Mauritius Research Council

Integrated Management of Sugar Cane Mill Wastewater for Environment Protection, Bioenergy Production and Irrigation

Final Report

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Integrated Management of Sugar Cane Mill Wastewater for Environmental Protection, Bioenergy Production and Irrigation

(A Mauritius Council Funded Project)
Project No. 95/19

Final Report

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Table of Contents

Preface

This report presents the results of the project funded by the Mauritius Research Council (Project No. 95/19): Integrated Management of Sugar Cane Mill Wastewater for Environmental Protection, Bioenergy Production and Irrigation. This was a collaborative project between the University of Mauritius and Rose Belle Sugar Estate. The Principal Investigators of the project were Dr. T. Ramjeawon, Senior Lecturer at the Faculty of Engineering of the University of Mauritius and Late Professor J. Baguant, former Pro-Vice Chancellor of the University of Mauritius who passed away in June 1998. My deep gratitude goes to the latter, who initiated the project and which would not have been possible without his encouragement, support and constant interest. This report is dedicated to him.

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

- Associate Professor A. Chan Chim Yuk, Dean of the Faculty of Engineering, University of Mauritius.

- Mr. B. Rajkumar and Mr. S. Marie Jeanne, respectively the current and ex General Manager of Rose Belle Sugar Estate, for their sustained interest in the project and for supporting the experimental work at the factory.

- The staff of Rose Belle sugar factory and particularly Mr. R. Tam Im, Factory Manager; Mr. V. Goorah, Process Manager and Mr. Boodhoo, Chemist.

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

- The Staff of Advance Engineering Co. Ltd.

DR. T. RAMJEAWON
Principal Investigator

To

Late Professor Jay Baguant

"Mentor, Friend and Academic Extraordinaire"

Executive Summary

High-rate anaerobic treatment systems such as the Upflow Anaerobic Sludge Blanket (UASB) reactor have gained increasing popularity in recent years due to their high capacity and relatively low operating cost. Treatment of high strength industrial wastewater using these systems has substantial benefits in operating costs compared to anaerobic systems. These treatment plants are being used in an increasing number of industries such as food processing breweries, dairy, etc.

A research programme on water and environment issues relating to the sugar industry has been undertaken at the University of Mauritius since 1991. Pilot UASBs have been operated in the laboratory and at sugar factories to determine design criteria. Within the context of promoting the use of biotechnology for environmental protection, funding was secured from the Mauritius Research Council (MRC) for a period of three years (1995 to 1998).

A water and wastewater auditing exercise has shown that, for effective wastewater management it is necessary to separate the wastewater generated into 3 main streams. The segregation of these streams has been done during the 1996 premilling season. Only the most polluting stream containing the mill house wastewaters, floor wash, spillages and miscellaneous condensates and cooling waters will undergo treatment in the UASB.

A 50m^3 demonstration plant was designed and the plant was constructed by Advance Engineering Co. Ltd. following a tendering procedure.

The major aim of this project was to build a demonstration industrial scale plant for wastewater treatment in collaboration with Rose Belle Sugar Factory.

The second phase of the project which is also funded by the Council, will consist of the start up of the reactor and its operation to determine optimum operation criteria.

1. Background 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. The research programme has been carried in collaboration with the Department of Civil Engineering of the University of Leeds. Within this research programme, an audit of water utilisation and wastewater disposal of all the cane sugar factories have been carried out during the period 1990 to 1991. These audits have enabled the creation of an extensive and reliable data bank on water utilisation, wastewater characteristics and treatment of the Mauritian sugar factories.

Among the anaerobic 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/m3. 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 has been secured from the council for a period of three years, i.e. 1995-1998.

The main objectives of the study were:

- Characterisation of the pollution load from a cane-sugar factory
- Review the technological merits of the UASB process
- Design of a UASB industrial pilot wastewater treatment plant for the high-strength effluents produced in a sugar factory.
- Construction of the plant.

The work plan for the project was as follows:

December 1994 - Submission of Research Proposal

July 1995 - Allocation of Research Contract

July 1995 - December 1995 - Pilot plant investigation

January 1996 - June 1996 - Appropriate modification of wastewater streams at Rose Belle of the high-strength streams to be treated by the UASB

July 1996 - December 1996 - Design and installation of an oil grease separator

- Design of a 50 m^3 UASB pilot/demonstration plant

January 1997 - June 1997 - Preparation of tender document and allocation of tender

August 1997 - October 1997 - Design and construction of a reinforced concrete base at Rose Belle sugar factory for installation of the treatment plant

- Characterisation of high-strength effluents to be treated by the UASB process

January 1998 - June 1998 - Supervision of construction of UASB seeding of the reactor with digested sewage sludge.

This final report summaries the work carried out within this research project during the period 1995/1998.

2. Pollution Load at Rose Belle Sugar Factory

The water circuit diagram for Rose Belle sugar factory is shown in Figure 1. The average flows, strengths and pollution loads of the various streams inside the factory is given in Table 1. From the results it is evident that for effective wastewater management, it is necessary to separate the wastewater generated into 3 main streams, as tabulated in Table 2.

Table 2: 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 were monitored during the 1992 milling season and the results are presented in Table 3. 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 week-end 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.

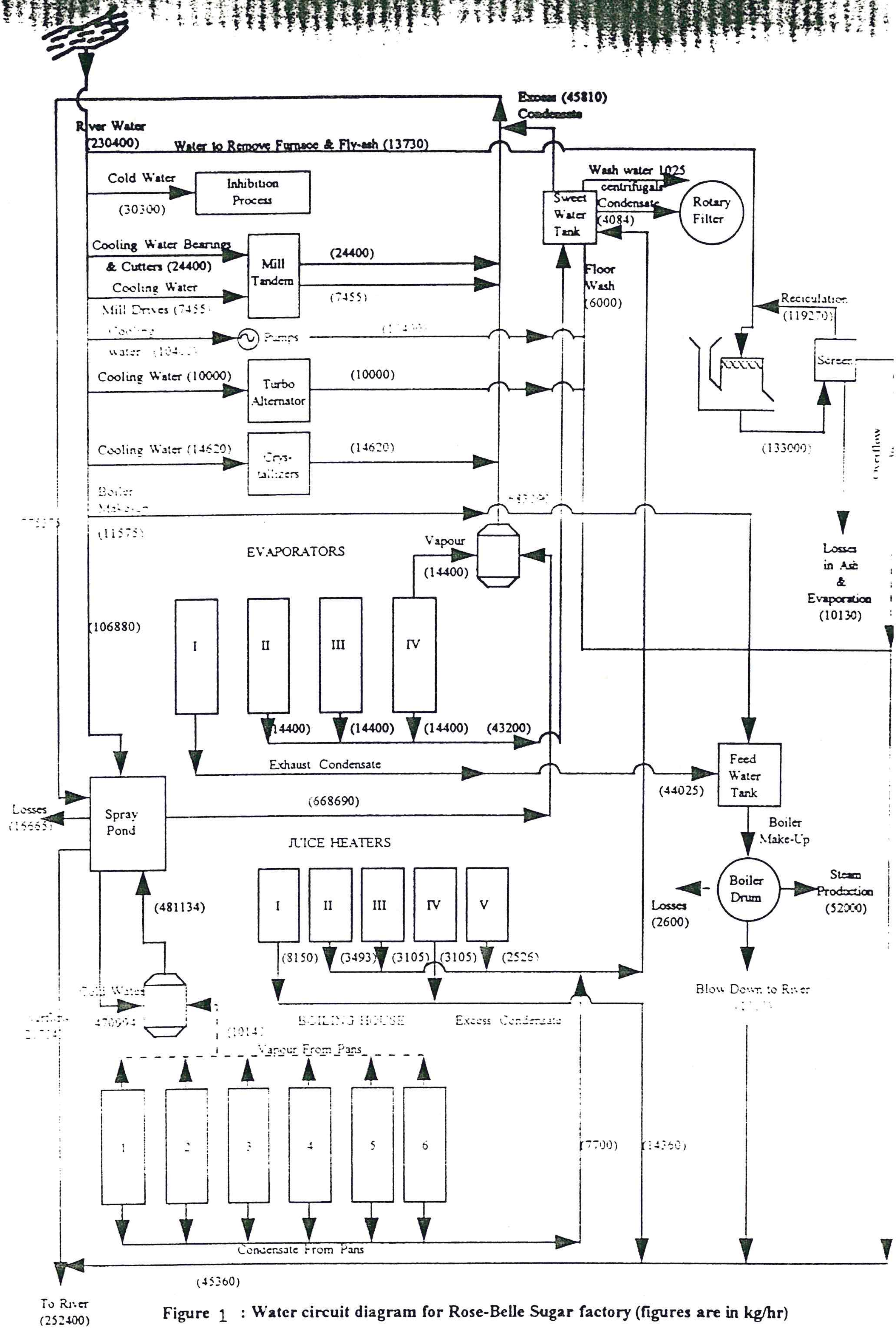

Figure 1 : Water circuit diagram for Rose-Belle Sugar factory (figures are in kg/hr)

Table 1: Average Flows, Strengths and Pollution Loads of Various Streams inside the Factory

WASTEWATER STREAM	FLOW		BOD			TSS		
	m^3/d	% of Total	mg/L	kg/d	% of Total	mg/L	kg/d	% of Total
1. Overflow spray-pond	4080	70.1	60	245	13.2	55	224	28.3
2. Excess condensates	720	12.4	380	274	14.7	5	4	0.5
3. Floor wash + Miscellaneous cooling waters	600	10.3	1850	1110	59.6	356	171	21.6
4. Mill House Wastewater	120	2.1	1650	200	10.7	282	34	4.3
5. Overflow flyash treatment	240	4.1	100	24	1.3	1480	355	44.8
6. Boiler blowdown	60	1.0	130	8	0.5	65	4	0.5
TOTAL	5820	100.0		1861	100.0		792	100.0

3. Technological Merits of the UASB Process

Earlier anaerobic reactor designs were of the continuous stirred tank type in which effective contact between the waste and the biomass was achieved by a lengthy retention time; whereas, the concept of high-rate anaerobic reactors is based on the following aspects:

- Biomass accumulation in the reactor by means of settling, attachment to solids (fixed or mobile) or by recirculation, increases solid retention time (SRT), compared to hydraulic retention time (HRT), which ensures growth.
- Improved contact between the biomass and wastewater, overcomes problems of the diffusion of substrates and products from the bulk liquid to biofilms or granules.
- Adaptation and growth enhances activity of the biomass.

The application of the above concepts have led to the design of different reactor types. Figure 2 is a schematic representation of one of these reactors - the UASB reactor.

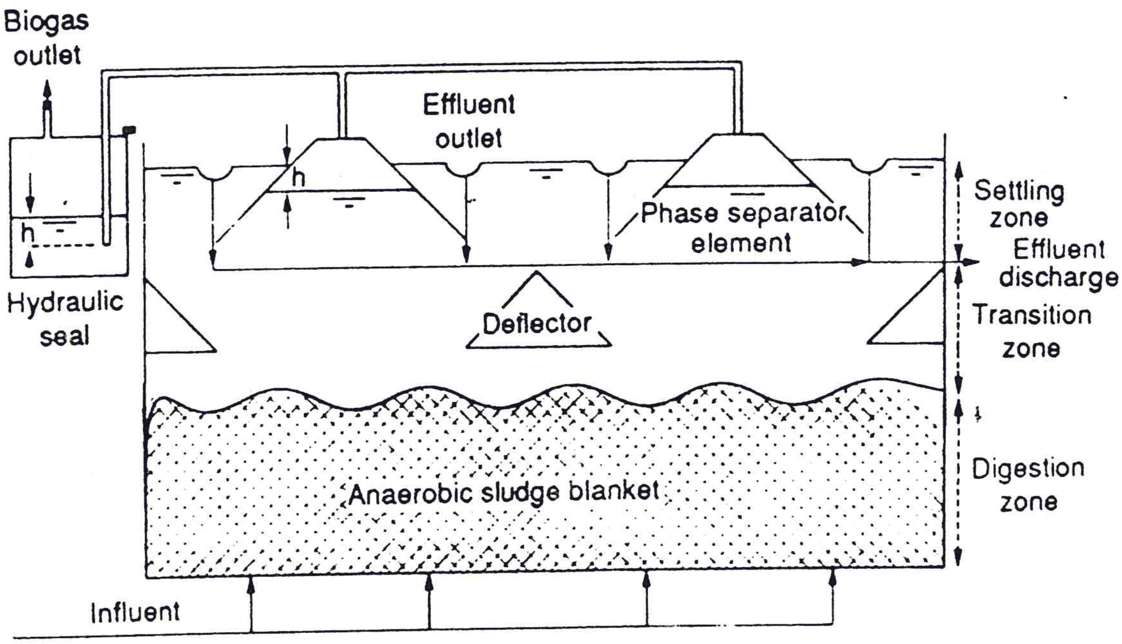

Figure 2: Schematic Representation of the Upflow Anaerobic Sludge Blanket (UASB) Reactor

The characteristic of the UASB reactor is the phase separator. This device is placed at the top of the reactor and divides it into a lower part, the digestion zone, and an upper part, the settling zone. The wastewater, introduced as uniformly as possible at the bottom of the reactor, flows upward through the sludge bed and enters into the settling zone via the aperture between the phase separators. Owing to the inclined walls of the phase separator the area for the liquid flow in the settling zone increases as the liquid approaches the water surface. Thus, the upflow velocity of the liquid decreases as it flows towards the discharge point. Owing to the decreasing liquid velocity, sludge flocs drawn into the settling zone can flocculate and/or settle. After a while, the weight of the accumulated sludge, aggregated on the phase separator, exceeds the frictional force which holds the mass. Consequently, the sludge mass slides downward into the digestion zone to become, once again, part of the sludge mass that digests the influent organic matter. Thus, the presence of a settler on top of the digestion zone enables the system to maintain a large sludge mass in the UASB reactor, while an effluent free of suspended solids is discharged.

The upward rise of the biogas creates a mixing effect which provides good contact between the biomass and the inflow. The biogas bubbles rise up to the liquid-gas interface under the phase separator. Sludge flocs with adhering gas bubbles rise to the interface in the gas collector, but settles when the gas bubbles are released to the gas phase at the interface. Baffles, placed beneath the apertures of the gas collector units, operate as gas deflectors and prevent the biogas bubbles from entering the settling zone, and avoids turbulence which could hinder settling of sludge particles.

Factors which tend to favour the UASB technology for the Mauritian cane-sugar industry are summarised:

- The high cost of traditional aerobic technologies for the treatment of industrial wastewaters in rural areas.
- 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.
- There have been many successful experiences of the UASB process with beet sugar industry wastewaters.

- Compared to anaerobic lagoons, UASB reactors have the following 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 installations are fairly simple in combustion, in 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. Furthermore, the existing infrastructure and expertise of the sugar factories are sufficient for design and construction of such a system.

4. Performance of the UASB Pilot-Plant

A one-cubic metre (950 liters net volume) UASB pilot scale reactor (height 2 m and diameter 0.8 m) was set up at the factory during the 1995 milling season. Figures 3 and 4 shows the pilot plant characteristics and set up. The reactor was seeded with digested cow manure from a rural digester and some granular sludge originating from a full-scale reactor processing wastewater of an alcohol producing industry in the Netherlands.

4.1 Performance during daily factory operation

When the milling season started, the reactor was fed with the factory's most polluted wastewaters and operated at 24 hours hydraulic retention time (HRT). The HRT was gradually decreased to 4 hours within 4 months after start-up.
During the same period the average organic loading rate increased from 1.8 to 2.4 kg COD/(m^3.day). The average influent COD was at 3940 mg/L.

The reactor performance over the entire period of operation during daily factory operation is summarised in Figures 5 and 6. The average reactor temperature during the experimental period was 26°C.

The following conclusions can be made from these results:

- It is feasible to design a UASB reactor for treating the most-polluting streams of a UASB reactor at a reactor at a HRT of 6 hours to remove effectively up to 90% of the COD at an average organic loading rate of 12.5 kg COD/(m^3.d). The average effluent COD is at 335 mg/L. The reactor efficiency drops sharply at HRTs equal to or less than 4 hours.
- The average total and filtered COD removal efficiencies over the whole experimental period based on weekly average values were 83.6% and 85.4% respectively. The average suspended solids removal rate was 85.7%.
- The sludge production was measured at 0.07 kg VSS/kg COD removed.
- The methane production rate amounted to about 0.3 m^3/kg COD removed.

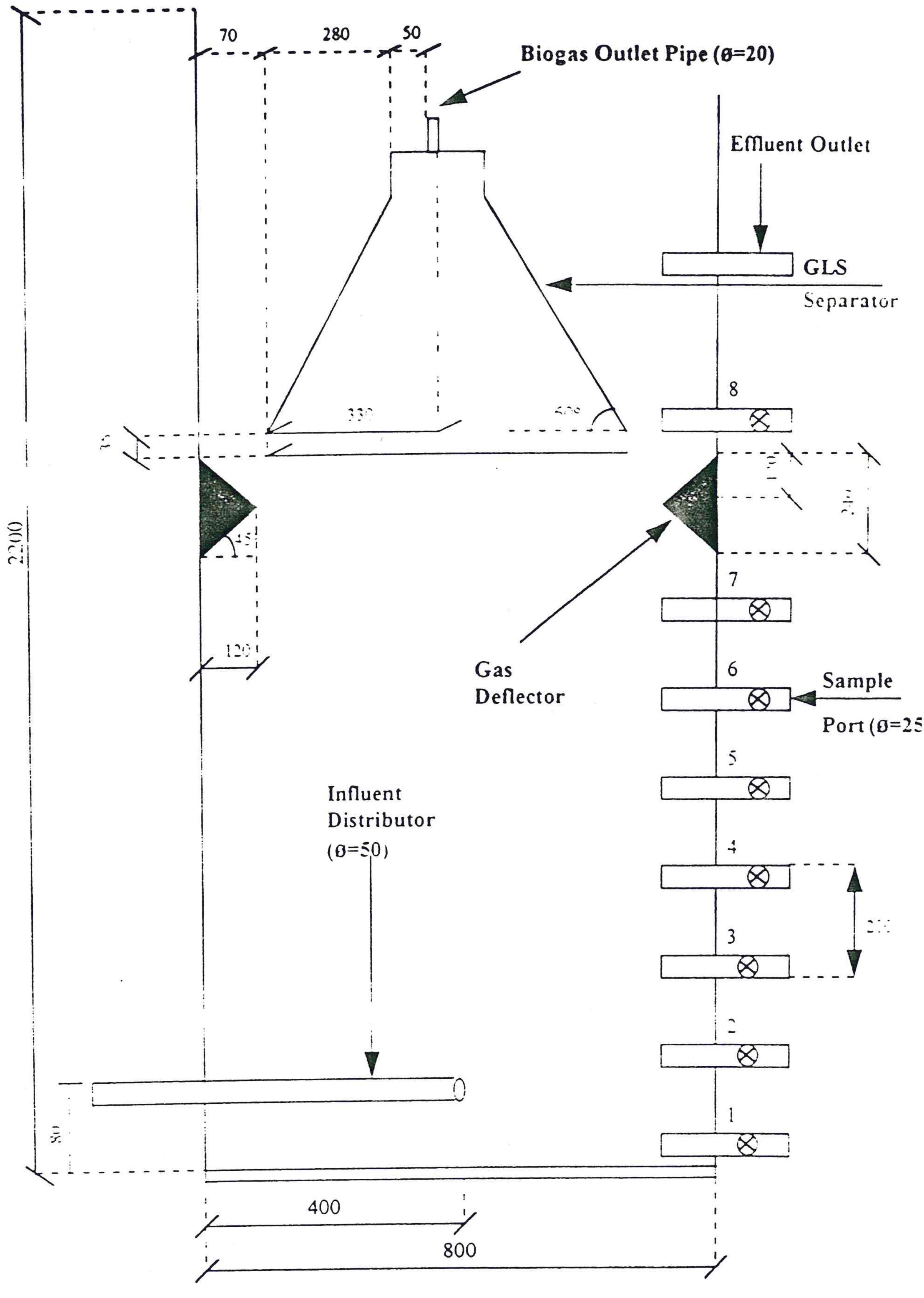

Figure 3: Sectional view of the 1m³ UASB pilot reactor (dimension in mm)

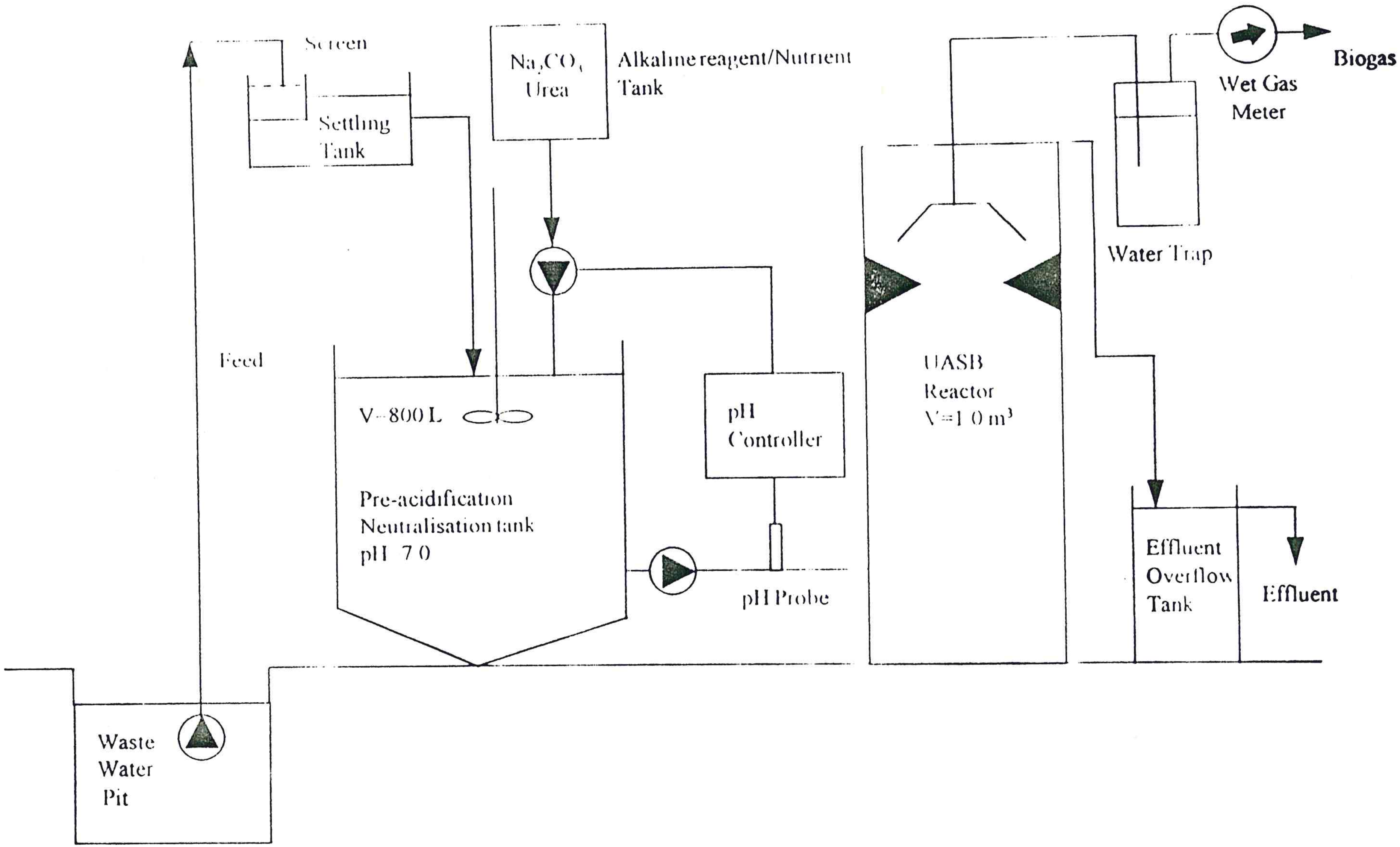

Figure 4 : UASB Pilot Plant installation at Rose-Belle Sugar factory

- Process control is important for reliable digester operation. The supplementation of alkalinity and a constant pH control is required to ensure a good process operation.

4.2 Performance during end-of-crop shutdown washings

The UASB reactor, which was operating at a HRT of 4 hours during daily factory operation at an average organic loading rate of 20 kg (COD/m^3.d), was subjected to an organic shock load during the end-of-crop washings for a period of 3 weeks. The HRT of the reactor was increased to 8 hours during this period and the average loading rate increased to 47.2 kg COD/m^3.d). Figures 7 to 9 show the performance of the reactor during this period.

The percentage COD removal efficiency decreased drastically from 76% to 28% during the organic shock load. The formation of volatile acids caused the pH value of the reactor to fall to around 6.0, causing the release of carbon dioxide from solution and a significant change in the composition of the biogas.

The UASB reactor is therefore potentially vulnerable to shock loads such as that caused by the end-of-crop shutdown washings. The imbalance in the digester is indicated by an increase in the % CO_2 content of the biogas, a decrease in pH and an overall decrease in the COD removal efficiency.

4.3 Conclusions on the Overall Performance of the Pilot Plant

- The medium-strength wastewaters generated by a cane-sugar factory during operation proved amenable to treatment in a pilot UASB reactor. At an HRT equal or above 6 hours and below an organic loading rate of 12.5 kg $COD/(m^3$.day), the % COD removal efficiency is in excess of 80% and is almost independent of the HRT.

- A two-phase system requires less start-up time and is more resistant to shock loads than a comparable single-phase system. However, a relatively short HRT should be used in the pre-acidification reactor so as to avoid complete acidification. The pre-acidification reactor must also be followed by some acidogenic sludge separating device. The supplementation of alkalinity and a pH control system are required to ensure good process operation. The effluent quality can be improved significantly by the provision of a sedimentation unit.

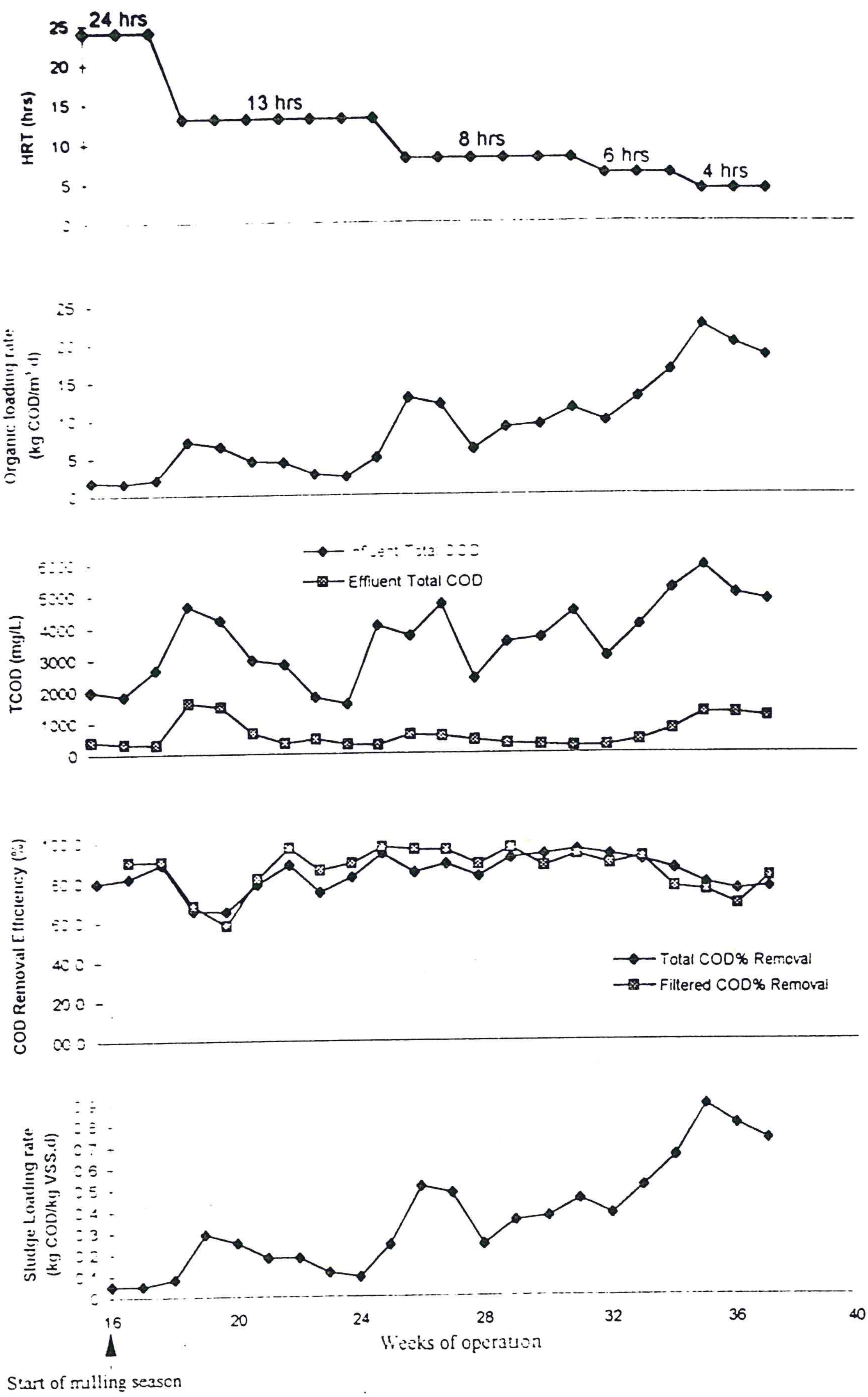

Figure 5.a : Average weekly Influent and Effluent characteristics for the full operational period of the UASB reactor during the 1994 milling season.

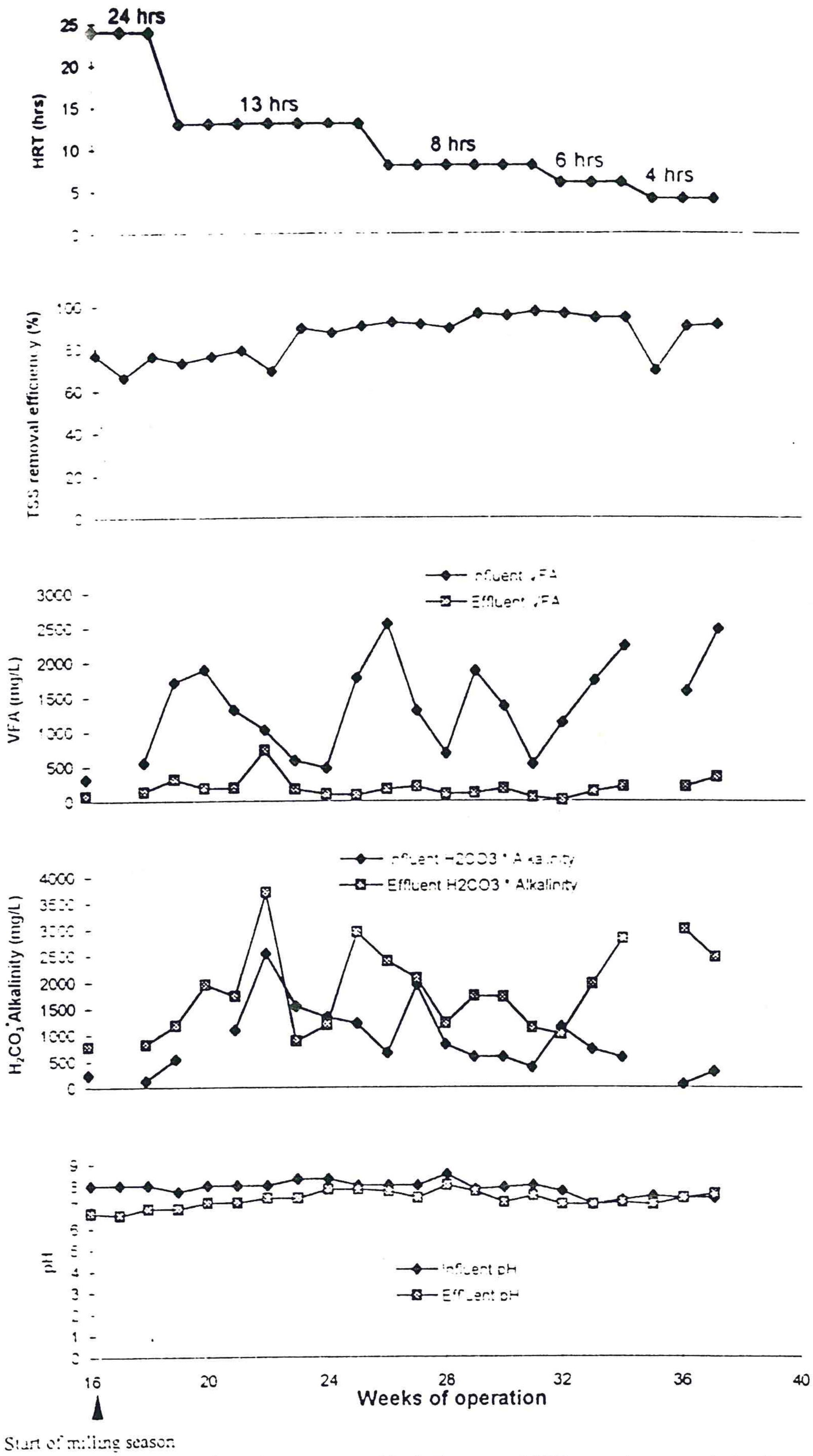

Figure 5 (b) : Average weekly Influent and Effluent characteristics for the full operational period of the UASB reactor during the 1994 milling season.

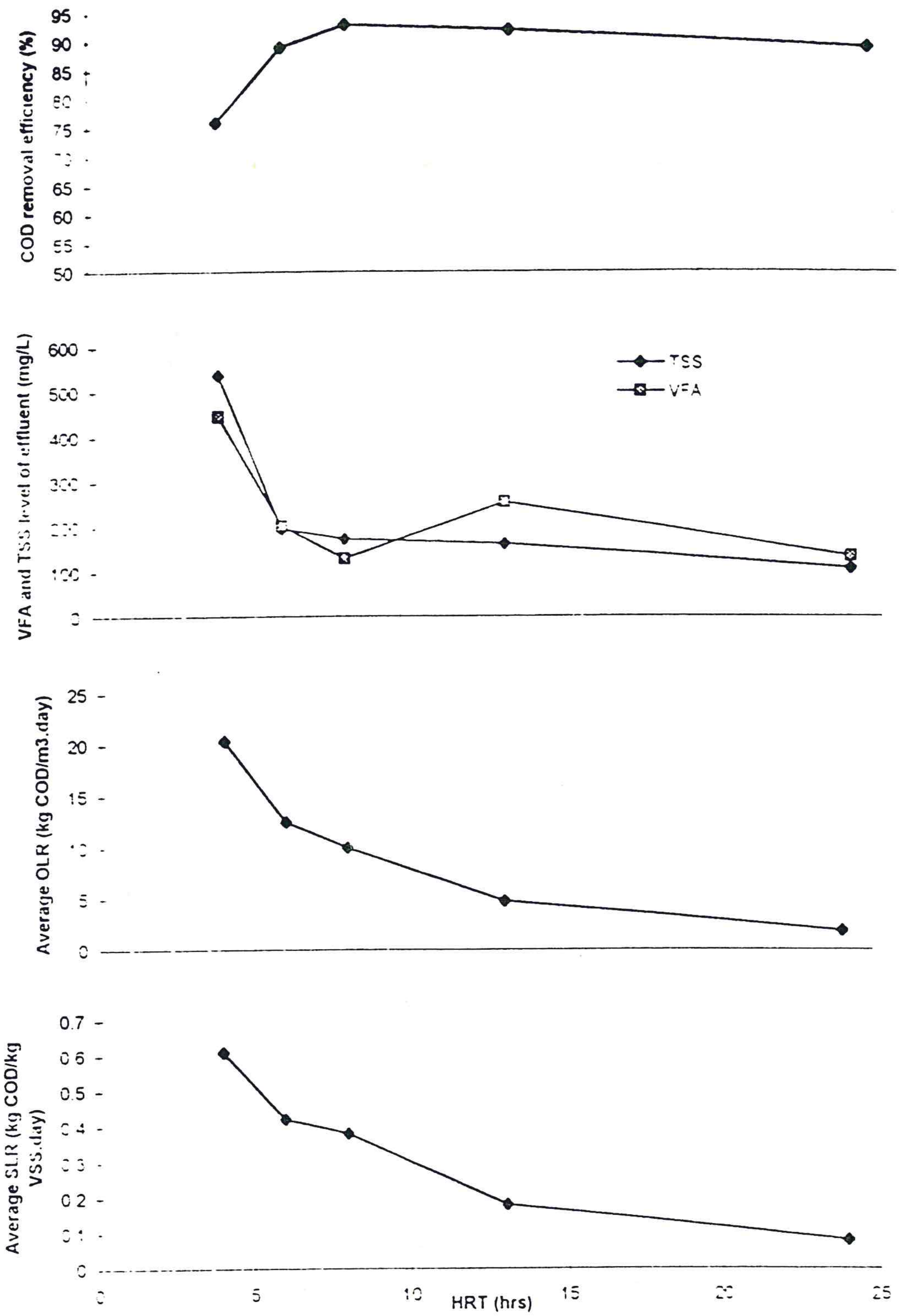

Figure 6 : Evolution of the average % COD removal, VFA and TSS level of effluent, organic loading rate(OLR) and sludge loading rate (SLR) with decreasing HRT

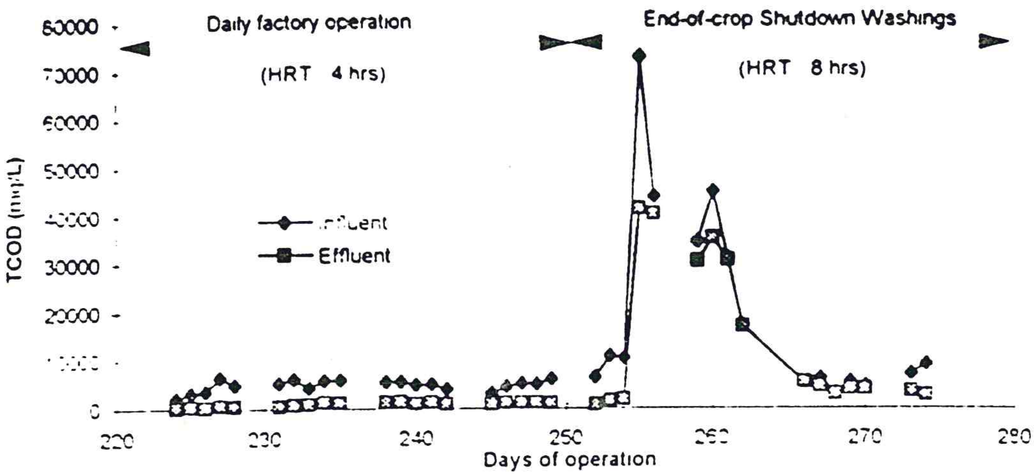

Figure 7 : Influent and Effluent COD during the organic shockload during end-of-crop shutdown washings

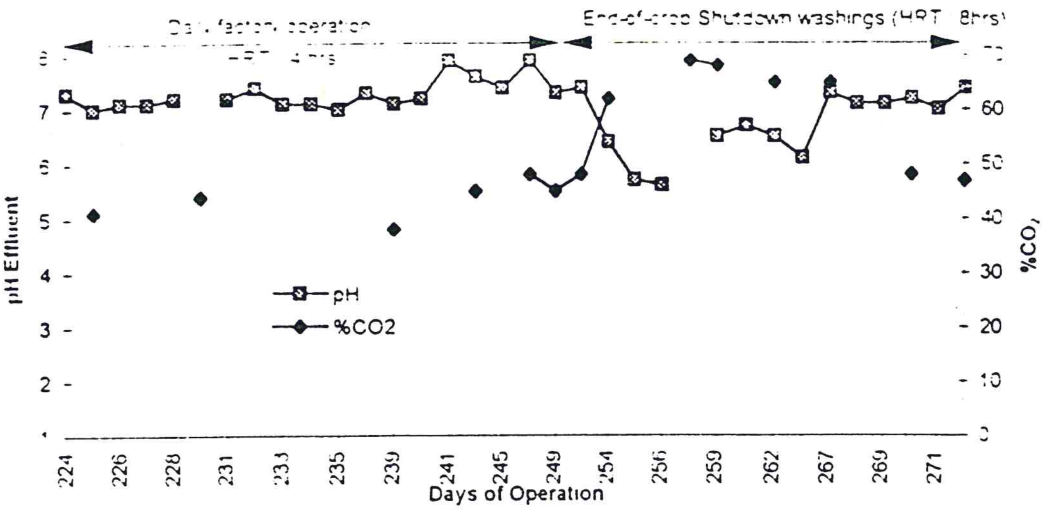

Figure 8 : Variation of pH and gas composition (%CO_2) during the organic shockload

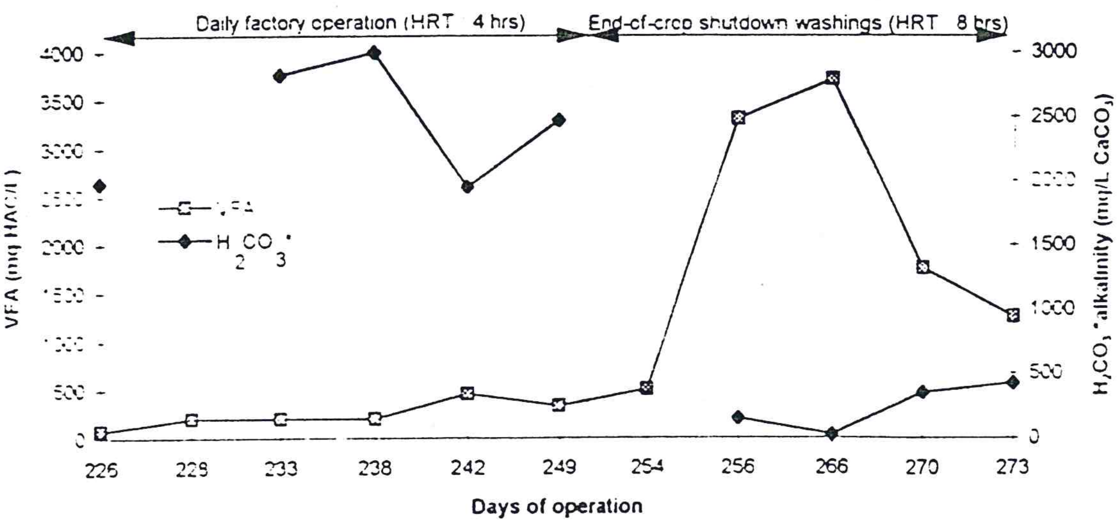

Figure 9 :Variation of VFA and $H_2CO_3^*$ alkalinity during the organic shockload

- The presence of a relatively high concentration of oil and grease in the wastewater, which originates mainly from the milling section, caused the accumulation of a dense layer of scum at the top of the reactor. This scum hindered an efficient biogas removal. It is important to do a pre-treatment of the milling-house wastewaters before UASB treatment.
- The reactor is potential vulnerable to shock loadings, such as that caused by the end-of-crop shutdown washings.

- The UASB process is stable, provided the system is monitored properly by qualified personnel. The start-up of a UASB reactor is rather delicate and time-consuming.
- A predesign cost estimate for a UASB full-scale plant showed that the cost of treatment per kg of influent COD is about 0.08 USD, making the UASB process an attractive option for sugar factories.

5. Design Criteria for UASB plant

5.1 Introduction

From the water balance carried out at the factory , it was concluded that, due to the characteristics of various streams in terms of volumetric flow and BOD content, it is recommended to separate the wastewater outflow into 3 main streams containing:

(i) the overflow of the spray-pond and any overflow from the fly-ash scrubbing water treatment plant;

(ii) condensates and boiler blow-down and,

(iii) the mill house wastewaters, the factory floor washings, spillages, leakages and miscellaneous pump cooling waters.

Only the last stream would need to be biologically treated by the UASB reactor. About 800m^3 of medium strength wastewater with a COD load of 3000 kg needs to be treated daily by a 200 m^3 UASB reactor. Due to financial constraints a 50 m^3 UASB demonstration plant was constructed during this project and eventually the plant would be upgraded in the long term to treat all the factory wastewaters

5.2 Design Criteria for UASB Plant

The design criteria for the UASB plant, as obtained during the auditing exercise and the pilot-plant experiments, are summarised in Table 4.

Table 4: 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^3 m^{-2} h^{-1})	:	0.33 (average)
Annual operation days	:	150 @ 24 hrs/day
Alkalinity requirement (no recycle)	:	0.5 g (as $CaCO_3$) 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})
Start-up period on diluted molasses	:	3 months

5.3 Design Considerations

5.3.1 Preliminary Treatment

(a) ***Screening:*** Bagasse fibres and other insoluble particles which hinder pumping and uniform distribution of the influent in the reactor, must be removed by screening. The system would require frequent cleaning to ensure proper operation.

(b) ***Oil & Grease Removal:*** The mill-house wastewaters of about 100 m^3/day are heavily loaded with suspended solids, oil and grease. This stream needs to pass through an efficient oil/grease separator or a dissolved air flotation (DAF) unit so as to avoid the formation of scum in the UASB reactor.

5.3.2 Equalization/Pre-acidification Tank

An equalization/pre-acidification tank provided upstream of the UASB reactor will benefit the system by:

- Equalising the daily flow and ensuring a constant organic loading rate into the reactor, leading to a uniform HRT.

- Dampening the effects of shock organic loads;

- Provide the necessary pre-acidication. As discussed previously, complete acidification is detrimental to the operation of the UASB and the equalization/pre-acidification tank will have a short retention time of about 6 hours or a volume of 50 m^3.

Since the buffering capacity of sugar-cane wastewater is insufficient, the system must be equipped with facilities for alkalinity and pH control. The equalization tank will also have to be equipped with a sludge removal pumping unit to separate the acidogenic sludge.

5.3.3 *Size and Features of the UASB Reactor*

The UASB reactor designed to treat 200 m^3 of wastewater per day at an average HRT of 6 hours requires a volume of 50 m^3.

5.3.4 *Depth*

According to literature, a 5 m deep reactor is considered to be optimum for industrial wastewater treatment (Lettinga and Hulshoff Pol, 1992; Souza, 1986). Wherever possible the UASB reactor needs to be built at such a level to allow feeding by gravity. Construction costs can be reduced by constructing the reactor partially above ground level. For a reactor of 5m depth designed for an average HRT of 6 hours, the average upflow velocity is 0.33 m/h. During the pilot plant experiment, the sludge bed solids had a V_{50} in the range of 26 m/h to 33 m/h and 95% of the sludge solids had a settling velocity greater than 5 m/h. Therefore, such a low upflow velocity will not destabilise or fluidise the sludge bed.

Depths of less than 5 m will result in the need to provide an excessive number of settlement compartments in order to ensure an adequate settler angle. Depth greater than 5 m may prove prohibitive because of the costs of excavating or pumping to accommodate the increased pressure head.

5.3.5 GLS Separator

The phase separator is an important characteristic and an important device in the UASB reactor. The principal design elements of the GLS separator, based on the recommendations of Lettinga and Hulshoff Pol (1992), used in the design of the pilot plant are summarised in Table 5:

Table 5: Guidelines for Design of the Gas-Liquid-Solids (GLS) Separator Device

1. Slope of the inclined wall of the gas collector should be between 45 to 60°.
2. Surface area of the apertures between the gas collectors should not be smaller than 15-20% of the total reactor surface area.
3. Height of the gas collector should be between 1.5-2 m at reactor heights of 5-7 m. The volume of the settler makes up 15-20 per cent of the total reactor volume.
4. A liquid gas interface should be maintained in the gas collector in order to facilitate the release and collection of gas bubbles and to combat scum layer formation. The gas evolution rate at the interface level should be in the range $1\text{-}3 m^3 m^{-2} h^{-1}$.
5. The overlap of the baffles installed beneath the apertures should be 10-20 cm in order to avoid upward flowing gas bubbles entering the settler compartment.
6. Scum baffles should be installed in front of the effluent weirs.
7. The diameter of the gas exhaust pipes should be sufficient to generate the easy removal of the biogas from the gas collection cap, particularly in the case where foaming occurs.
8. In the upper part of the gas cap anti-foam spray-nozzles should be installed where the treatment of the wastewater is accompanied by heavy foaming.

(Source: Lettinga and Hulshoff Pol, 1992)

5.3.6 Reactor Shape

There are two basic geometrical shapes for the UASB reactor: rectangular and circular. A circular shape offers the advantage of higher structural stability, but the construction is more difficult than a rectangular unit. Small reactors are generally constructed in a cylindrical shape and large units in a rectangular/square shape. Hybrid designs are possible, e.g. a circular reactor with a rectangular separator. When more than one reactor unit is constructed, the rectangular shape is advantageous because sidewalls can be shared by the different units. The rectangular shape facilitates influent distribution at the bottom of the reactor, and modularisation of the system.

It is obvious that geometrically less material is required for circular design compared to rectangular design for the same volume. This advantage of the circular design is important only if a single reactor is used. In practice, two or more reactors are constructed and the rectangular reactors can be constructed with shared vertical walls.

5.3.7 Modular Design

A modular reactor design offers a number of advantages over the application of a single compartment reactor design:

- The construction of the treatment system can be phased better in time.
- Different compartments might be operated in series, which will improve the overall efficiency of the process.
- The first start-up of the plant will be easier in the case where a small amount of seed sludge is available. One or two more modules can be started separately from the other module(s) so that less seed sludge is required.
- Cleaning and/or repair of the separate modules will prove to be relatively easier.

Obviously for modular design, rectangular reactors are favoured over cylindrical reactors. It is recommended here to build four square reactors in the long term, with shared vertical walls, each reactor having a volume of 50 m^3.

5.3.8 *Influent Points*

The proper design of the influent distribution system is essential for a well-performing UASB plant. To obtain a uniform distribution of the influent at the bottom of the UASB reactor, it is necessary to use a flow-splitting device to introduce the influent flow at several points at the bottom.

The maximum area covered by one inlet point has been studied extensively. For the type of sludge that would be present in the reactor (granular sludge or medium thick floccculent sludge) and the organic load that would be applied (> 10 kg $COD/m^3.d$), an area of 2 m^2 per feed inlet point is recommended. (Lettinga and Hulshoff Pol, 1992). The number of feed inlet points in the reactor will therefore be 5 .

The effluent collection device should collect the treated wastewater at the top of the UASB reactor as uniformly as possible. The UASB reactors can use a device traditionally employed in gravity settlers, i.e. horizontal gutters with V-notches at regular distances.

5.3.9 *Reactor Materials*

The choice of proper construction materials is of great importance for the durability of a UASB reactor since the anaerobic digestion process generates a corrosive environment. Corrosion is an important parameter that needs to be considered while choosing construction and coating material. From the pilot plant study it can be concluded that bitumous paint coating offers little protection to mild steel. Lettinga and Hulshoff Pol (1992) recommend the use of polypropylene coated concrete for the reactor body and plastic impregnated hardwood for the settlers. Plastic fortified plywood has also been used for effluent weirs (van Haandel and Lettinga, 1994).

Generally, concrete or concrete reinforced brickwork are the most suitable construction materials for reactor walls. For the construction of specific devices for which concrete is less suitable, non-corroding materials should be employed, such as PVC for inlet and outlet pipes, sheets of hardwood for parts of the GLS separator or scum retention baffles, and glass fibre reinforced polyester for feed inlet distribution boxes.

The most commonly used construction materials for UASB reactors have been steel or concrete. The use of steel generally implies easier construction/installation for shapes with circular sections, while for concrete, the rectangular section is simpler.

Use of anti-corrosive, internal coatings are essential. Given the long experience of the sugar industry in steel structures, it is recommended here to use steel.

5.3.10 Special devices

- **Sampling points for sludge at different depths**

  Samples can be withdrawn at different levels by gravity discharge. A pump is not necessary when the available head exceeds about 1 m and if the diameter of the sampling tube is 25 mm or more.

- **Sludge discharge device**

  It is recommended to discharge the sludge periodically once the sludge bed in the reactor reaches a certain prefixed maximum level. In general, sludge discharge will follow a pre-established routine schedule in the sense that at regular intervals (for example, weekly) a certain volume of sludge is withdrawn, equal to the amount accumulated during that period. Sludge discharge should, however, be preceded by a determination of the sludge concentration profile. Generally a good place for discharging excess sludge is halfway up the height of the reactor (Lettinga and Hulshoff Pol, 1992).

- **Scum control**

  In the pilot-plant investigation heavy scum formation occurred in the gas compartment of the UASB reactor where oil, grease and floating granules collect as a scum under the GLS separator. The depth of the scum remained stable at a few centimetres. Some provision should be made for removal of such a build up because dense scum limits the gas transfer, forcing it into the settlement section.

  If the scum is frequently mixed with the reactor contents and protected from dessication, degradation of its grease, solids etc. would eventually occur. Therefore, a gas injection system may be installed to allow periodic injection of gas just below the scum layer. To allow for a possible removal of scum, at both extremes of the gas collectors removable covers must be placed.

The suggestion of sprinklers (Lettinga and Hulshoff Pol, 1986) is found not feasible, since sprinklers are usually only effective for the abatement of foam rather than scum.

Scum formed in the settling compartment can be allowed to leave the reactors and be eventually collected in the inlet distribution channel of the sedimentation tank where it would be removed periodically.

- **Odour**

  A major problem of all treatment plant, including anaerobic plants, is the possible emission of odours. If the plants have to be built near dwelling areas, preliminary systems, the influent distribution systems and the effluent channels of UASB's should be covered and ventilated. The extracted air can eventually be treated in a compost filter.

- **On-line monitoring of the UASB process**

In order to circumvent delayed analysis of and response to indicators of imbalance of the UASB, real time on-line control measurements need to be developed, as well as, automatic feedback control strategies for digester operation. The objective is to detect immediate signs of digester imbalance and to modify automatically operation to prevent advanced stages of imbalance.

Major parameters determining digester operation (e.g. levels of volatile fatty acids, COD reduction) are monitored off-line, often only once per day. Thus a deterioration in performance may be undetected for many hours, and be followed by impaired treatment efficiency through a prolonged recovery period.

An ideal control system should monitor continuously for a parameter which is sensitive to disturbances. For anaerobic digesters, on-line monitoring of pH (Kennedy and Muzar, 1984), buffering capacity (Powell and Archer, 1989), gas production and composition (Collins and Paskins, 1987; Hickey and Switzenbaum, 1991) have been suggested.

The pilot-plant investigation has shown that the risk of operation failure due to overload is high, especially during factory shutdown washings. A constant control is required to ensure a good process operation. There is, therefore, a need to develop an automatic system able to control this high-performance digester.

Moletta *et al.* (1994) found that only three parameters were realistic for the monitoring of a reactor: pH in the liquid phase, the biogas production and its concentration of hydrogen. Some authors do not consider the concentration of hydrogen as useful (Kilby and Nedwell, 1991) and find its monitoring relatively expensive (Hawkes *et al.*, 1994). Therefore pH and biogas production can be used to develop an algorithm based on expert system principle and the automatic control system would calculate the flow rate of the feeding pump in order to adjust continuously the load applied to the reactor.

The following process control procedure is recommended:

(a) The maximum applicable load can be fixed at 15 kg COD $m^{-3}.d^{-1}$. The initial organic load would be fixed at 5 kg COD $m^{-3}.d^{-1}$ and the control of the system increases the load to 12.5 kg COD $m^{-3}.d^{-1}$ after 24 hours.

(b) If the control process starts detecting some signs of organic overload such as a decrease in pH, it reacts by stabilizing and later decreasing the loading rate to about 10 kg COD $m^{-3}.d^{-1}$. Later, the control process would increase the load to 12.5 kg COD $m^{-3}.d^{-1}$. If the reactor is comfortable with this change, the control system would regulate the influent charge between 12 and 15 kg COD $m^{-3}.d^{-1}$.

5.3.11 Seeding

Granulation is an important characteristic of sludges used in upflow anaerobic sludge blanket (UASB) reactors. As the UASB technology may be rapidly spreading, there is a need of granular sludge for inoculation of new reactors, particularly in Mauritius where anaerobic technologies is not yet developed. Alternative sources of inocula are digested sludge, digested manure, septic tank sludges and pond sediments.

If the UASB system spreads, a bottle-neck situation can be encountered due to a shortage of granular slude and even digested sewage, the second choice inoculum, considering that sludge treatment has been neglected in the limited number of existing aerobic wastewater treatment plants. In this context, raw waste activated sludge may be a convenient feedstock for anaerobic inocula production process, as it is available from hotels and textile dyeing industries treatment plants. The feasibility of using adapted raw waste activated sludge for that purpose has been assessed by Wu *et al* (1987) and Arias and Noyola (1988). Another solution may be to take advantage of the septage tankers on the island to provide a partial seeding of the reactor before start-up.

The cultivation of sufficient amount of well-adapted anaerobic sludge from a poor quality seed sludge may take several months. However, as anaerobic sludge can be stored unfed for very long periods without loss of its conversion capacity, this problem of primary start-up will disappear once a sufficient amount of adapted sludge is available. It should be emphasised that granular sludge is not a pre-requisite for satisfactory performance of a UASB system. Excellent results have been obtained using a well-settling and sufficient active flocculent sludge (as it was the case in the pilot investigation) although the loading potential of such flocculated sludge bed systems is lower.

5.3.12 Biogas: Disposal and Utilisation

The gas collection device should enable a reliable release of the gas accumulating in the gas chambers, while maintaining a constant level at the gas-liquid interface. It is important to install an additional gas release device to allow gas to escape in case of pressure build up, thus avoiding large hydraulic forces on the GLS separator structure. It is also of great importance to avoid the development of a partial vacuum in the GLS separator as this can lead to an implosion. This may occur as a result of erroneous operation such as when the sludge flow exceeds the influent flow during the discharge of excess sludge. To avoid damage to the GLS separator, it is advisable to equip the system with a vacuum relief device.

Generally, collecting gas for use outside the factory is possible but not profitable in light of the requirements for such supply: reliability, treatment, compression, gas enrichment, etc. Utilising the gas as a fuel on site is a much more cost-effective solution. It may provide power to satisfy the plant's energy requirement, including that for post-treatment. Use of the biogas to run modified diesel engines might also be a potential proposition.

5.3.13 Recycle Line and Alkalinity Addition

With alkalinity addition, the dosing point and dosing chemical need to be selected such that a drastic pH increase at the dosing point is avoided. An appropriate dosing point is the recycle stream; the presence of dissolved CO_2 and $H_2CO_3^*$ alkalinity in the recycle stream buffers pH downstream of the dose point to prevent elevated pH. Addition to the influent is normally not recommended and it is better to carry out the alkalinity addition in the equalisation/acidification reactor.

5.3.14 Temperature Control

To improve the performance of the UASB reactor, the temperature of the influent can be increased to 37°C using a plate heat exchanger and excess condensates or barometric condenser cooling waters to provide the necessary thermal loading. Alternatively hot steam can be injected directly into the equalization/pre-acidification tank.

5.3.15 Post-Treatment: Sedimentation

The effluent quality from the UASB is similar to that of domestic sewage. The pilot UASB reactor showed that at a 6 hours HRT the average difference between the effluent total and filtered COD was 204 mg/L, indicating a theoretical maximum improvement of 47% in the COD quality. The effluent quality can therefore be improved by the provision of a system such as a primary sedimentation tank.

Assuming an average overflow rate of 48 $m^3/m^2.d$ for the sedimentation tank, the area required for sedimentation is therefore 5 m^2. At a depth of 3.6 m (Peavy *et al.*, 1985), the volume is 18 m^3, resulting in a HRT of 2.2 hours.

The average TSS in the effluent at a HRT of 6 hours was 180 mg/L. The solids collected during the pilot-plant experiment settled to a concentration in the range of 5 to 8%. This concentration compares well with typical values for primary sludge (2% to 8% dry solids). Assuming a solid concentration of 6%, the production of solids in the sedimentation tank will be about 0.6 m^3 per day.

5.3.16 Sludge Disposal

The excess sludge from a reactor, especially the granular type, is a very precious material for the inoculation and start-up of other UASB units or for the eventual re-inoculation of the unit itself.
A sludge storage tank needs to be provided. On the basis of cost and ease of operation for large- scale application, Wu *et al.* (1995) recommend storage of granules at ambient temperature as compared to storage at low temperature (such as 4°C). They also recommend supply of limited quantity of substrate (or wastewater) to granules prior to their storage and once every four months during the storage period. If excess sludge cannot be sold or stored, it should be submitted to some liquid-solid separation process to reduce its volume. Sludge produced at a temperature above 25°C is normally sufficiently stable to allow direct liquid-solid separation without prior treatment. The stable solids may be used as a fertilizer or soil conditioner in agriculture.

In a warm and tropical country like Mauritius, sludge drying beds are the most appropriate method to achieve liquid-solid separation. It should be noted that the drying beds do not necessarily have to be near the treatment site; the wet sludge can be pumped or transported to another convenient location. Design criteria for sludge drying beds from UASB treatment plants have been formulated by van Haandel and Lettinga (1994) and these will be used here to design sludge drying beds.

The pilot-plant study has shown the following sludge production characteristics:

- Average solids production, 0.07 kg VSS per kg of COD removed or about 0.1 kg TSS per kg of COD removed, assuming a VSS/TSS ratio of 0.7.

- Average discharged sludge TSS concentration, 75 g TSS/L
- Average sludge VSS concentration in the reactor, 30 kg VSS/m^3.
- For a daily COD load of 750 kg to be treated and a COD removal efficiency of 90%, about 70 Kg of TSS or 1.0 m^3 of excess sludge will be produced.

Sludge drying beds are designed according to the following criteria (Van Haandel and Lettinga, 1994):

- Final solids fraction of 50 per cent in the dried sludge.
- Maximum bed productivity of 1.5 kg TSS m^{-2} d^{-1}.
- Solids level of 30 kg TSS/m^2.
- To account for rain and other adverse conditions, a safety factor of 50% is adopted.

With the above criteria, the required design area is 3.5 m^2. For a load of 30 kg TSS/m^2 and a bed productivity of 1.5 kg TSS m^{-2} day^{-1}, the total period of one cycle is 20 days. At an initial sludge concentration of 75 kg TSS m^{-3}, the sludge layer to be discharged on the beds at the imposed load of 30 kg TSS/m^2 is 0.40 m. As the final mass of dried sludge is twice the solids mass (humidity of 50%), for the applied load, the dry sludge layer has a mass of 60 kg/m^2.

Assuming that the maximum sludge discharged at any time does not exceed 20 per cent of the sludge mass in the UASB reactor, so as to assure the stable performance of the reactor, the maximum period between two consecutive sludge discharges is about 5 days. At this frequency, the sludge mass discharged is 350 kg TSS. At a concentration of 75 g TSS/L, the volume is 5 m^3 and the area required is about 20 m^2, for example 4m * 5 m. As the cycle period is 20 days, a minimum of four beds is necessary, but for operational stability at least one more should be constructed.

5.3.17 Treatment of Shutdown Washings

The weekend shutdown washings are generated at a volume of about 500 m^3 and at an average concentration of 11600 mg/L. These washings can be tolerated by the UASB reactor provided sufficient alkalinity is supplemented and the hydraulic retention time is increased to 10 hours. However, the pilot plant investigation showed that the reactor is potentially vulnerable to shock loads such as that caused by the end-of-crop shutdown washings. Thus, these washings should be diverted to a holding pond/tank and three options are available:

- **Use of evaporative lagoons** - The high strength but low volume streams can be reduced to a dry cake using an evaporative lagoon, especially in a hot climate. Seepage contributes to dewatering where permeable strata underly a lagoon but this will decrease with time as solids accumulate in void spaces. A dried cake approaching 20% solids will accumulate and can be removed at intervals. Evaporation from the lagoon surface can also be assisted by blowing air across the surface and by injecting hot waste gases from the mill into the effluent, thus reducing the land requirements.

- **Composting with filter cake** - The washings can be composted by mixing it with filter cake. In India, vinasse (distillery waste) is composted in pits where it is mixed with filter cake with the help of mechanical mixing for twenty-one days and stacked on a surface at one meter height for about one month for maturation (Subba Raes *et al.*, 1995).

- **Diluting the washings with the overflow from the spray pond or excess condensates and treatment in the UASB reactor** - The end-of-crop shutdown washings, generated at a volume of about 2000 m^3, needs to be diluted at least 10 times to bring its COD in the range of 4000 to 5000 mg/L.

5.3.18 *Typical Arrangements for the UASB Treatment Plant*

Based on the design criteria obtained after the pilot-scale study and on the design considerations discussed previously, the typical arrangements of the UASB treatment plant are as follows:

- Segregation of wastewater streams and treatment of only the concentrated streams in the UASB reactor.
- Screening and oil & grease removal.
- Equalization/Pre-acidification reactor of 50 m^3 volume with a pH control system and nutrient addition facilities.
- Main UASB Reactor consisting of a 3.2m square vessel with a 5 m sidewall depth, having an effective volume of 50 m^3. 5 inlet points should be provided in the reactor.
- Gas collection and conversion or conveyance. If the amount of biogas exceeds the utilisation level, the surplus is burnt off by a flare stack.
- Sludge drying beds (of a surface area of about 450 m^2) and a sludge storage tank (of a volume of about 75 m^3). In the event of a shock load affecting the sludge activity, it is possible to re-start the plant using excess sludge from the storage tank.
- Post-treatment facility - A sedimentation tank with a volume of 108 m^3 will improve the final effluent quality significantly. Other post-treatment methods are optional, depending on method of disposal of the effluent and on the effluent standards.

6. Design and Construction of UASB Demonstration Plant at Rose Belle Sugar Factory

6.1 Tendering Procedure

The University of Mauritius requested for quotations for the structural design, manufacture, installation and commissioning of a pilot UASB wastewater treatment plant at Rose Belle sugar factory. A copy of the Tender sent to selective tenderers in given in Appendix 2. Quotations were received by the following two companies:

(1) Advance Engineering Ltd.
(2) Forges Tardieu Ltd.

Following the technical and financial evaluation, the tender was awarded to Advance Engineering Ltd. The price quoted by the company was Rs 525, 850.

6.2 Structural Design of Reactor and Concrete Base

The location of the UASB plant with respect to the factory is shown in Appendix 3. The structural details of the reactor as given by Advance Engineering ltd. is given in Appendix 4. Steel of grade 316511 was used by the contractor. The assumptions and results for the reactions at the base of the UASB reactor were as follows:

- Basic wind speed = 300 km/h = 83.33 m/s
- $S_1 = 1.0$; $S_2 = 0.74$ $\therefore V_s$ = design wind speed = 61.7 m/s
- Dynamic pressure $q = 0.613 \times (61.7)^2 = 2.3$ kN/m^2
- Assume a triangular distribution for the pressure of water on the wall panel
- Weight of wastewater = 57.95 kN/m2
- The supports of the reactor are assumed to be fully fixed

- Assuming fully fixed supports:
  Maximum Lateral force per support = 59 kN
  Maximum overturning (Z-force uplift) = 249 kN per support
  Maximum X and Y moment = 79.2 kN per support.

  The base reinforcement design for the UASB is given in Appendix 4.

6.3 Construction of UASB Plant at Rose Belle

Plates 1 to 8 illustrate the various design features of the UASB plant erected at Rose Belle sugar factory. To avoid leakage problems a 3mm thick fiber-glass lining was made on the interior side of the reactor.

Phase 1 : UASB demonstration plant (volume 50m³ and 5m high) on concrete base at Rose Belle Sugar Factory. Note the oil/grease seperator in the foreground with the effluent intake pipe and the sampling pipes on the reactor.

Plate 2 : Influent distribution channel at the top of the reactor and Gas-Solids-Liquid seperator made in fibre glass

Plate 3 : Gas-Liquid-Solids seperator and influent distribution pipes

Plate 4 : Influent distribution pipes at bottom of reactor

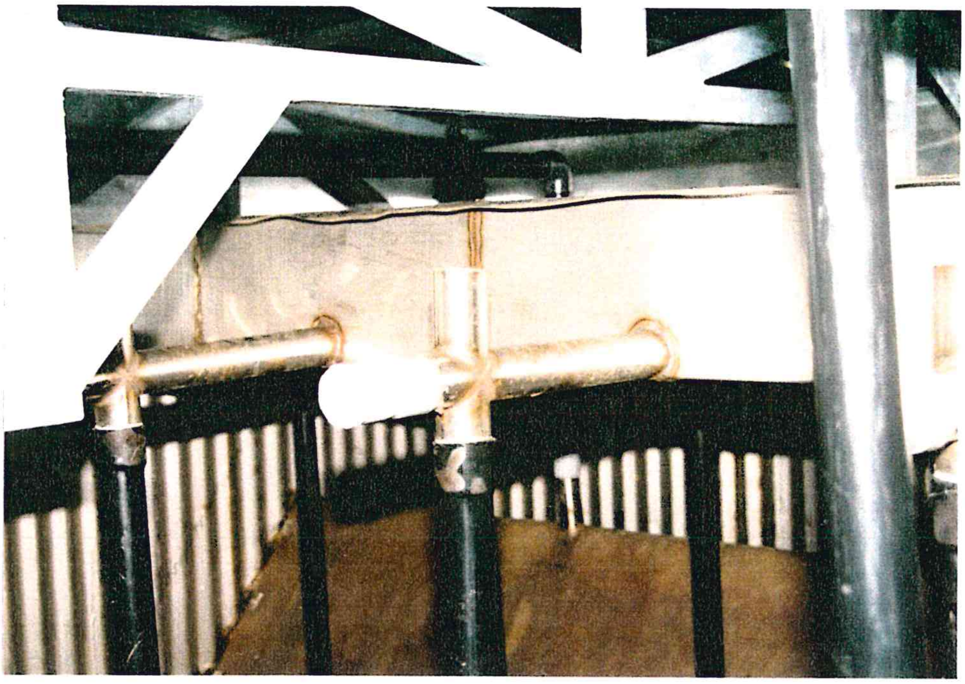

Plate 5 : Influent distribution channel and inlet pipes with air vents

Plate 6 : Inside of Gas-Liquid-Solids seperator with influent distribution pipes and gas outlets

Plate 7 : Change in diameter of influent distribution pipes at the bottom of the reactor

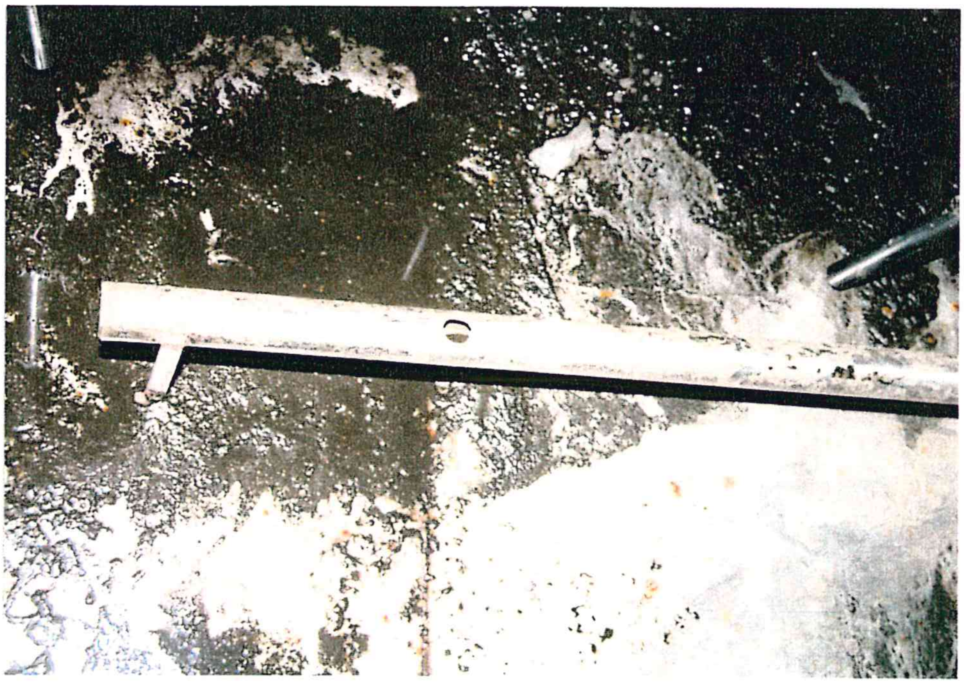

Plate 8 : Horizontal perforated influent distribution pipe

7. Future Work

The following project has been approved for funding by MRC: Start-up and Operation of the UASB Process". The major aim of the project is to start-up the treatment plant during the 1998 milling season and to operate it during two milling seasons to determine optimum operation criteria. The final phase of the project will involve the dissemination of the results to the sugar industry through a half-day seminar. The full-scale pilot project will enable:

- The determination of optimum criteria during the start-up phase using a suitable inoculum.
- Determination of the technical and economic feasibility of the treatment system for the Mauritian Sugar Industry.

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APPENDICES

APPENDIX 1: Effluent Standards for Cane Sugar factories in Mauritius

Government Notice No. 34 of 1997

THE ENVIRONMENT PROTECTION ACT 1991

Regulations made by the Minister under section 34 of the Environment Protection Act 1991

1. These regulations may be cited as the Environment Protection (Effluent Limitations for the Sugar Industry) Regulations 1997.

2. In these regulations—

"Act" means the Environment Protection Act 1991;

"condenser waste water" means effluent originating from a factory condenser;

"factory" means a sugar factory;

"influent raw water" means water diverted from a river, stream, spring or canal, or water abstracted from underground and used by a factory;

"other factory waste water" means effluent originating from the washing, general maintenance and workshops of a factory.

3. (1) Subject to paragraph (2), the national environmental standards in relation to effluent limitations for the sugar industry shall be as set out in the Schedule.

(2) Paragraph (1) shall apply to effluents discharged underground or into a river, stream, spring, canal, reservoir or lake by a factory.

(3) Any effluent which—

(a) has one or more of the parameters specified in the first column of the Schedule;

(b) does not comply with the corresponding limit specified in the second or third column of the Schedule, as the case may be; and

(c) is discharged from a factory,

shall be deemed to be a pollutant.

4. These regulations shall come into operation on 1st October 1999.

Made by the Minister on 10 March, 1997.

SCHEDULE

(regulation 3(1))

The following standards are maximum limits for the corresponding parameters except where an upper and a lower limit are specified.

Parameter	*Standards*	
	Condenser waste water	*Other factory waste water*
pH	6.0-9.0	6.0-9.0
Temperature (°C)	40	40
COD (mg/l)	I* + 50	100
TSS (mg/l)	I* + 30	60
Oil (mg/l)	I* + 5	I* + 10 I* + 5 (as from 1st October 2001)

Note: I* refers to influent raw water.

BY AUTHORITY: SILVIO M. EMPEIGNE, GOVERNMENT PRINTER 1411/3/97 — 1831

APPENDIX 2:
Tender Document

To :

Invitation to Tender for the Structural Design, Manufacture, Supply, Installation and Commissioning of a Pilot UASB Wastewater Treatment Plant at Rose-Belle Sugar Factory

The University of Mauritius (hereafter referred to as the Employer) wishes to invite selective tenderers to tender for the structural design, manufacture, supply, installation and commissioning of one pilot UASB Wastewater treatment system to be located at Rose-Belle Sugar Factory.

You are invited to submit your bona-fide offer to the following address in sealed envelopes bearing no identification marks whatsoever, but clearly marked " Tender for the Structural Design, Manufacture, Supply, Installation and Commissioning of a UASB treatment plant" :

The Registrar
University of Mauritius
Reduit
MAURITIUS

at latest by at hours.

Tenders received after the specified time and date will **not** be considered.

The University reserves the right :

(a) to accept or reject any bid
(b) to annul the bidding process and reject all bids at any time prior to award of contract without thereby incurring

  (i) any liability towards any bidder
  (ii) any obligation to inform any bidder of the grounds for the University's action

Structural Design, Manufacture, Supply, Installation and Commissioning of a Pilot UASB Wastewater treatment plant at Rose-Belle Sugar Factory

INSTRUCTION TO TENDERERS

1. Documents

The Tender must be based upon all the Tender Documents. The complete set of documents comprises the following:-

(a) The present Tender Documents

(b) Drawings as listed in Appendices F(a) and F(b)

The contractor will be deemed to have consulted these documents before tendering .

2.Description of Work

The work shall comprise of the structural design, manufacture, supply, installation and commissioning of a UASB waste water treatment system that shall be made up of the following parts :

(i) The reactor

The reactor shall consist of a rectangular box shape of dimension 3.2m x 3.2m x 5.2m high so as to have a minimum fluid capacity of $50m^3$. The box shall be fitted with two nos triangular shaped hoods 1200mm wide x 3.2m long that shall act as gas collector. A triangular shaped gas deflector together with a middle piece shall be fixed to the wall of the reactor so as to direct the gas formed into the hoods. The tenderer shall provide adequate supports at discrete points along the length of the gas deflectors and collectors. A manhole is to be provided on each gas collector for inspection .

Outlet pipes(50 mm diameter) fitted with necessary valves shall be fixed to the apex of the gas collecting hoods.

A sludge removal system shall be provided at the floor or lower part of the walls for annual emptying of the reactor. The tenderer shall provide a water tight manhole access at the bottom of the tank for cleaning purposes and a ladder system for access to the top of the reactor. The reactor must be totally closed at the top with removable light covers.

(ii) Influent Distribution Device

To obtain a uniform distribution of the influent over the bottom of the UASB reactor, it is necessary to employ a flow splitting device to introduce the influent flow at several points on the reactor bottom. The following two distribution systems are to be provided :

(1) A distribution system situated at a hydraulic level higher than the water level in the reactor is to be used. Feeding will then be accomplished using gravity. Six small distribution boxes are connected on either side of a distribution channel situated 20 cm above the water level. A 50 mm inlet pipe to the distribution channel is to be provided. A set of triangular weirs is to be connected between the distribution channel and the small distribution boxes. Flexible polyethylene tubes connect the twelve distribution boxes to twelve inlet points distributed uniformly at a level of 150 mm above the reactor bottom . The diameter of the polyethylene tube is to be 50 mm above the gas seperator and 30 mm below it.
The influent distribution device is to be covered with removable light covers.

(2) A 50mm inlet pipe situated at a height of 100mm above the reactor bottom is to be provided fitted with a non return valve. The pipe leads to six inlet points distributed uniformly through a manifold system.

(iii) Out flow of treated water

The treated water shall flow off the 2 opposite sides of the top of the reactor through a set of 3 outlet PVC tubes(of diameter 50mm)on either side of the reactor and at a level of 5m from the bottom. All the outlet tubes eventually connect to a 100 mm diameter pipe. Baffles (25 cm height of which 5 cm extends above the water level)extending over the length of the reactor must be provided in front of the outlet tubes to prevent the overflow of floating materials.

(iv) Sampling pipes and sludge discharge pipe

Six sampling pipes, 50mm in diameter, must be located along the depth of one side of the reactor - at heights 200 mm, 800 mm, 1800 mm, 2600 mm, 3400 mm and 4500 mm above the bottom. The sampling pipes must be fitted with butterfly valves.
A sludge discharge pipe, 100 mm in diameter and having a length of 1000mm inside the reactor , must be provided at a height of 1500 mm above the reactor bottom for regular discharge of sludge. The sludge discharge pipe must be fitted with a butterfly valve.

(v) The base

The reactor shall sit on a concrete base that shall be constructed by other parties. However, the tenderer shall provide necessary anchor bolts to secure the reactor to the base. The successful tenderer shall also supply to the employer, within 7 days of order, the calculated reaction forces to which the base shall be designed and the necessary anchor bolts.

Schematic drawings of the system are included in Appendices F(a) and F(b).

3.Specifications

A. **Materials**

(i) The attention of the tenderer is drawn to the fact that this system shall be working in an aggressive environment and that the materials used shall be such that to cater for rusting and other corrosion damages. No painting is envisaged to the structure for the first 5 years of service.

(ii) Standards for materials: The current British Standards shall apply for the materials to be used in the project.

(iii) All the piping must be made of PVC material.

B. **Loading**

(i) The structure shall resist wind loads of up to 280km/hr.

(ii) The topography factors shall be taken as follows :

$S_1 = 1.0$
$S_3 = 1.0$
Open country with scattered wind breaks for a class B structure shall be used to determine S_2.

The wind loads shall be calculated according to CP3 chapter V part 2.

(iii) The density of the waste water shall be taken as 1030 kg/m³. The reactor will also contain about 1500 kg of sludge.

4.Design

The structural analysis and design shall be carried out according to BS5950 and other relevant codes of practice. However, it is preferable that a finite element analysis be carried out on the structure for materials minimisation.

5.Fabrication and Erection

The structure shall be detailed in a way such that the manufacture can be done in a knocked down system. It is preferable to reduce the site intervention to the minimum.

No site welds shall be allowed for any mild steel used. However, if in the course of welding of stainless steel damage is caused to the protective coating of mild steel, the damage shall be made good immediately by means of rust anode treatment.

6.Duration of work

The contract period shall be 3months from date of order.

7.Liquidated damages

Liquidated damages shall be applied as per the Appendix E of the tender documents

8.Payment

An advance payment of 20% shall be made upon submission of an advance payment guarantee as per Appendix D.

30% of contract value shall be upon delivery of the works in knocked down conditions on site.

40% of the amount shall be paid upon practical completion of the work.

The 10% balance shall be retained for a period of 6 months following the practical completion and shall be released on the condition that all snags and defects found are made good by the contractor.

9.Bonds & Securities

(i) Tender Bond

The tenderer shall submit a tender bond for the bank or in cash for the amount of Rs 10,000.00. The tender bond shall be of the format as in Appendix B.

(ii) Performance Bond

A performance bond from the contractor's bankers to the amount of 10% of the contract value shall be submitted for the contract period plus the defects liability period upon award of the contract. The format for the performance bond shall be as per Appendix C.

10. Tenderer to inform himself

Tenderers are invited to visit the proposed site before submission of the tenders. The successful Tenderer shall be deemed to have satisfied himself as to the nature and extent of the works. No claim for extra expense or for extension of time under the contract will be allowed on the grounds that insufficient information was given in the Tender Documents, that the Tenderer was not conversant with the conditions prevailing at the site or that during the course of the work he encountered unexpectedly difficulty which could have been avoided by inspection of site.

11. Interpretation of Documents

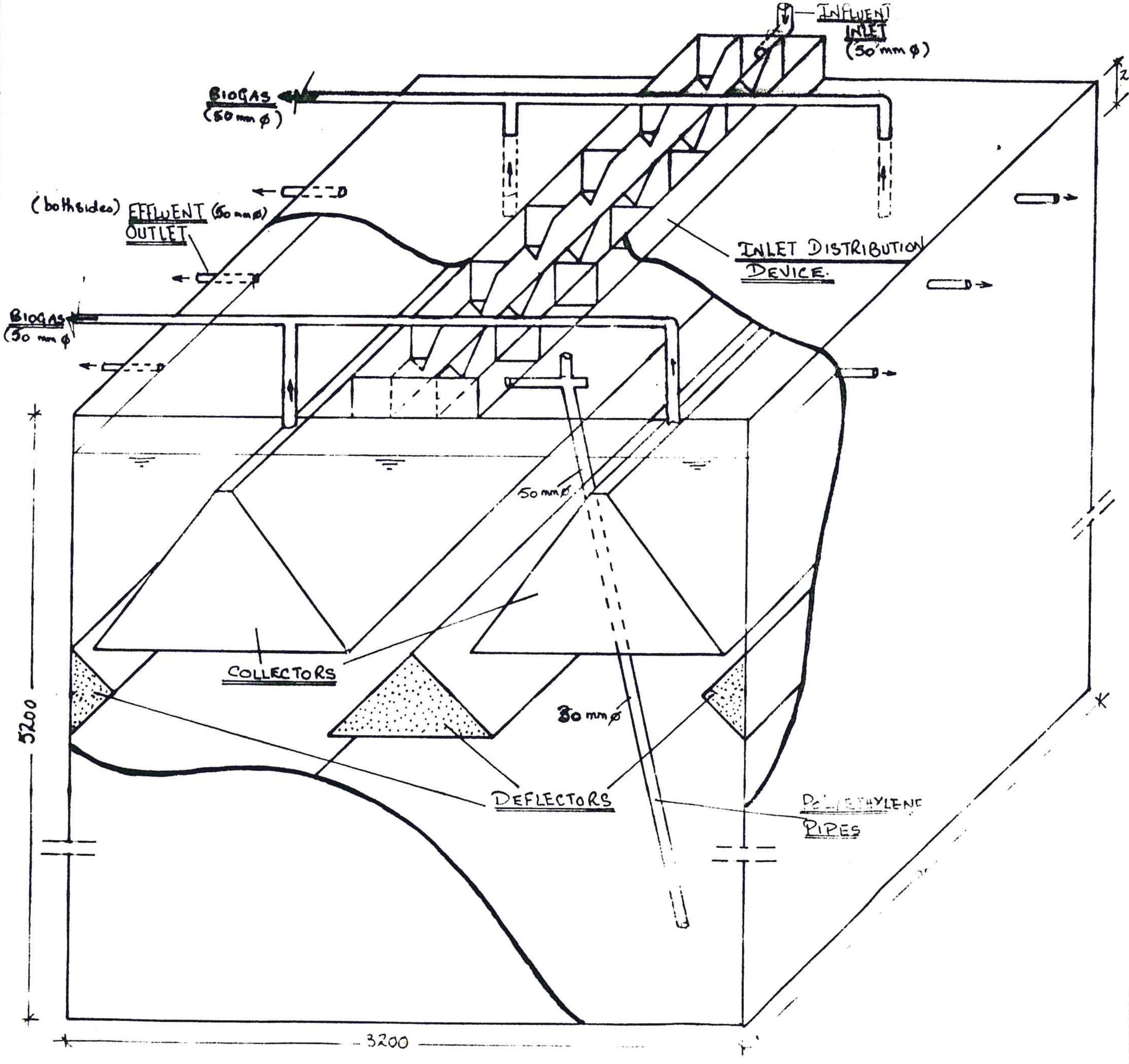
The present Tender documents are meant to be a general guide to the contractor and are not meant to replace applicable codes of practice and regulations, nor shall they provide him with any excuse for claiming additional costs and for not executing the job to the full satisfaction of the Employer.

12. Discrepancies

Should the Tenderer find any discrepancies in the Tender Documents or require any clarification on any part of the documents, he must notify **The Registrar of the University of Mauritius** in writing not less than 7 days prior to Tender's closing date.

13. Revisions

The Employer may issue Addenda to amplify or clarify the Tender Documents. Each Addendum will be issued to all firms to whom the Tender documents have been issued. The firms will acknowledge receipt of the addendum by returning a duplicate of the forwarding letter duly signed. The Addendum will be duly included in the Tender Documents.

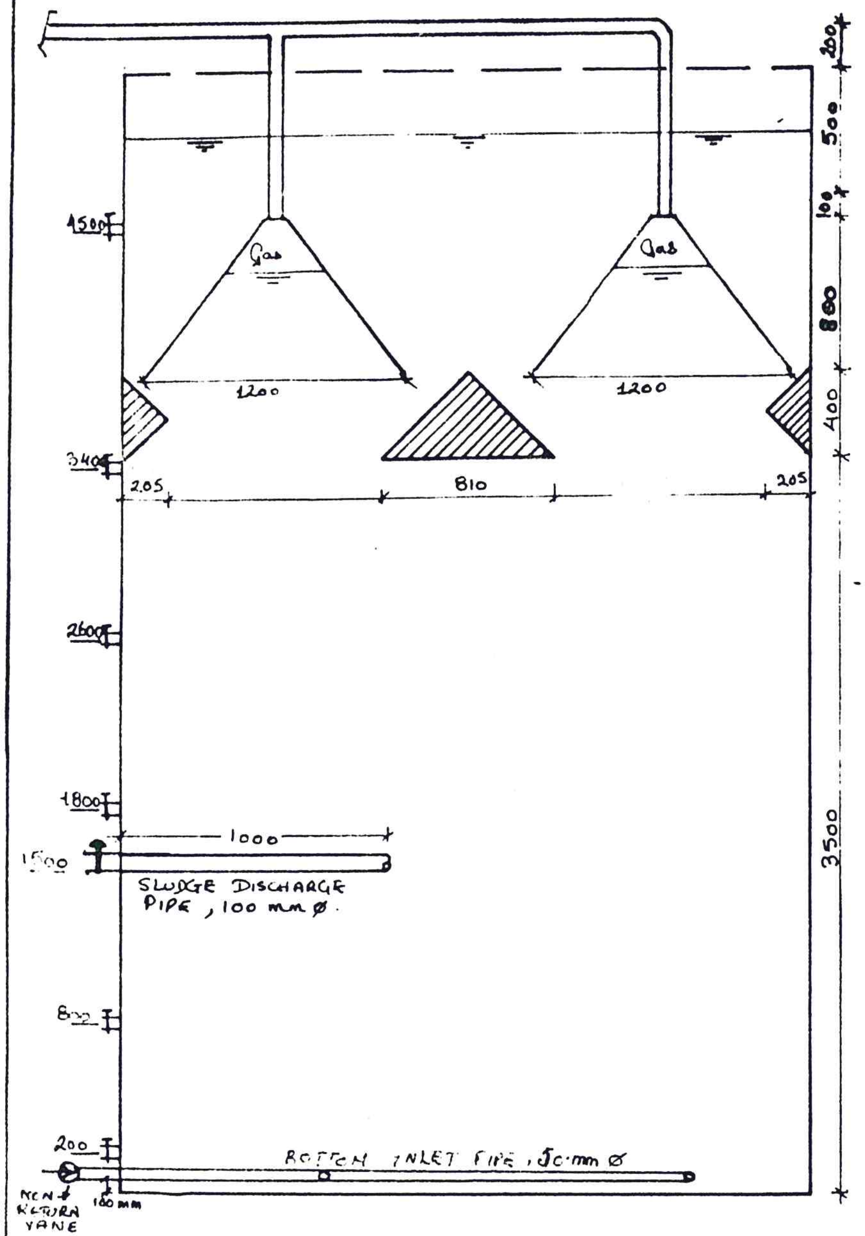


OVERVIEW OF 50 M³ PILOT SCALE U.A.S.B

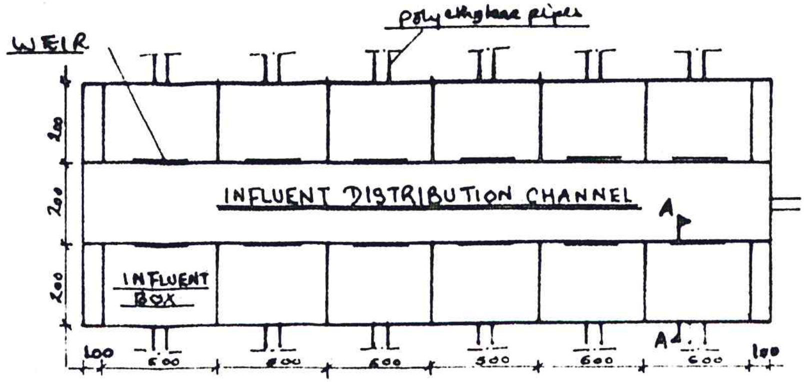
GENERAL NOTES

1. REFER TO SPECIFICATIONS FOR TYPES OF MATERIALS, CONNECTIONS & WELDING
2. REFER TO APPENDIX F(b) FOR DIMENSIONS OF INLET DEVICE & GAS COLLECTORS AND DEFLECTORS
3. ONLY ONE OF THE 12 POLYETHYLENE PIPES IS SHOWN
4. SUPPORTING DEVICE OF COLLECTOR NOT SHOWN. REFER TO SPECIFICATION
5. SAMPLING PORTS, BOTTOM INLET PIPE & SLUDGE DISCHARGE PIPE NOT SHOWN. REFER TO APP. F(b).
6. REFER TO SPECIFICATIONS CONCERNING THE CHANGE OF ϕ OF THE 12 POLYETHYLENE PIPES FROM 50 MM ϕ TO 30 MM ϕ through a REDUCER

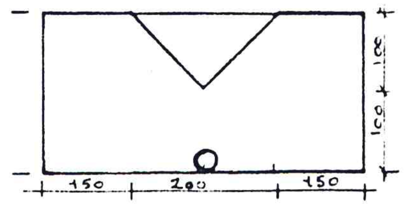
U.A.S.B WASTE WATER TREATMENT PLANT.
UNIVERSITY OF MAURITIUS, RÉDUIT.
APPENDIX F(a)
Drawing not to scale. 20.03.97



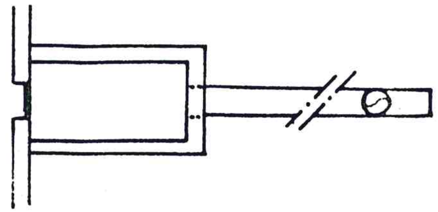
LAYOUT OF COLLECTORS, DEFLECTORS, SAMPLING PORTS, SLUDGE DISCHARGE PIPE & BOTTOM INLET PIPE

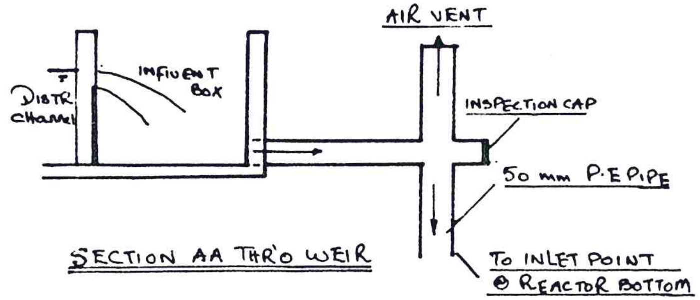


DETAILS OF DISTRIBUTION DEVICE.

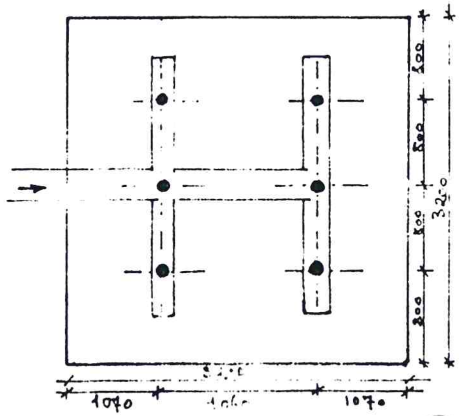


FRONT VIEW OF INFLUENT





SECTION AA THRO WEIR



POSITIONS OF DISCHARGE POINTS @ BOTTOM INLET PIPE

U.A.S.B WASTE WATER TREATMENT PLAN

UNIVERSITY OF MAURITIUS, RÉDUIT.

APPENDIX F(b)

Drawing not to scale

20.03.97

APPENDIX 3: Site Location of UASB Demonstration Plant at Rose Belle Sugar Factory

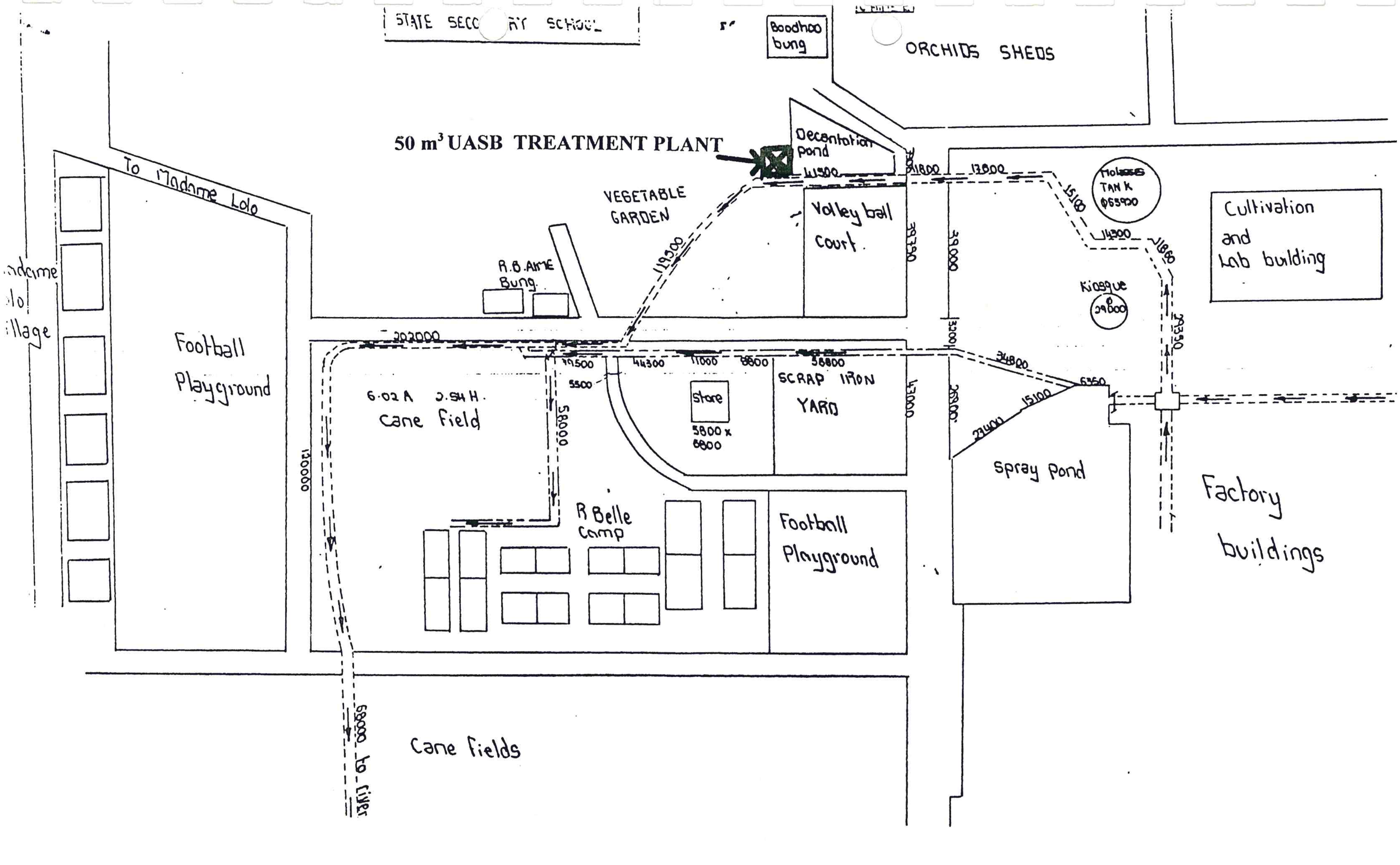
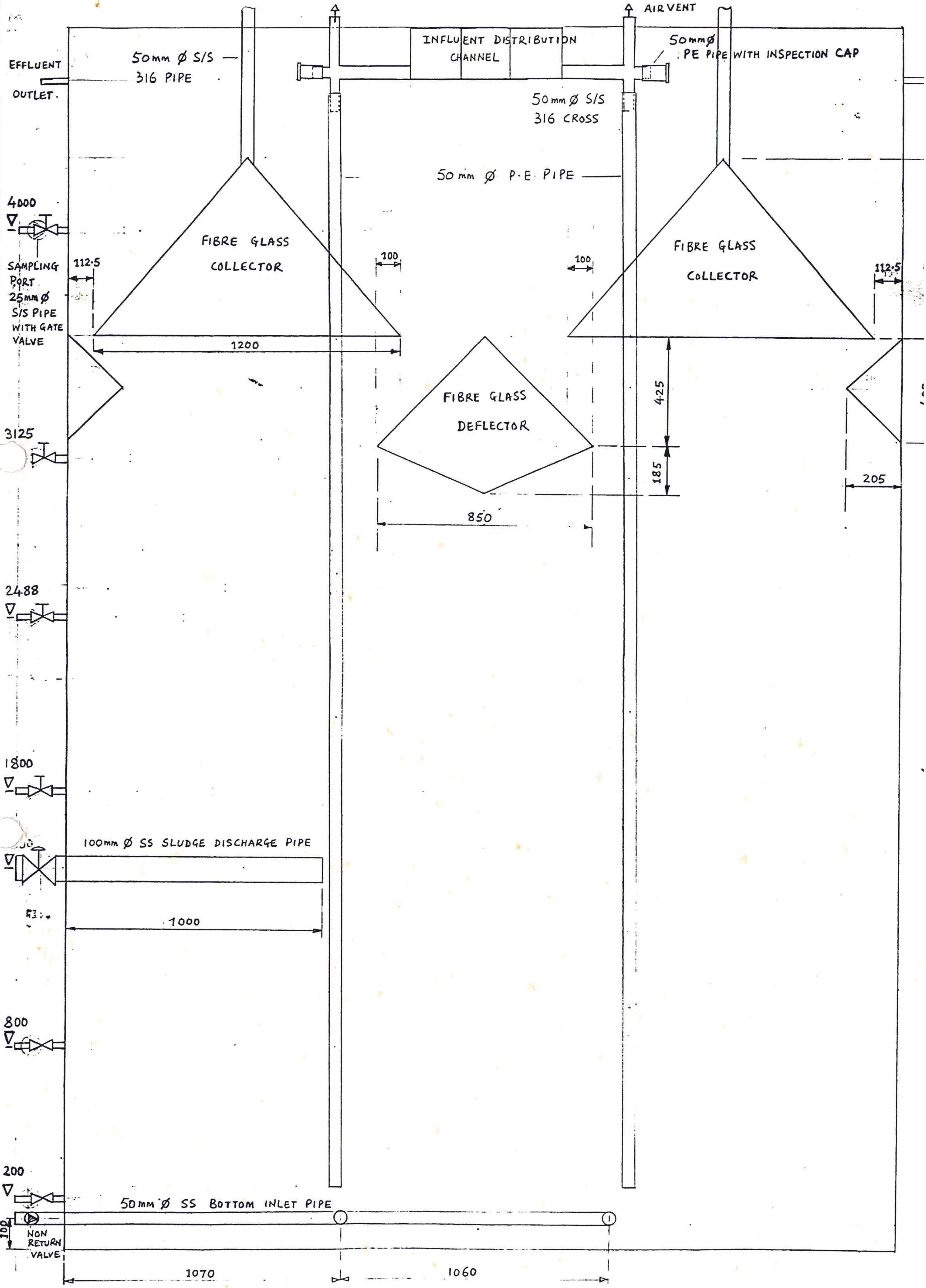


Figure : Site location of UASB demonstration plant at Rose-Belle Factory

APPENDIX 4:
Technical Drawings of UASB Demonstration and Base-reinforcement Design Plant at Rose Belle Sugar Estate


AIR VENT
INFLUENT DISTRIBUTION CHANNEL
50mm Ø PE PIPE WITH INSPECTION CAP
EFFLUENT OUTLET
50mm Ø S/S 316 PIPE
50mm Ø S/S 316 CROSS
50 mm Ø P·E· PIPE
4000
SAMPLING PORT 25mm Ø S/S PIPE WITH GATE VALVE
112·5
FIBRE GLASS COLLECTOR
100
100
FIBRE GLASS COLLECTOR
112·5
1200
FIBRE GLASS DEFLECTOR
425
185
205
850
3125
2488
1800
100mm Ø SS SLUDGE DISCHARGE PIPE
1000
800
200
50mm Ø SS BOTTOM INLET PIPE
100
NON RETURN VALVE
1070
1060