ISSN:0128-7680
Pertanika J. Sci. & Technol. 4(2): 263-273 (1996)

Treatment of Palm Oil Mill Effluent by Mesophilic Anaerobic Digestion with Flocculant Addition

Nasiman Sapari, T.Y. Chew[1] and M.I. Yaziz

Department of Environmental Sciences
Faculty of Science and Environmental Studies
Universiti Pertanian Malaysia
43400 Serdang, Selangor, Malaysia

[1]SIRIM
Shah Alam, Selangor, Malaysia

Received 7 February 1995

ABSTRAK

Kertas kerja ini membentangkan penemuan kajian berkenaan penggunaan flokulan dalam proses pencernaan effluen kelapa sawit (POME) di peringkat mesofilik (37°C). Satu poliakrylamida berketumpatan molekul tinggi, Zetag 88N, telah diguna dengan memasukkannya ke dalam pencerna tersebut di peringkat awal operasi. Didapati penggunaan flokulan ini dapat membantu pembentukan pelet di dalam pencerna selepas tiga bulan proses dimulakan. Tanpa flokulan, POME sebagai substrat sukar membentuk granul. Kesan dari pembentukan pelet ialah satu peningkatan kecekapan dalam rawatan effluen kelapa sawit serta membolehkan pencernaan berjalan dengan bebanan organik lebih tinggi. Pencernaan di peringkat mesofilik yang stabil dapat dilakukan hingga ke kadar bebanan maksimum 19 kg COD m^{-3} day^{-1} (masa tahanan hidrolik = 3.6 hari) dengan kecekapan pengurangan COD 96%. Kadar kecekapan ini adalah tiga kali lebih baik dari rawatan secara pencernaan anarobik proses kontak termofilik. Penilaian awal ekonomi menunjukkan proses ini adalah wajar dan menguntungkan.

ABSTRACT

This paper presents research findings on the use of flocculants in the anaerobic digestion of palm oil mill effluent (POME) under mesophilic conditions (37°C). Zetag 88N, a cationic polyacrylamide of high molecular density, was added to the digester at the beginning of the operation. The use of the flocculant enabled pelletization to occur in the digester within three months of start-up for the substrate which is difficult to granulate naturally. The effect of pelletization resulted in an increase in biomass concentration and produced a good solid-liquid separation within the digester, resulting in enhanced treatment performance and the ability to tolerate higher organic loads. Stable mesophilic anaerobic digestion can be operated up to a maximum organic loading rate of 19 kg chemical oxygen demand (COD) m^{-3} day^{-1} (hydraulic retention time = 3.6 days) with 96% COD removal efficiency. This rate was three times better than the anaerobic digestion of the thermophilic contact process. Preliminary economic assessment of the system showed the process to be viable.

Keywords: palm oil mill effluent, treatment, high rate, mesophilic, anaerobic digestion, flocculant, pelletization

INTRODUCTION

Since the enactment of the Environmental Quality (Crude Palm Oil) Regulation 1977 which specified a final biochemical oxygen demand (BOD) effluent of 100 mg/l, several treatment systems have been developed in Malaysia for the treatment of palm oil mill effluent (POME) (Lim 1981; Chan and Chooi 1982; Lim *et al.* 1984). The treatment systems for POME consist essentially of anaerobic and aerobic processes. The three most common treatment systems adopted are stabilization ponds, open-tank digesters with extended aeration, and closed-tank digesters with biogas recovery and land application systems. Of these, the ponding system is the most popular and has been adopted by more than 85% of the palm oil mills in Malaysia (Ma and Ong 1985).

The existing anaerobic treatment systems suffer inefficiencies due to low biomass yield and poor separation of solids. Also, these treatment systems have several disadvantages either because of low treatment efficiency or the need for a large land area, high capital and running costs. Therefore, it would appear that the development of an efficient anaerobic process would be the most effective solution (Cail and Lane 1986). Anaerobic digestion with flocculant addition was chosen to artificially granulate the active bacteria or biomass so that good separation of solid from liquid could be obtained. The main aim was to develop a treatment system with improved treatment efficiency that can be operated with high loading rates, short retention times and a significant reduction in start-up time.

MATERIALS AND METHODS

Two semi-continuous digesters, each of 4-l capacity and equipped with a stirrer, were operated on a fill-and-draw mode at the mesophilic temperature. The experimental set-up of the digester is shown schematically in *Fig. 1.* The digester was immersed in a water bath at 37°C. The feed was stirred by a magnetic stirrer for homogeneous mixing. As the feed was introduced into the reactor, effluent was withdrawn from the reactor by means of a peristaltic pump (Gilson Minipuls HP4HF). Flocculant was continuously added during the first three month of the operation at an average dosing rate of 1 mg/ml effluent.

The digester was initially seeded with 3.6 litres of active palm oil mill sludge which was obtained from an existing commercial anaerobic digester

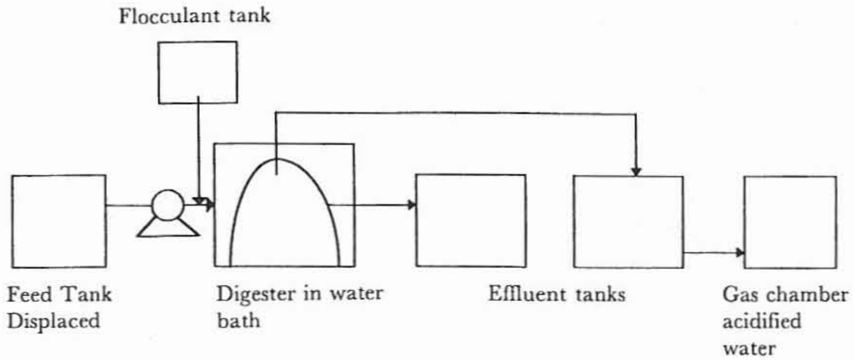

Fig. 1. Flow diagram of mesophilic semi-continuous anaerobic digester

treating palm oil mill effluent. The sludge was analysed and found to have the characteristics of 3,145 mg/l total solid (TS), 14,285 mg/l suspended solids (SS), 12,640 mg/l volatile solids (VS) and 9,130 mg/l volatile suspended solids (VSS). The volatile portion contributed 88% to the total solids.

An initial feed rate of 170 ml/day POME, corresponding to an organic loading rate (OLR) of 2.8 kg COD/m^3/day, was introduced into the digester. The loading was slowly increased to about 300 ml per day, corresponding to an OLR of 5.85 kg COD/m^3/day, over a period of 52 days. The characteristics of the POME used as substrate in the experiment are shown in Table 1.

TABLE 1
Palm oil mill effluent characteristics used as substrate in the mesophilic anaerobic digestion

Parameter (mg/l)	Runs 1	2	3	4	5	Average
Chemical oxygen demand (COD)	72510	67030	39440	56110	66490	59000
Biochemical oxygen demand (BOD_5)	25500	25725	13375	29815	20420	22000
Total solids (TS)	59260	56440	36550	50110	50710	50000
Suspended solids (SS)	40770	34270	23750	30350	33870	34000
Volatile solids (VS)	45030	45770	26940	38280	38820	38000
Volatile suspended solids (VSS)	31880	29140	19690	24300	26220	26000
Total nitrogen (T-N)	1402	1086	825	396	497	900
Phosphorus (P)	–	–	178	270	–	250

Digester operation was controlled by timers on a fill-and-draw system following the sequence shown in *Fig. 2*. The feed was first stirred for 30 min to homogenize the contents prior to feeding into the reactor. The feed with added flocculant was introduced from the base of the digester and an equal amount of effluent was withdrawn from the supernatant zone in the upper part of the reactor. The contents of the digester were then mixed gently by stirring at a speed of 60 rpm for 30 min, followed by settling for 2 h. The whole process took 3 h, and this operation was repeated throughout the duration of the experiment.

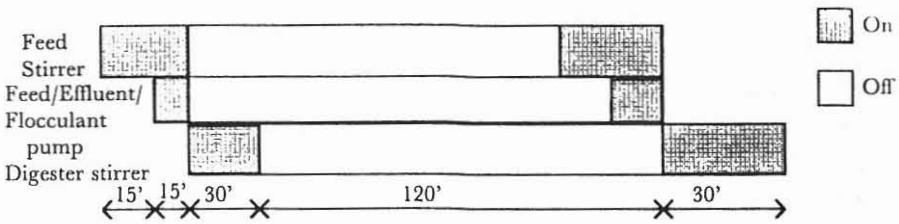

Fig 2: Time sequence of the operation of semi-continuous anaerobic digester

The supernatant from the digester was collected in a measuring cylinder which also acted as a clarifier. The biogas produced by the reactor was collected in a plastic container filled with acidified water (1 N H_2SO_4). The feed rate was increased gradually to an organic loading rate (OLR) of about 5.5 kg COD/m^3/day, after which it was maintained at a constant rate for a period of 2 or 3 times the hydraulic retention time (HRT) or until a steady state condition when a consistent volume of biogas was obtained. Flocculant was added only when necessary, that is, when the supernatant was visually seen to be turbid. The addition would clear the supernatant. Sampling was carried out 3 times a week for a period of 2-3 weeks, at the same time the feed rate was slowly increased to higher loading rates. The experiment was terminated when a further loading caused instability in the anaerobic digestion process.

Throughout the experiment, the digester was monitored daily for its feed rate, effluent discharge rate, flocculant addition rate, biogas production, biogas quality, mixed liquor volatile fatty acid content, alkalinity, pH of the influent, effluent and mixed liquor, volume of settled sludge in effluent and biogas pressure. When the steady state conditions were achieved, 100-ml samples of feed, effluent and mixed liquor (ML) were collected 2 or 3 times a week for a period of 2 or 3 weeks. The analytical parameters such as COD, soluble COD, TS, VS, SS, VSS, T-N and P were analysed according to APHA standard methods (APHA 1989). Analysis for COD was based on the dichromate reflux method using the supernatant after centrifuging at 9000 pm for 10 min. In this way, more consistent results for COD could be obtained.

RESULTS AND DISCUSSION

Operational Parameters

The operational parameters of the digester for the five runs are shown in Table 2. The average ratio of COD to BOD_5 of the raw POME was determined to be 2.8 : 1. The POME had a high proportion of volatile solids (about 77% of the total solids). The influent also contained a high proportion of suspended solids of which the majority was volatile organic matter (68% of TSS). Gas production increased from an average of 6.2 l/day in run 1, which had a feed rate of 291 ml/day (5.9 kg COD/m^3/day) to an average of 9.3 l/day in run 2, which had a feed rate of 342 ml/day (6.4 kg COD/m^3/day). The digester was able to maintain stable operating conditions at all times. The pH of the digester was above 7.0, the mixed liquor volatile fatty acids (VFA_{ML}) was lower than 500 mg/l, mixed liquor alkalinity (ALK_{ML}) was above 2,000 mg/l and carbon dioxide (CO_2) content of the biogas was less than 40% by volume. The increase of feed rate to 502 ml/day, with a similar organic loading rate to that in run 3 (5.5 kg COD/m^3/day), did not cause any increase in gas production. It was clear that the rate of gas production was related to the organic loading rate. A further increase of feed rate to an average of 668 l/day (10.8 kg COD/m^3/

TABLE 2

Operational data of mesophilic semi-continuous anaerobic digester treating POME

		Average	Values		
Parameters	Run 1 (22 samples)	Run 2 (15 samples)	Run 3 (22 samples)	Run 4 (14 samples)	Run 5 (14 samples)
Feed rate (ml/day)	291	342	502	688	993
Gas production (ml/day)	6.2	9.3	9.2	13.6	11.8
Volume settled sludge (%)	18	23	14	26	32
Flocculants added (mg/l)	1000	0	0	0	0
Sludge removed (ml/day)	–	–	–	33	0

day) corresponded to the gas production of 13.6 l/day. The increase in feed rate resulted in a subsequent increase in gas production. However, a further increase in feed rate to 993 ml/day (18.5 kg COD/m^3/day) in run 5 resulted in a decrease in gas production to an average of 11.8 l/day.

The volume percentage of settled sludge (V_S) to effluent volume increased from 18% to 23% in runs 1 and 2 respectively. In run 3, the V_S was low at 14% but it increased again to 26% and 32% in runs 4 and 5 respectively. Termination of the flocculant addition after run 1 resulted in an increase of V_S in run 2. However, in run 3, the low V_S indicated that the flocs seemed to settle better than run 1. After run 3, the V_S varied between 30-90%. Thus, it was necessary to remove some of the settled sludge from the digester. An average of 33 ml per day of the settled sludge was removed in run 4. At the higher feed rate in run 4 dan 5, the V_S were 26% and 32% of the effluent. Although the influent pH was low (< 4.5), the pH of the mixed liquor maintained itself at about 7.2 without any buffer addition. A stable digestion was observed throughout the runs.

The VFA_{ML} contents were mainly low (less than 500 mg/l for runs 1, 2 and 4). The low VFA_{ML} (<500 mg/l) corresponded to low values of ALK (<1500 mg/l) whilst the higher VFA_{ML} (>500 mg/l) corresponded to higher values of ALK (>3,500 mg/l). This illustrated the self-sufficient buffering capacity of the digestion process. Biogas from the process contained 62-67% methane and 32-37% carbon dioxide.

PROCESS PERFORMANCE

Digester Stability

The performance and stability of the digester is shown in Table 3 and *Fig. 3.* Initially, sludge flotation was observed in the digester due to entrapment of the gas within the flocs causing a considerable amount of sludge to be discharged in the effluent. This was not apparent at the later periods when the digester was fully stabilized.

A notable phenomenon in the digester was the occurrence of pelletization on the 104th day of operation in the first run. The addition of flocculants averaging 1000 mg/l feed for a period of 3 months of start-up had resulted in pelletization of the digester biomass at an organic loading rate of 6 kg COD/m^3/day. The pellets were distinctly black, compact and spherical of about 1-2 mm size in diameter amidst the brown loose flocs. Pelletization might have occurred earlier but was not detected. At the higher loading rates the pellets changed to a much smaller size of less than 0.5 mm.

Without the addition of flocculant and with increasing feed rate the effluent quality deteriorated throughout run 2 compared to run 1. The unsettled flocs were washed out during run 2, indicated by SS in the effluent as high as 1470 mg/l. However, the effluent quality improved again in run 3

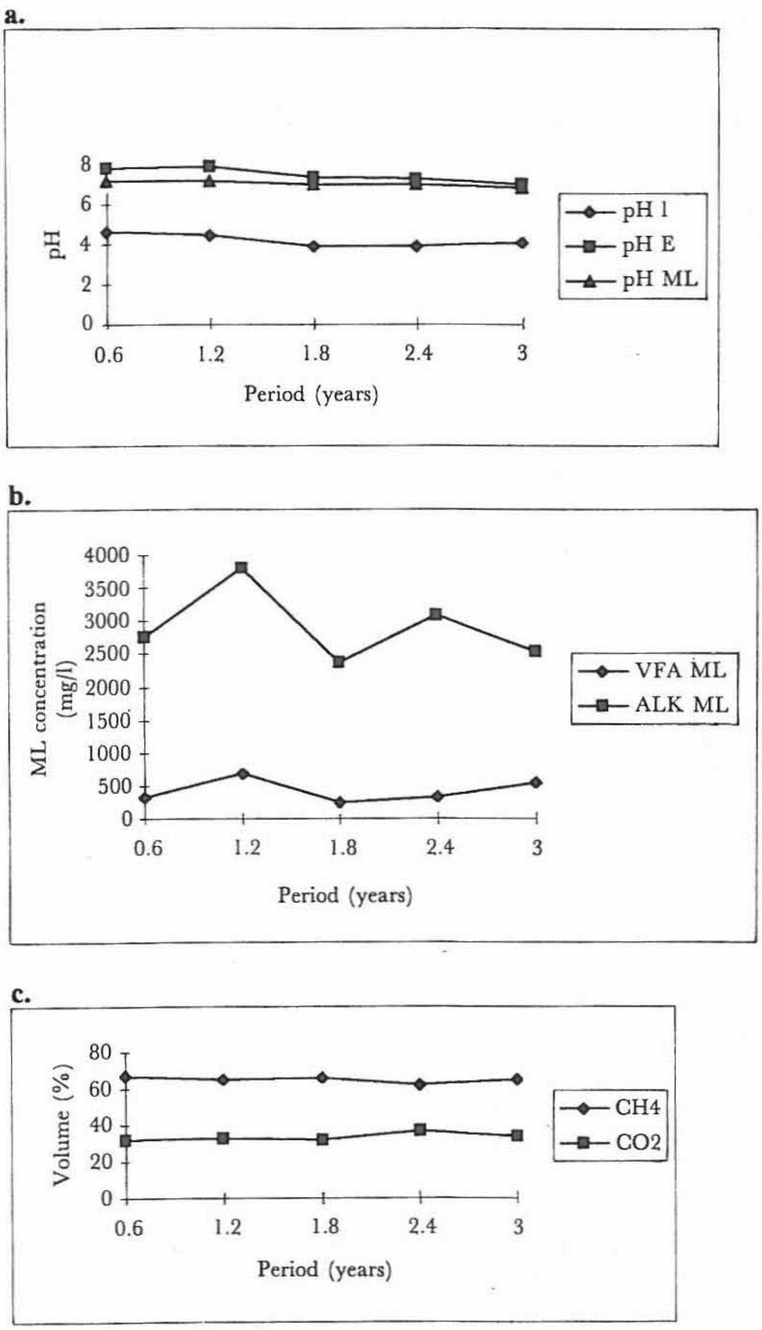

Fig. 3: Digester stability in terms of pH, alkalinity and gas production (a) pH of feed, mixed liquor and effluent; (b) VFA and ALK of mixed liquor; and (c) biogas content

TABLE 3
Process performance of mesophilic semi-continuous anaerobic digestion of POME

	Average	Values			
Parameter	Run 1 (22 samples)	Run 2 (15 samples)	Run 3 (22 samples)	Run 4 (14 samples)	Run 5 (14 samples)
OLR_{COD} (kg COD/m^3/day)	5.85	6.38	5.48	10.79	18.5
OLR_{BOD} (kg BOD/m^3/day)	2.06	2.45	1.86	5.73	5.67
OLR_{VS} (kg VS/m^3/day)	3.63	4.36	3.74	7.36	10.78
HRT (day)	12.4	10.5	7.2	5.2	3.6
COD removal efficiency (%)	98.3	95.2	94.5	90.5	92.7
BOD removal efficiency (%)	99.2	96.7	98.2	96.5	95.7
VS removal efficiency (%)	97.4	94.0	93.5	89.8	89.4
Methane yield (m^3/kg COD destroyed)	0.2	0.28	0.32	0.24	0.13
Methane yield (m^3/kg BOD destroyed)	0.56	0.71	0.92	0.42	0.27
Methane yield (m^3/kg VS destroyed)	0.32	0.41	0.48	0.36	0.34
Sludge loading (kg COD/kg MLVSS/day)	0.31	0.27	0.21	1.17	2.03
ML VSS (kg/m^3)	19	24	25	9	9

where the average SS level in the effluent was 930 mg/l. Settling of the stable and well-developed granules in run 3 resulted in a lower solids content in the effluent. In runs 4 and 5, the effluent quality deteriorated again due to the sludge bulking occurring at the higher HLR. The average effluent quality of the runs are shown in Table 4.

Methane Yield

The methane yield was influenced by HRT. As the HRT decreased from 12

TABLE 4
Effluent characteristics of mesophilic anaerobic digestion of POME

		Average	Values		
Parameter (mg/l)	Run 1 (22 samples)	Run 2 (15 samples)	Run 3 (22 samples)	Run 4 (14 samples)	Run 5 (14 samples)
COD	1247	3207	2185	5451	4848
BOD	192	854	240	1044	879
TS	5968	9639	5905	10442	9729
SS	273	1475	931	1595	1599
TVS	1165	2743	1756	3915	4103
VSS	218	1062	613	1003	1118
N	201	329	161	396	186
P	–	53	76	125	–

to 7 days, the yield increased but it declined with further reduction in HRT to 3.6 days. A maximum methane yield of 0.32 m^{-3} per kg COD destroyed was obtained at a HRT of 7.2 days (OLR_{COD} of 5.48 $kg/m^3/day$). This value was slightly lower than the theoretical yield calculated at 0.395 m^3 CH_4 per kg COD removed at 35°C (Metcalf and Eddy 1979). At the lower HRT of 5.2 and 3.6 days, corresponding to loadings of 10.8 and 18.5 kg COD m^{-3}/day respectively, the conversion efficiencies were at 0.24 to 0.13 m^3 per kg COD removed. The relatively low conversion of COD to methane indicated that a considerable portion of the influent COD was not degraded in the digester despite the high removal efficiencies obtained. This was expected as the influent contained a high portion of suspended solids which are difficult to microbiologically hydrolyze within the short HRT. However, these residues do not pose any problem in the effluent as they settled rapidly and can be easily removed before final effluent discharge.

Treatment Efficiencies

Generally, the treatment efficiencies decrease with reduction in HRT. The maximum treatment efficiency was obtained at a HRT of 13 days (OLR of 5.9 kg COD m^{-3}/day), which gave removal efficiencies for COD, BOD and VS at 98.3, 99.2 and 97.4% respectively. Throughout the experiment, the treatment efficiencies were greater than 90%. Even at the shortest HRT, COD, BOD and VS removal efficiencies were still high, at 93, 96, and 89% respectively.

A maximum loading of 18 kg COD m^{-3} /day was achieved at 3.6 days of HRT. These results were 2 or 3 times faster than the contact digester of Yeoh *et al.* (1986). The sludge loading of about 0.3 kg COD/kg MLVSS/day was constant at a HRT above 7 days, which increased linearly to 2 kg COD/kg MLVSS/day at reduced HRT of 3.6 days. However, the MLVSS profile showed a reverse reaction to the reduction in HRT. At a long HRT of 12 days, the MLVSS (19 g/l) began to increase and remained at about 24 g/l for HRT between 7 and 11 days, after which it drastically declined to 9 g/l below 5 days HRT due to poor solid-liquid separation.

The increase in MLVSS at 11 days HRT (equivalent to 6 kg COD/m^3/ day) of run 2 was probably due to the effect of granulation and aggregation of biomass accumulated in the digester. Increase in loading rates after run 3 and rapid gas production coupled with the high suspended solids concentration in the digester caused the sludge to float and escape in the effluent. Sludge removal was subsequently carried out in run 4 at an average rate of 30 ml/ day. Although the MLVSS was only 9 kg/m^3 at 10.8 kg COD m^{-3}/day, the treatment efficiency maintained at 90% with a sludge loading of 1.17 kg COD/kg MLVSS/day.

Economic Implications

To visualize the economic implications, reference is made to two commercial conventional closed-tank digesters (4,200 m^3) operating at 10 days HRT treating 360 m^3/day wastewater of a 60 ton/hour mill. The capital cost of the digesters was about RM1 million (Quah and Gillies 1981). Assuming a 4% inflation rate, the present capital cost of digesters would be RM1.6 million. From the present study, it should be reasonable to assume that the design HRT for the modified commercial mesophilic digester is 5 days. This could reduce the digester size by 50%, hence one reactor of 4200 m^3 capacity would be sufficient for the mill. A 50% reduction in capital cost of the digester could be assumed as only 1 digester of similar capacity would be required. Therefore, the estimated capital costs for the mesophilic would be about RM800,000.

The flocculant dosage has been determined to be 1000 mg/l feed introduced into the mesophilic digester. For the start-up of the 4200 m^3 digester at a loading rate of 6 kg COD m^{-3}/day, pelletization is assumed to occur within 3 months. Based on the present cost of flocculant at RM10.00/ kg, the total cost of flocculant was determined to be RM158,000. Assuming another RM50,000 would be required for a flocculant tank and dosing pump, the overall capital costs of the mesophilic digester would be RM1,008,000. Therefore, savings of about 37% based on the conventional system costs can be obtained with the use of the mesophilic digester with flocculant addition.

CONCLUSION

A cationic polyacrylamide of high molecular weight density, Zetag 88N, was found to be a suitable flocculant for use in the mesophilic anaerobic digestion of POME. It helped the formation of flocs that have good settling properties and did not cause toxicity to the anaerobic digestion process. The use of the flocculant resulted in an increase in biomass concentration in the digesters, thus enabling higher space loadings to be applied. A maximum achievable loading rate of 19 kg COD m^{-3}/day was obtained at a hydraulic retention time of 3.6 days under the mesophilic condition of 37°C. The flocculant helped pelletization to occur in a substrate which is difficult to granulate naturally. The high levels of suspended solids in POME did not inhibit the formation of the pellets. With the onset of substantial levels of granulation of the biomass, flocculant dosage was able to be discontinued. Preliminary economic assessment showed the process to be viable with cost reduction of about 40% over the conventional closed-tank digesters.

REFERENCES

APHA. 1989. *Standard Methods for the Examination of Water and Wastewater*. 18th edn. Washington D.C.

CAIL, R.G. and A.G. LANE. 1984. Recent advances in the design of high rate digesters for treatment of wastewater – laboratory pilot and full scale.

CAIL, R.G. and A.G. LANE. 1984. Recent advances in the design of high rate digesters for treatment of wastewater – laboratory pilot full scale. In *Proc. 2nd ASEAN Workshop on Biogas Technology Applied to the Management and Utilization of Food Waste Materials*, 8-13 Oct. 1984. Kuala Trengganu, Malaysia, ed. Rahim Bidin, C.N. Chong and C.W. Wang, p. 21-82. Committee on Science and Technology ASEAN.

CHAN, K.S. and C.F. CHOOI. 1982. Ponding system for palm oil mill effluent. In Proc. Reg. *Workshop on Palm Oil Mill Technology and Effluent Treatment*, 17-18 Aug. 1982. Bangi: PORIM, p. 185-192.

LIM, K.H. 1981. Review of HMPB effluent treatment plants performance. In *PORIM Workshop* No. 9, p. 11-41. Bangi, Selangor, Malaysia.

LIM, K.H., S.K. QUAH, D. GILLIES and B.J. WOOD. 1984. Palm oil mill effluent treatment and utilization in Sime Darby plantation – the current position. In *PORIM Workshop* No. 9, p. 42-52 Bangi, Selangor, Malaysia.

MA, A.N. and A.S.H. ONG. 1985. Pollution control in palm oil mills in Malaysia. *JOACS* **62**: 261-266.

METCALF and EDDY Inc. 1979. *Wastewater Engineering Treatment, Disposal and Reuse*. 2nd edn. New York: McGraw Hill.

QUAH, S.K. and D. GILLIES. 1981. Practical experience in production and use of biogas. In *Proc. National Workshop on Oil Palm By-product Utilization*, 14-15 Dec. 1981, Kuala Lumpur, Malaysia, p. 119-125, PORIM.

YEOH, B.G., T.Y. CHEW, A.N. MA, S.C. CHEAH, M.C. CHOW, R. RAJ, A. IBRAHIM and M.J.A. WAHID. 1986. Improved anaerobic digestion of palm oil mill effluent using the thermophilic contact process. In *National Workshop on Recent Development in Palm Oil Milling Technology and Pollution Control*, 5-6 Aug. 1986. Kuála Lumpur, Malaysia.