 Pollution Control System at Rose Belle Sugar Factory

- Two classes of floor drains are used in the factory

    (a) an effluent drain carrying the floor washings, mill-house wastewaters and shutdown washings, cooling waters, overflow from the fly-ash treatment system, storm water runoff and laboratory effluents. This drain goes through a treatment system before discharged into the river.

    (b) a barometric condenser cooling water/overflow spray pond drain which carry also excess condensates and boiler blow-down waters. This drain is discharged directly into the river.

- The treatment system consist of the following unit operations:

    - oil and grease separator
    - clarification/sedimentation pond
      (approximate volume = 1500 m^3; hydraulic retention time = 1.5 days)
    - anaerobic digestion in a pilot-plant UASB reactor.

About 800m^3 of medium strength wastewater with a COD load of 3000 kg needs to be treated daily by a 200m^3 UASB reactor. Due to financial constraints a 50m^3 UASB demonstration plant was constructed through MRC funding. Eventually the plant would be upgraded in the long term to treat all factory wastewaters.

4.3 Design Criteria for UASB Plant

The design criteria for the UASB plant are summarised in Table 5. The site location and design details of the UASB plant are given in Figures <1> and <2> respectively.

Table 5: Design Parameters for UASB Plant

Average daily flow rate	: 200 m^3/d
Average HRT of Equalization/Preacidification reactor	: 6 hrs
Volume of Equalization/Preacidification reactor	: 50 m^3
HRT of UASB reactor (Average)	: 6 hrs
UASB reactor volume	: 50 m^3
Average organic loading rate	: 12.5 kg COD/(m^3.d)
Average sludge loading rate	: 0.5 kg COD/kg VSS.d.
Upflow velocity ($m^3m^{-2}h^{-1}$)	: 0.33 (average)
Annual operation days	: 150 @ 24 hrs/day
Alkalinity requirement (no recycle)	: 0.5 g (as $CaC0_3$) per g of influent COD
COD removal efficiency	: 90%
Biogas production	: 0.30 m^3 CH_4 per kg of COD removed (i.e 200 m^3d^{-1})
Sludge Production	: 0.07 kg VSS/ Kg COD removed
Start-up period on diluted molasses	: 3 months

4.4 Seeding and Operating Conditions of Reactor

The Commissioning of the plant took place in September 1998 and all snags identified were corrected by the contractor in October 1998. Seeding of the reactor with an appropriate anaerobic sludge proved difficult. The reactor was seeded with $10m^s$ of septic tank sludge, obtained from the Wastewater Authority and with activated sludge obtained from a hotel wastewater treatment plant. The reactor was operated during the 1998 crop season at an HRT of about 48 hours while in 1999 it was operated at an HRT of 24 hours. An anaerobic pond sediment seed was added prior to the 2000 milling season to improve the performance of the plant.

4.5 Sampling Procedures

Daily samples of influent and effluent were taken. Samples were acidified to pH<2 and if not immediately analysed were refrigerated at 4ºC. Samples taken for the determination of the sludge profile were taken directly from each port.

4.6 Analytical Procedures

The physico-chemical analysis used were as recommended by Standard Methods for the analysis of Water and Wastewater (APHA et al, 1992) except for bicarbonate alkalinity and volatile fatty acids which were measured using the 5 pH point titration method (Moosbrugger et al, 1992). COD was measured by Knetchels method (1977). Soluble COD was obtained by filtering the sample through a glass-fiber filter paper (Whatman GF/C) having an approximate pore size of 1-2 µm.

Sludge from the reactor was sampled from the eight sample ports and the concentration, settling velocity and methanogenic activity were measured. The sludge concentration profiles were used to estimate the sludge hold-up of the reactor during the period of operation. For this purpose the sludge profile was linearised, i.e. the reactor volume was divided in various imaginary layers. The first layer was L1 from 0 to 0.80 above the reactor bottom, i.e. from the bottom to the middle of P1 and P2. The sludge concentration in L1 was assumed to be equal to the concentration found at P1. Similarly, the concentrations in the other layers were estimated, e.g. P2 was indicative of the concentration at the layer between 0.5 and 1.1 m above the reactor bottom.

The total sludge mass was expressed as:

$$M_{SL} = A \sum_{i=i}^{I} L_i C_i$$

where MSL = sludge hold up in the reactor

Li = height of layer I

C = sludge concentration at layer I (total of I layers)

A = cross-sectional area of the reactor.

Chapter 5

Results & Discussion

- The clarification/sedimentation pond constructed by the factory behaves as a big equalisation pond. The effective Hydraulic Retention Time is about 1 day.

  During the 1999 milling season seepage has prevented any overflow from the pond to the river. The low buffering capacity of the wastewater resulted also in the production of acids – which caused a drop in pH and the production of odours. Lime and caustic soda (approximate dosage of 50kg and 25kg daily respectively) were added to increase the alkalinity of the wastewater. A chlorine compound was also being added to alleviate the odour problem.

  The average characteristics of the various effluent streams, at Rose Belle as monitored during the 1999 milling season are as follows:

	Stream	**COD (mg/L)**	**pH**
1.	Overflow spray pond	114	7.3
2.	Effluent drain to equalisation pond and UASB	2733	5.3
3.	Effluent to river	169	7.7

- The reactor performance during the 1998, 1999 and 2001 milling seasons are given in Appendix. The average performance of the reactor is summarised in Table 6:

Table 6: Average Performance of Reactor during 1998, 1999, 2000 and 2001 Milling Season

	1998 Milling Season (Commissioning of Plant)	**1999 Milling Season**	**2000 Milling Season**	**2001 Milling Season**
Seeding of reactor	Septic Tank Sludge	Septic Tank Sludge + Activated Sludge	Septic Tank Sludge + Activated Sludge + Pond Sediments	Septic Tank Sludge + Activated Sludge + Pond Sediments
HRT (hrs)	48	24	24	24
Flow rate (m^3/day)	25	50	50	50
No of days of operation	60	90	50	42
Average Influent COD (mg/L)	2537	3602	3500	3236
Average Influent Temperature (ºC)	29	25	26	25
Average Influent pH	5.9	5.4	6.1	6.8
Average Organic Loading rate (Kg COD/m^3.d)	1.2	3.6	3.6	3.5
Average Effluent COD (mg/L)	670	2694	1431	984
Average Effluent Temperature (ºC)	22.1	23.5	23	23
Average Effluent pH	6.8	5.4	6.3	6.6
Average Effluent VFA (mg/L)	400	1000	250	300
Mass of Sludge in reactor (kg VSS)	200	50	200	600
Average COD removal efficiency (%)	73	25	59	70

- The sludge COD and pH profiles in the reactor carried out at the end of the 1998, 1999 and 2001 milling seasons were as follows:

	TSS (mg/L)			TCOD (mg/L)			PH		
	1998	1999	2001	1998	1999	2001	1998	1999	2001
Influent	80	95	120	2578	2900	2650	6.0	5.1	4.4
Tap 2 (800mm from base)	170	185	58250	1654	2500	835	5.4	4.8	6.2
Tap 3 (1800m from base)	140	175	26100	684	2430	960	5.9	5.3	6.2
Tap 4 (2500mm from base)	145	155	1230	630	2335	740	6.2	5.4	6.2
Tap 5 (3125mm from base)	141	150	325	532	2420	730	6.0	5.3	6.2
Tap 6 (4000mm from base)	132	142	230	472	2520	725	6.2	5.4	6.2
Effluent	31	28	100	433	2495	735	6.2	5.4	6.5

- The following conclusions can be drawn from the above results:

  - The mass of sludge seeded in the reactor in 1998 was estimated at about 200 kg of septic tank sludge. There was an initial overall good removal efficiency at a low organic lading rate. However there was poor retention of sludge and the amount of sludge dropped to 50 Kg during the 1999 milling season. The pH of the reactor remained in the acidic zone i.e. below 6.0, leading to poor COD removal efficiency. The alkalinity addition to the system had to be increased.
  - The start-up of the reactor has proved to be difficult due to the absence of a good quality and quantity of sludge in the reactor. The process has shown signs of overloading during the 1999 milling season with an

average organic loading rate of 3.6 kg COD/m^3.day and a high sludge loading rate.

- Following the addition of the anaerobic pond sediments, the reactor efficiency improved considerably and reached 70% during the 2001 milling season. The organic loading rate was 3.5 Kg COD/m3.day for a HRT of 24h and the sludge loading rate was about 0.3 Kg COD/Kg VSS.day

Chapter 6

Conclusions and Recommendations for Future Work

6.1 Conclusions of the Study

- The factory needs a good water and wastewater management with the separation of the different wastewater streams. The storm water runoff and miscellaneous cooling waters in the factory must be diverted away from the effluent drain. An objective must be set by the factory to send about 0.4 m^3 of wastewater per tonne of cane crushed to the treatment system.
- A good equalisation pond is a pre-requisite for the successful operation of the anaerobic system. Alkalinity has to be added to this equalisation pond in the form of caustic soda or sodium carbonate.

- The COD removal efficiency of the reactor will be poor if there is insufficient quantity of seeding sludge. The start-up of the plant has proved to be difficult, with the rector having to be reseeded with fresh sludge, following the loss of the original sludge.

- Good quality seed sludge needs to be available. With poor quality sludge the start-up of the reactor will take a very long time. The presence of good quantity of seed-sludge with a proper balanced anaerobic bacterial consortia is the key for success of the UASB plant. It is proposed that in the Mauritian context the reactor be seeded with the following types of sludge:
  - septic tank sludge
  - anaerobic pond sediments
  - import of granular sludge from existing high-rate anaerobic reactors (this is however an expensive option).

- A proper pH-control system need to be devised to maintain the reactor pH above 6.0. Process control is very important for reliable digester operation. The supplementation of alkalinity and a constant pH control is required to ensure a good process operation.
- Increased recycling of process water in industries will lead to lower amounts but higher concentrated effluents and an increased demand for anaerobic processes can be experienced in the future. The effluent charges set by the Wastewater Management Authority for discharge into sewers will increasingly lead to pre-treatment of industrial effluents using anaerobic technologies.
- A pre design cost estimation arrived at a capital investment of about Rs 12,000 per m^3 of reactor. A 150 TCH factory will have to invest about 5 million rupees for a UASB treatment plant. The net annual operating cost is estimated at about Rs 3.00 per kg of influent COD.

6.2 Recommendations

<u>Recommendations for Future Research</u>

- The effect of recycle on the alkali consumption and operating cost of the UASB need further investigation. The introduction of effluent from the UASB reactor back to the acidification reactor will reduce the consumption of alkali required to maintain the pH of the acidification reactor at its set point. But the effect of recycle on gas production and composition, and the biomass concentration and on the overall operational condition of the reactor need to be assessed.
- Real time on-line control system need to be developed so as to increase the confidence of industry in anaerobic systems.
- If the UASB system is adopted by sugar and food processing factories, shortage of good seeding sludge may occur. Research needs to be carried out on the feasibility of using alternative options such as raw waste

activated sludge or anaerobic pond sediments for the start-up of new reactors.

Recommendations to Industry

- Effluent of a large number of different industries can be treated anaerobically. These industries include specifically the agro-industry in Mauritius. Pilot Plant investigations need to be carried out before the selection of any treatment system. Anaerobic technologies are cost-effective in reaching discharge standards into sewers.
- There is a need for specialized training courses on anaerobic treatment as well as on-the-job training for industry personnel and plant operators.

Recommendations to MRC

- The full potential of high-rate anaerobic technology has so far not been exploited in the Mauritian context. The know-how availability can be supported by:
    - Establishing a network of specialists and institutions and providing appropriate information material through this network.
    - Detailed analysis of model plants
    - Broadening the know-how base by organizing and supporting training courses in the area of planning, construction, operation and plant maintenance.
    - Documentation and accessibility of training, seminar and empirical report material.
    - Provision of information to the specialist public.
    - Activities need to be initiated to inform responsible authorities, industry and financial organizations on the potential of Anaerobic Digestion Technologies.

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APPENDICES

Appendix 3.1: Reactor Performance during the 1998 milling season

DATE	INFLUENT				EFFLUENT			
	T°C	pH	TCOD (mg/l)	SCOD (mg/l)	T°C	pH	TCOD (mg/l)	SCOD (mg/l)
1.9.98	43.6	4.2	1536	1418				
2.9.98	43.4	4.2	1300	1260				
3.9.98	41.5 41.6	5.1 5.5	1344 1088	1265 1037	2.1	6.5	198	138
4.9.98	37.9 40	4.3 4.8	1929 1811	1536 1457				
7.9.98	30.6 31.4	4.1 4.02	4133 3465	3937 3150				
8.9.98	43.6 43.4	4.3 4.3	2402 2618	2322 2520				
9.9.98	43	4.9	1653	1575				
10.9.98	43.8	5.3	1024	1004				
11.9.98	40.8	5.2	906	867				
14.9.98	34.5	11.2	2579	1654	23.1	6.6	433	
15.9.98	37.1	4.9	1733		24.2	5.3	1181	
16.9.98	34.5	4.7	1181	1141	23.9	6.5	985	944
17.9.98	25.1	4.9	1181		22.5	6.2	453	
18.9.98	43.5	5.4	749	708	25.1	5.8	827	807
21.9.98	25.8	7.9	1024	1003	22.5	6.2	100	
22.9.98	39.5	5.1	630		22.6	7.6	512	
23.9.98	38.9	7.2	1477		22.6	7.9	670	
24.9.98	39. 8	7.2	1241		22.5	7.5	571	
28.9.98	23.1	3.7	3741		22.5	6	453	
29.9.98	28.7	7	2441		22.4	6.2	670	
30.9.98	27.9	6.8	1811		22.5	6.4	1063	

1.10.98	29.6	5.5	709		22.5	7.5	512	
2.10.98	23.5	7.6	394		22.5	6.8	748	
3.10.98								
4.10.98								
5.10.98	22.6	4.4	3740	3710				
6.10.98	32.9	6.7	2440		22.7	7.1	787	
7.10.98	30.5	7	866		22.4	7.1	591	
8.10.98	22.9	7	787	787	22.4	7.2	511	452
9.10.98	24.2	7.1	787	787	22.4	7.2	590	452
10.10.98								
11.10.98								
12.10.98	22.5	7.5	1585	1575	22.4	7.3	433	403
13.10.98	26.7	7.5	1575		22.4	7.3	394	
14.10.98	25.8	5.2	1140	1121	22.4	6.5	1003	985
15.10.98	29.1	6.6	1003		22.6	7	866	
16.10.98	23.7	5.3	551		22.6	7.8	987	
17.10.98								
18.10.98								
19.10.98								
20.10.98	23.9	6.7	1732	1732	22.3	7.5	411	374
21.10.98	23.6	6.5	1575		22.4	7.4	411	
22.10.98	23.7	6.4	866	866	22.3	7	787	787
23.10.98	24.1	6.7	748		22.4	7.1	669	
24.10.98								
25.10.98								
26.10.98	23.1	5.3	3425	3425	22.4	7.1	411	394
27.10.98								
28.10.98	24.2	6.7	1496		22.4	7	669	
29.10.98	24.9	7.3	985		22.4	7.1	866	
30.10.98	23.8	7.3	669		22.4	7.1	411	
2.11.98	24.1	7	3818		22.4	7	411	

3.11.98	25.4	7.1	2914	2914	22.4	7.3	511	511
4.11.98	24	7	1496		22.3	7.1	1004	
5.11.98								
6.11.98	24.1	5.2	512	512	22.4	6.7	650	650
7.11.98								
8.11.98								
9.11.98	22.5	6.9	2623	2583				
10.11.98	22.9	6.8	1732					
11.11.98	22.6	6.9	1024	984	22.4	6.9	411	411
12.11.98	23.7	6.9	69		22.3	7	703	
13.11.98	23.9	6.9	411	393	22.4	7	650	650
14.11.98								
15.11.98								
16.11.98	22.4	3.9	11910	11811				
17.11.98	22.4	6.2	6378					
18.11.98								
19.11.98	22.4	5.1	6299	6299				
20.11.98		7						
21.11.98	22.4		6299					
22.11.98								
23.11.98	22.4	3.9	6299	6299	22.4	5.1	1003	
24.11.98	22.4	6	6299		22.4	5.2	1024	
25.11.98	22.4	3.9	6299					
26.11.98	22.4	3.9	6378					
27.11.98								
28.11.98								
29.11.98								
30.11.98	22.4	3.9	5906		22.4	5.9	1181	
1.12.98	22.4		6299	6299				
2.12.98	22.4	6.3	9847		22.4	6.3	1024	
	29.04	**5.894**	**2537**	**2352**	**22.12**	**6.798**	**668.5**	**568.4**

Appendix 3.2: Reactor Performance during the 1999 milling season

DATE	INFLUENT				EFFLUENT			
	T°C	pH	TCOD (mg/l)	SCOD (mg/l)	T°C	pH	TCOD (mg/l)	SCOD (mg/l)
27.8.99	25	5.8	2727		22	5.4	2562	
4.9.99	24	5.6	1653		21	5.3		
5.9.99	27	5.8	3306		23	5.2	2474	
8.9.99	26	6.2	4628		21	5.4	3967	
9.9.99	25	6.8	2975		21	6.2	1405	
10.9.99	29	5.7	9711		21	5.6	1653	
11.9.99	26	5.6	1900		23	5.2	2562	
12.9.99	24	5.4	2474		21	5.2	2066	
13.9.99	25	6.8	9100		21	6.2	3140	
14.9.99	24	5.5	1570		21	5.1	2149	
18.9.99	21	6	3471		21	5.1	2149	
21.9.99	24	4.9	672		21	5.4	988	
22.9.99	37	6.2	2373		38	7.2	245	
29.9.99	37	6.2	2373		38	7.2	245	
17.10.99	24	4.7	1847		22	5	1660	
19.10.99	21	4.8	1542		22	5	1774	
20.10.99	24	5.1	1818		22	4.9	1423	
21.10.99		4.8	1542			4.8	1700	
22.10.99	22	4.9	1383		22	4.9	1462	
23.10.99	23	4.9	1581		23	4.9	1502	
24.10.99	24	5.1	2253		23	5.2	1423	
25.10.99	23	5.1	2095		22	5.2	1937	
26.10.99	22	5.1	9516		22	5.2	3992	
3.11.99	22	5.3	1423		22	5.2	1260	
4.11.99	22	5	2008		23	5	2336	

5.11.99	23	5.1	1885		23	5.1	2172	
6.11.99	25	5.3	4262		24	5.5	4426	
7.11.99	34	5.2	3115		25	5.3	3279	
8.11.99	24	5.2	3770		24	5.4	3689	
9.11.99	29	5.3	3279		24	5.4	3033	
10.11.99	25	5.3	3115		25	5.4	3115	
11.11.99	24	5.3	3361		24	5.4	3371	
12.11.99	24	5.3	3361		24	5.4	2951	
13.11.99	24	5.3	4426		24	5.4	2869	
14.11.99	25	5.2	7049		25	5.4	4016	
15.11.99	25	5.2	4180		25	5.3	3770	
16.11.99	24	5.2	4918		24	5.3	4754	
18.11.99	23	5.2	3934		23	5.3	3361	
19.11.99	26	5.2	4672		24	5.3	3934	
20.11.99	23	5.2	4836		24	5.3	4508	
21.11.99	23	4.9	5082		24	4.9	4672	
22.11.99	32	5.3	4344		24	5.3	5164	
23.11.99	23	5.3	4836		23	5.3	4262	
24.11.99	22	5.3	3852		22	5.3	3852	
25.11.99	23	5.3	4836		23	5.3	5328	
26.11.99	23	5.2	4180		23	5.4	4590	
27.11.99	24	5.3	4918		24	5.5	4836	
29.11.99	24	5.3	4672		24	5.7	3361	
1.12.99	24	5.5	3689		24	6	3197	
	24.94	**5.371**	**3602**		**23.52**	**5.388**	**2894**	

Appendix 3.3: Reactor Performance during the 2001 milling season

DATE	INFLUENT				EFFLUENT			
	T°C	pH	TCOD (mg/l)	SCOD (mg/l)	T°C	pH	TCOD (mg/l)	SCOD (mg/l)
2.10.01	23	11.4	2537		21	5.1	1530	
3.10.01	23	7.1	821		22	7.3	500	
4.10.01	22	6.3	2430		22	7.6	790	
5.10.01	21	7.1	2610		22	7.7	950	
6.10.01	22	6	3320		22	7.8	1530	
9.10.01	21	5.5	3060		21	5.4	1791	
10.10.01	22	5.4	2425		21	5.7	1194	
11.10.01	22	5.1	2761		21	5.9	970	
12.10.01	21	4.5	3545		22	5.8	1851	
15.10.01	26	6.7	1157		24	6.3	970	
16.10.01	24	8	1604		23	6.7	784	
17.10.01	32	6.6	2425		26	6.4	1948	
18.10.01			Reactor not working					
19.10.01			Reactor not working					
24.10.01	21	5.1	3657		22	6.7	1045	
25.10.01	30	9.8	2010		21	7.3	493	
26.10.01	32	4.7	6370		23	5.8	1666	
27.10.01	28	5.1	6716		23	5.8	1306	
29.10.01	25	5.1	5000		26	5.4	970	
30.10.01	26	6.7	1567		24	6.4	1007	
31.10.01	26	7.6	2612		24	6.8	940	
3.11.01	26	7.3	5187		24	7	985	
5.11.01	27	7.1	4104		25	7.2	515	
6.11.01	22	8.9	3582		23	7.2	672	

7.11.01	29	6.7	3291		21	7.9	1269	
8.11.01	26	10.4	2836		24	7	261	
9.11.01	27	7.3	3619		23	7.1	112	
10.11.01	34	7	6866		24	6.8	320	
12.11.01	25	7.6	1269		24	6.9	201	