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MANAGEMENT OF SUGARCANE MILL WASTEWATER IN HAWAII

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ABSTRACT

Current sugarcane mill wastewater management system in Hawaii was surveyed at Oahu Sugar Co. on the island of Oahu. Problems generated from the improper wastewater management such as odor nuisance, field silting, crop reduction and large land requirement, motivate a new management system for Hawaiian sugar industry. Based on the results of preliminary laboratory treatment on sugarcane wastewater, and the cost analysis for different alternatives, an appropriate wastewater management system for Hawaiian sugar industry is recommended. This system incorporates sedimentation, anaerobic pretreatment(UASB), and aerobic polishing(EAFB) for anaerobically treated effluent. It efficiently(≥99%) removes the organics and solids in wastewater within 2 days of hydraulic retention time provided. Therefore, the problems generated from the present treatment facility can be eliminated by implementing the proposed management system. More importantly, reuse of the properly treated wastewater for drip irrigation and cane washing will provide extra profit for the Hawaiian sugar industry.

KEYWORDS

Sugarcane wastewater; treatment; reuse; wastewater characteristics; anaerobic sludge blanket; anaerobic fixed bed; aerobic fixed bed; entrapped microbial cell; management alternatives; cost analysis.

INTRODUCTION

It has been projected that by the year 2000 the water demand on the island of Oahu, Hawaii, will be greater than the sustainable yield(Dugan and Lau, 1980; Lau, 1981). At that time, it is expected that the municipal demand will be 220 MGD(836,000 m^3/day), nearly equal to that for sugarcane irrigation which is expected to remain constant at about 240 MGD(912,000 m^3/day). On the island of Oahu, as in so many other areas of the state of Hawaii, there is a growing need for new and alternative sources of water.

Sugarcane industry, including sugar cane plantation and sugar processing, has been the major water consumption and wastewater generation source in Hawaii (U.S. EPA, 1971). Sugarcane irrigation consumes nearly 50 percent of the amount of daily water usage in the state. On the other hand, the sugar processing mills discharge approximately 100 MGD(380,000 m^3/day) of wastewater which nearly corresponds to daily domestic sewage generated in Oahu (DPED, State of Hawaii, 1984).

Formerly, sugar processing mills simply discharged their untreated wastewater and even bagasse to nearby ocean, which not only caused severe environmental pollution, but also affected the travel industry in Hawaii. After 1971, owing to the results of a survey conducted by U.S. EPA, which revealed these problems, the ocean dumping was banned.

Currently, most sugarcane industry facilities reduce their total wastewater volume by recycling, settling or separating solids in large open ponds or through hydroseparators. Effluent from these facilities is either used for irrigation in cane fields or for cane washing in the processing mills (U.S.EPA, 1971). However, the uncontrolled settling ponds and the poor effluent quality result in problems such as odor nuisance, silting of transport ditches, furrows, and fields, reduction of crop yields, and corrosion of the washing equipment. These concerns, along with the loss of productive lands used for handling the wastewater prior to irrigation, inspired the Hawaiian sugar industry to investigate potential alternatives to handle its wastewater.

The sugar beet industries in Europe have been successful in reducing their water pollution problems (Morris et al, 1984, Nawar et al, 1984, Pette, 1979; Pette et al, 1981a, 1981b; Shore et al, 1984). Thus, it is logical to examine the adaptability of the sugar beet wastewater management system for Hawaiian sugarcane wastewater.

Based on the results of a literature review on various wastewater treatment alternatives for sugar industry, wastewater characteristics surveys conducted at Oahu Sugar Co., and preliminary laboratory work on the treatment of sugar mill wastewater, a tentative wastewater management system at Oahu Sugar Co. was developed, which can be used as a guideline for the other existing sugarcane mill wastewater management systems in the state of Hawaii.

WASTEWATER FLOW AND CHARACTERISTICS

The typical sugarcane factory consists of three operating sections: (1) the cane preparation plant, (2) the milling plant, and (3) the boiler power plant. These plants serve the basic steps for making sugar from sugarcane which include washing, extraction, purification and crystallization.

Wastewater samples were taken from the sites of cane washing water, filter cake washing water, and composite mill wastewater (excluding domestic sewage) for characteristics analysis. The results shown in Table 1 can be further used as treatment and design basis.

Table 1 Wastewater Characteristics at Various Waste Producing Sources (based on 90% occurrence frequency)

Waste producing source	Cane washing	Filter cake washing	Composite
Alkalinity (mg/L)	1600	4300	1100
BOD_5 (mg/L)	3000	30000	2800
COD (mg/L)	7400	43000	7000
SS (mg/L)	19000	24600	11700
N (mg/L)	3	17	4
P (mg/L)	0.17	66.6	1.76
K (mg/L)	21.8	40.6	18.6
SO_4 (mg/L)	39.8	19.5	28.5
pH	6-7.6	7.4-8.1	6.5-7.6
Temperature (^oC)	31-38	35-50	32-40

Wastewater characteristics such as COD, BOD_5, alkalinity and SS are fluctuant due to soil type, water quality, and harvesting method. Analysis data indicate that the sugar mill wastewater contains high organic matter (COD, BOD_5), and high solids content. Also, the COD (BOD_5)/N ratio is significantly high. Other nutrients such as P, K, and SO_4 are expectedly low. In general, the characteristics of sugarcane wastewater are similar to that of the sugar beet wastewater, except for the high solids content, which results from the special harvesting method in Hawaii.

PRELIMINARY TREATMENT

Anaerobic Process

Upflow Anaerobic Sludge Blanket(UASB) and Anaerobic Fixed Bed(ANFB) have been successfully applied for treating beet sugar wastewater(Lettinga et al, 1980, 1983, 1984, 1986; Nawar et al, 1984; Pette et al, 1981a; Pette et al, 1981b; Verrier et al, 1985). Therefore, these two processes were evaluated in the laboratory scale for treating sugarcane processing wastewater. Two UASB reactors and one ANFB were used for the investigation. Results are shown in Table 2. The result indicated that the UASB process presented more reliability for treating sugarcane processing wastewater in terms of performance efficiency and stability. Moreover, UASB had an easier start-up than ANFB. Thus, UASB was chosen for the anaerobic treatment of the sugar mill wastewater in Hawaii.

Table 2 Experimental Conditions and Results for UASB and ANFB Treating Sugar Mill Wastewater

Reactor	UASB(I)	UASB(II)	ANFB
Reactor void volume(L)	5.5	10.2	1.74
Substrate of initial sludge	glucose	chicken manure	chicken manure
Initial sludge amount (g TSS/L)	16.2	52.7	1.7
Sludge VSS/TSS	-	0.41	-
Initial organic load (g COD/L/day)	1	0.5	0.5
Initial sludge load (gCOD/gTSS/day)	0.06	0.009	0.29
Max. organic load (gCOD/L/day)	6	7.34	2
Min.HRT(hrs)	6	4.32	18
COD removal efficiency(%)	86	85	64
Biogas production rate (1/L/day)	0.7	1.6	0.28
Methane yield (L/gCOD removed)	0.17	0.21	0.21
Methane content(%)	64	57	70
Days of operation	158	100	87
Start-up period(day)	50	20	40

Aerobic Process

The aerobic fixed bed reactor was recommended to treat the anaerobically treated effluent. It is more compact in design, easier to operate, and is more energy efficient than the conventional processes, such as activated sludge, trickling filter, or extended aeration (Owen, 1982). Two aerobic fixed bed reactors were assessed: one was Aerobic Fixed Bed(AFB), the other was Entrapped Aerobic Fixed Bed(EAFB), which was developed recently to treat organic wastewater(Yang et al, 1988). Results of these two reactors are shown in Table 3.

Table 3 Experimental Conditions and Results for AFB and EAFB Reactors Treating Effluent from UASB Reactors

Reactor	AFB	EAFB
Reactor void volume(L)	0.45	1.8
Organic load applied (gCOD/L/day)	0.5	0.5
HRT applied(hours)	24	12
COD removal efficiency(%)	80	80
SS removal efficiency(%)	22	80
NH_4^+-N removal efficiency(%)	75	80
Start-up period (day)	≤10	≤10
Sludge removal frequency(week)	3	6

Table 4 shows the sugar mill wastewater quality before and after anaerobic and aerobic treatments based on the data from the preliminary laboratory experiments. Effluent quality from anaerobic treatment is correspondent to that of the domestic sewage. At the same organic loading rate, AFB and EAFB provide almost equal treatment efficiencies in COD and NH_4-N removal. However, EAFB presents higher solid removal efficiency(80%), lower HRT and less sludge yield than AFB. These features notably reduce the frequency and energy for backwashing of the reactor. Moreover, the effluent quality from EAFB is more appropriate for drip irrigation due to its low suspended solid(≤ 50 mg/L). Thus, EAFB is considered to be the aerobic polishing process for sugarcane wastewater management system.

Table 4 Sugar Mill Wastewater Characteristics Before and After UASB, AFB and EAFB Treatment

	Initial	After UASB	After Settling & AFB	After Settling & EAFB
Soluble COD(mg/L)	1500	225	45	45
BOD_5(mg/L)	1200	113	12.6	12.6
BOD_5/COD	0.8	0.5	0.28	0.28
TSS(mg/L)	650	250	195	50
pH	7.8	8.5	9	9

COMPARISON OF POSSIBLE ALTERNATIVE SYSTEMS

As industries in many countries of the world are now encountering limited fresh water supplies and more stringent wastewater discharge standards, the reuse of treated industrial effluent is considered to be an effective measure resolving these two concerns simultaneously (Costa et al, 1986; Frankel and Phongsphetraratana, 1986; Law, 1986). Over the next seven years, Oahu Sugar Co. is facing a 32 per cent cut in water management (Young, 1989). Therefore, the implication of a wastewater management system comprising of water reuse is imperative.

Alternative 1: Separate wastewater sources treatment

There are three wastewater sources being investigated at the Oahu Sugar Co., which represented the main waste loading at the sugar mill. Alternative 1 suggests to treat wastewater from these three sources separately.

Site 1(cane washing water) and site 3(composite water) have much the same waste characteristics, which are moderate COD and BOD, low alkalinity, low nutrients and high suspended solids. In considering anaerobic treatment, pH and nutrients adjustments should be properly supplied. However, continuous flows and the highly sedimentary solids which could be easily removed in the sedimentation unit, provide a beneficial influent condition for the treatment system.

In spite of its low flow rate(4% of the total daily flow, Site 2(filter cake washing water) contributes high waste loads to the sugar mill wastewater, due to its high COD, BOD, and suspended solids. The high COD and BOD of filter cake washing water render the anaerobic treatment economically favorable. Besides, no pH and alkalinity adjustment are required because of its high pH and alkalinity. Therefore, the annual operation cost could be reduced. Nonetheless, two factors make separate treatment of wastewater from site 2 difficult. First, the Jord vacuum filter, representing about 75 percent of the total filtering capacity, sloughs off large sheets of filter cake periodically. This action slows down this waste stream until enough water accumulates to move it again, resulting in a discontinuous, inhomogeneous stream.

Secondly, the solids in the wastewater are not as easily settled as that of the other two sites, which require a highly efficient settling device. The large amount of bagasse floating in the stream also needs an extra screening apparatus to be removed.

Alternative 2: Composite wastewater - UASB - Reuse

As shown in Table 4, the effluent quality from UASB is close to that of domestic sewage. This effluent cannot be applied for drip irrigation owing to the possible clogging problem caused by its high BOD_5 and solids content. Because the water quality requirement for cane washing is not as strict as that for drip irrigation, this effluent may be recycled for cane washing, thus will drastically reduce fresh water demand for the sugar mill. No equipment corrosion is expected because of the high pH and buffer capacity of the anaerobically treated effluent.

Alternative 3: Composite wastewater - UASB - EAFB - Reuse

Effluent quality from combined anaerobic-aerobic treatment is shown in Table 4. Reuse of this effluent for drip irrigation is applicable due to its low BOD_5 and solids content. Design parameters for this alternative are based on Tables 2 and 3. This alternative highlights more than 99 % of solids and organic removal efficiencies at 48 hours of overall HRT applied.

Alternative 4: Composite wastewater - UASB - Aerated Lagoon(AL) -Reuse

The conventional aerated lagoon is recommended for aerobic polishing in this option. HRT in aerated lagoon is designed as 40 hours, and the expected performances for COD and SS removal are 90 % and 90% respectively. Thus, the COD, BOD_5 and SS would be 22.5 mg/L, 7 mg/L, and 25 mg/L respectively, which meet the state discharge standard. Reuse of this treated water for drip irrigation is also possible. The drawbacks of this option are large land requirement and long overall retention time(more than 70 hours).

Alternative 5: Composite wastewater - UASB - Domestic sewage treatment plant

Discharge of partially treated wastes to a domestic sewage treatment plant can be another option for sugarcane mill wastewater. The advantages include assurance that the wastes are adequately treated or disposed of, the community retains the economic base of the industry, and the industry avoids increased capital investment in waste treatment facilities and avoids the need for increased waste treatment personnel(Loehr, 1984).

This option mainly considers the post treatment of the anaerobically treated effluent. Characteristics of the effluent from anaerobic treatment process(see Table 4) are approximately the same as those of the domestic sewage. Therefore, it is considered to be directed to the municipal sewer system and be discharged to the sewage treatment plant. The upgraded effluent can be either discharged to the nearby water bodies, or used for irrigation. If based on 10 MGD of daily flow and suspended solids lower than 200 mg/L, the service charge for the sewage treatment plant would cost the sugar company $ 285,000 per month($ 2,280,000 per year). Along with the UASB pretreatment cost($ 1,051,920/year), the total annual cost for this option is $ 3,331,920. The cost for producing 1 million gallon treated wastewater would be $ 1,388, which is much higher than any other alternatives.

Moreover, the seasonal nature of the sugarcane milling process can cause serious problems at municipal treatment plants. In addition, there is no sewage treatment facility around the sugar mill area currently. Even the most adjacent treatment plant does not have the capacity to absorb the sugar mill wastewater without difficulty. The result is large shock loads on the municipal treatment plant caused by seasonal condition. It is difficult to operate or to design an efficient municipal waste treatment plant under such conditions.

COST ANALYSIS

Alternatives 2, 3 and 4 are considered to be the appropriate management systems for sugarcane wastewater. Design parameters and cost analysis for UASB, EAFB and aerated lagoon are listed in Tables 5, 6, and 7.

RECOMMENDATION

To select the suitable wastewater management system, both tangible and intangible profits should be taken into consideration. Table 8 lists the comparison of the three alternatives.

There are no net revenue for the three alternatives, although they all produce biogas to be recovered as fuel. Alternative 2 (UASB only) has the lowest capital and annual operational costs, least land requirement and detention time. However, the effluent quality is only good for cane washing, which will merely reduce fresh water consumption but without directly increasing crop yield. Therefore, in considering future profit, alternative 2 is subordinate to alternatives 3 and 4.

Alternatives 3 and 4 generate much the same quality of effluent which can be applied for drip irrigation. The large land requirement (more than 10 times of alternative 3) is one of the major disadvantages of alternative 4. This will severely hinder communities and sugar plantations which also require this productive land to develop. Another disadvantage for alternative 4 is its long overall HRT (24 hours more than that of alternative 3). Although the total capital cost (including land cost) of alternative 3 is twice that of alternative 4, the annual operational cost is 66% of alternative 4. It would break even after 6 years of operation. Thus, alternative 3 is recommended as the most suitable wastewater management system at Oahu Sugar Co. Figure 1 shows the proposed system, retention time and effluent quality from the system. Global COD, BOD_5 and SS removal efficiencies of this system is 99.3%, 99.6% and 99.6%, respectively.

CONCLUSION

A wastewater management system comprising of sedimentation, anaerobic pretreatment (UASB), aerobic post treatment (EAFB) and effluent reuse for drip irrigation and cane washing, is proposed for Oahu Sugar Company. It not only will solve the environmental pollution problems but also provide profit by increasing cane yield. This system is expected to serve as a guideline for the other existing sugar industries in Hawaii. However, wastewater characteristics and local circumstances should be considered.

The required effluent quality for drip irrigation and the impact of the effluent on the cane growth need more study.

Table 5 Design Parameters and Cost Analysis for UASB

Average daily flow rate	10 MGD = 38000 m^3/day
Min HRT	6 hrs
Annual operation days	240 days
Reactor volume (12 m height)	2 * 5000 m^3
Land requirement	900 m^2
Organic loading	6 gCOD/L/day
Capital cost:	
Reactor (2 * 5000)	$ 3,000,000*
Land	$ 48,925
Total capital cost	$ 3,048,925
Annual Operational cost:	
Maintenance, labor	$ 1,374,000**
Analysis, control, nutrient	
Electricity	$ 84,000***
Total annual cost	$ 1,458,000
Annual Methane Credit:	$ 406,080***

* Souza, 1986.
** Lettinga and Hulshoff, 1986.
***Biothane Corporation, 1988.

Table 6 Design Parameters and Cost Analysis for EAFB

Average daily flow rate	10 MGD = 38000 m^3 day
HRT applied	12 hrs
Annual operation days	240 daya
Reactor volume (12 m height)	4 * 6000 = 24000 m^3
Packing ratio	80%
Reactor void volume	19,000 m^3
Land requirement	2,000 m^2
Organic loading	0.45 gCOD/L/day
Cost:	
Capital Cost	
Reactor (4 * 6000 m^3)	$ 4,080,000*
Carrier	$ 2,940,000*
Land	$ 108,722
Total Capital Cost	$ 7,128,722
Annual Operational Cost	
Maintenance, labor, analysis, control	$ 700,000*
Electricity	$ 140,400*
Total Annual Cost	$ 840,400

* Wang, M. L., 1988.

Table 7 Design Parameters and Cost Analysis for Aerated Lagoon

Average daily flow rate	10 MGD = 38000 m^3/day
HRT applied	40 hrs
Annual operation days	240 days
Reactor volume (3 m height)	63,460 m^3
Land requirement	21,200 m^2
Organic loading	0.13 gCOD/L/day
Cost:	
Capital Cost	
Reactor	$ 800,000*
Land	1,152,458
Total Capital Cost	$ 1,952,458
Annual Operation Cost	
Maintenance, labor	$ 133,000*
Analysis, control	
Electricity	$ 1,680,800*
Total Annual Cost	$ 1,813,800

* Biothane Corporation, 1988.

Table 8 Comparison of Alternatives 2, 3 and 4 for Sugar Mill Wastewater Management

Alternative	2	3	4
Process	UASB	UASB+EAFB	UASB+AL
Minimum Total HRT (hours)	30	42	70
Approximate land requirement m^2	900	2,900	22,100
Land cost* $	48,925	157,647	1,201,383
Capital Cost $	3,000,000	10,020,000	3,800,000
Total Capital Cost $	3,048,925	10,177,647	5,001,383
Annual Operational Cost $	1,458,000	2,298,400	3,271,800
Annual Energy Saving** $	406,080	406,080	406,080
Net Annual Cost $	1,051,920	1,892,320	2,865,720
Cost for producing 1 MG treated water $ (excluding capital cost)	438	788	1,194
Effluent Application	Cane Washing	Drip Irrigation	Drip Irrigation
Annual saving on fresh water demand*** $	96,000	252,000	252,000

* $220,000/Ac.
** Methane produced from UASB = 12608 m^3/day; Methane heat value = 950 BTU/ft^3; Methane credit = $4/million BTU (Biothane, 1988).
*** Based on effluent discharge of 10 MGD, 240 annual operation days. Cost of pumping 1 million gallons fresh water for cane washing and drip irrigation is $40 and $105, respectively.

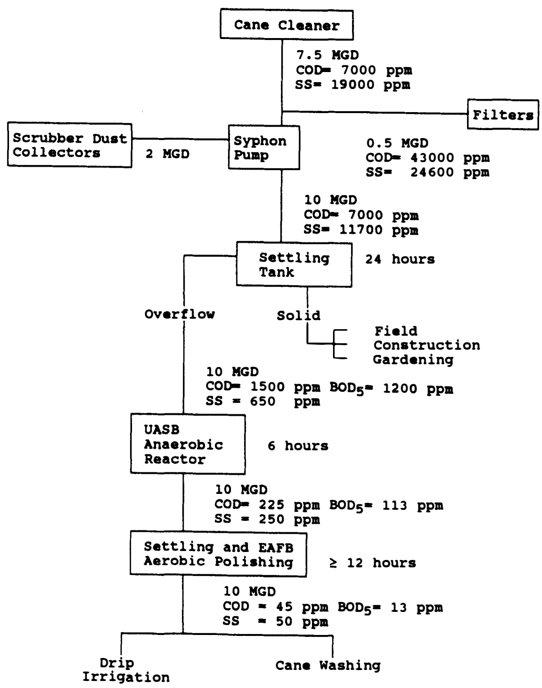

Fig. 1. Proposed wastewater management system at Oahu Sugar Co.

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